IOP Conf. Series: Materials Science and Engineering **160** (2016) 012014 doi:10.1088/1757-899X/160/1/012014

# Development of Vehicle Model Test for Road Loading Analysis of Sedan Model

**M K Mohd Nor*[1], A Noordin, M F S Ruzali, M H Hussen**

Crashworthiness and Collision Research Group, Engineering Mechanics Department, Faculty of Mechanical and Manufacturing Engineering, UniversitiTun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

E-mail: khir@uthm.edu.my

**Abstract**. Simple Structural Surfaces (SSS) method is offered as a means of organizing the process for rationalizing the basic vehicle body structure load paths. The application of this simplified approach is highly beneficial in the design development of modern passenger car structure especially during the conceptual stage. In Malaysia, however, there is no real physical model of SSS available to gain considerable insight and understanding into the function of each major subassembly in the whole vehicle structures. Based on this motivation, a physical model of SSS for sedan model with the corresponding model vehicle tests of bending and torsion is proposed in this work. The proposed approach is relatively easy to understand as compared to Finite Element Method (FEM). The results show that the proposed vehicle model test is capable to show that satisfactory load paths can give a sufficient structural stiffness within the vehicle structure. It is clearly observed that the global bending stiffness reduce significantly when more panels are removed from a complete SSS model. It is identified that parcel shelf is an important subassembly to sustain bending load. The results also match with the theoretical hypothesis, as the stiffness of the structure in an open section condition is shown weak when subjected to torsion load compared to bending load. The proposed approach can potentially be integrated with FEM to speed up the design process of automotive vehicle.

## 1. Introduction

The SSS method was originally developed to analyze the load path of the vehicle during the concept stage of the design process. It can help to design automotive vehicles with a simple structure during the conceptual stage. Furthermore, it is useful to enhance the understanding related to the design concepts and structural body of the vehicle.

SSS model can be easily adopted to show the required space for major components such as engine, suspension, transmission, radiator, steering systems, fuel tanks, space for passengers, luggage or payload, etc. SSS is a plane structural element or subassembly that can be considered as rigid only in its own plane [1]. The plane can carry loads such as tension, compression, shear and bending. Each plane or surface involve in this method is held in a static equilibrium by a series of forces, which are created by the weight of the different components [1, 2]. The method reveals there is lack of support in the structure if a suitable adjacent subassembly is omitted hence affect the structural stiffness [2]. It can be used to define loads on components such as roof panels hence can help toward identification of design features that must be incorporated to provide stiffness [1, 2]. Low stiffness may result in undesirable vibration within the structure.

Different stiffness caused by different load cases, and the torsion stiffness is often been used as a 'benchmark' to indicate the effectiveness of the vehicle structure [3, 4]. Torsion stiffness defines the torsional deflection θ of the structure subjected to pure torque about the longitudinal axis of the vehicle. It is generally observed that the design for torsion case is the most difficult to ensure satisfactory vehicle handling. Torsion stiffness of chassis frame can be improved by incorporating closed cross-members (closed-box members). For instance, roll cage can be introduced into the structure of racing vehicle to increase the torsion stiffness by over 500 per cent as compared with the basic chassis frame [5].

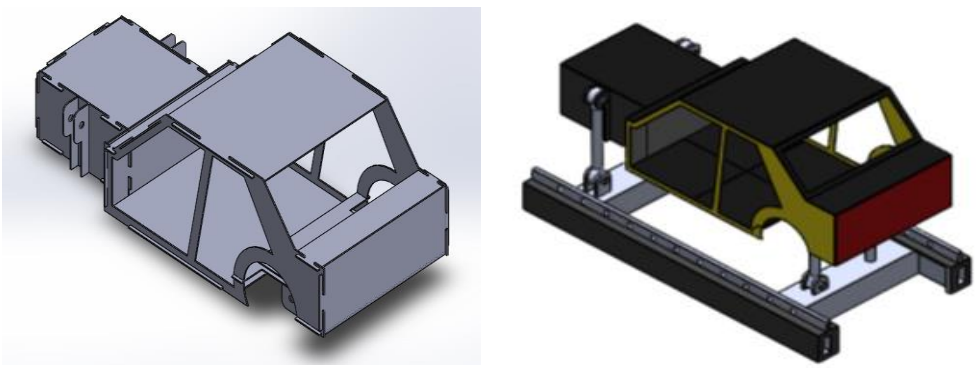
In Malaysia, many researches have been conducted in respect to vehicle structures. In addition, the SSS has been widely adopted in various automotive programs. However, there is no physical model of SSS or experimental procedure is available. Based on this motivation, a physical model of SSS for sedan model with the corresponding vehicle model test of bending and torsion is proposed in this work [3, 4]. Specialists in advanced structural analysis techniques like finite element analysis, vehicle system designers, production engineers, development engineers as well as students at undergraduate and postgraduate levels will find the importance of the proposed SSS model since load paths within the vehicle structures can be easily overviewed.

.

## 2. SSS Experimental Model for Sedan

The structures of different sedan passenger car structures vary according to size, vehicle layout and type and assembly methods used by different manufacturers. However, the nature of integral construction dictates that there will also be similarities. In this work, a simplified car structure referred to as the 'standard sedan' is used as a reference to finalize the design of the proposed sedan model. The major factor is the capability of the model to evaluate major load cases bending and torsion where the actual road loads will be a combination of these load cases.

The standard sedan consists of a 'closed box' passenger compartment, comprising floor, roof, side frames, front and rear bulkheads and windscreen. All of these surfaces are assumed to be plane in the proposed model. The suspension loads, at both front and rear, are carried on deep, stiff boom/panel cantilevers attached to the ends of the compartment. Altogether, 16 simple structural surfaces SSS are introduced in the proposed sedan model as shown in figure 1. Later in this paper, the proposed sedan model will be shown to be sufficient to demonstrate the effects of two fundamental load cases of bending and torsion, calculate overall bending and torsional stiffness of the vehicle and correctly predict responses of the vehicle model. The chosen support reactions are designed compatible with boundary conditions of the proposed experimental procedures. The SSS model can be divided into SSS structures, supports and basement frame including measurement tools. Reference on several sedan models is made before the actual geometry was decided. Solidworks 2012 is used to define the preliminary design structure as shown in figure 1.



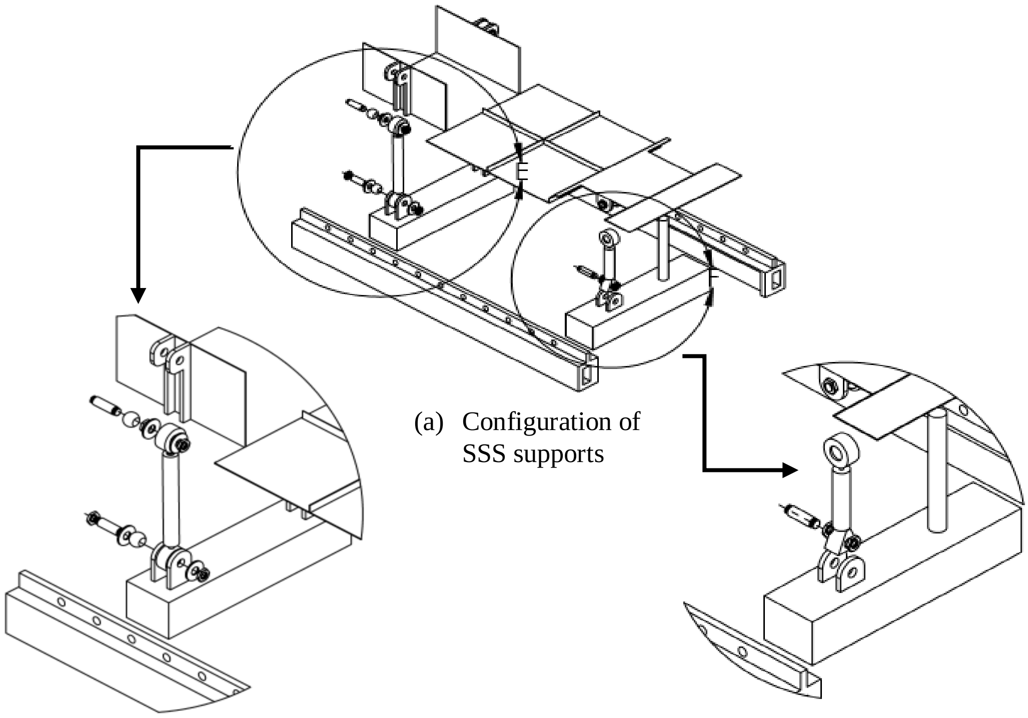
(a) Main subassemblies of SSS structures

(b) Complete SSS structures (including supports and base frame)

**Figure 1.** Design of SSS model

Figure 2 shows a complete SSS model based on the design in figure 1. The geometry is scaled-down by ratio 1:6 from the given geometry in [1] using the principles of ratio [6]. All of the subassemblies and the basement frame are made of plastic polypropylene (PP) and aluminum alloy, respectively [7]. Details geometry for subassemblies can be found in [3, 7, 8]. Type of supports and base frame of the model are shown in figure 3.

Figure 2. SSS model for sedan



(a) Configuration of SSS supports

(b) Front support

(c) Rear support

**Figure 3.** Supports configuration of SSS model

Figure 4 further explains configuration of the chosen supports for the SSS model. As can be observed, four supports are attached to the base frame of the model to transmit road loading (bending and torsion) to the vehicle structure. At front side (P3 and P4), ball joint is used to constrain movement in y-axis. P2 at the back side is completely constrained. P1 has a ball joint at top, and hinge at the bottom side. Ball joint at P1 allows movement in z-axis.

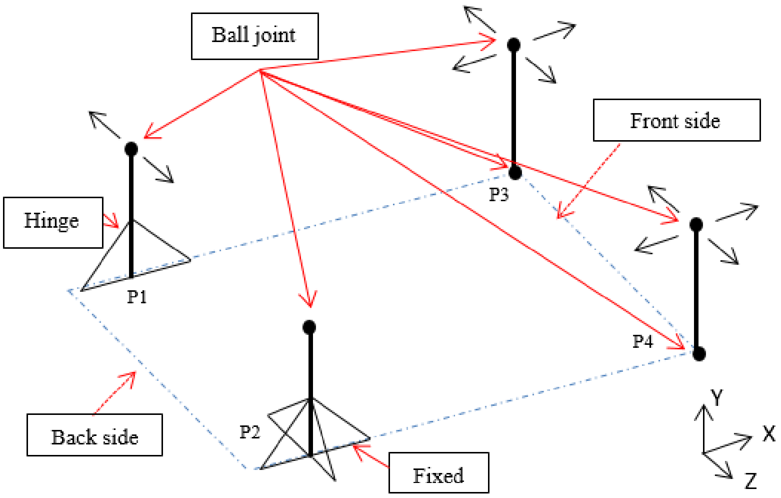



**Figure 4.** Configuration of supports for SSS model

## 3. Development of Vehicle Model Test

The primary objective of the proposed test procedures is to demonstrate the importance to have continuous load paths within the vehicle structures.

### 3.1. Bending Model Test

The test allows for relative comparison of the model bending stiffness when one or more panels are removed from a complete body structure. Bending stiffness relates to the symmetrical vertical deflection of a point near the center of the wheelbase. This type of loading is created from the weight of components that distributed along the frame of the vehicle in the vertical plane, which causes bending about y-axis. Bending case depends mainly on the weight of major components in the vehicle including its payload. Therefore, supports configuration defined in figure 4 is modified by applying load at the middle of the floor as depicted in figure 5.

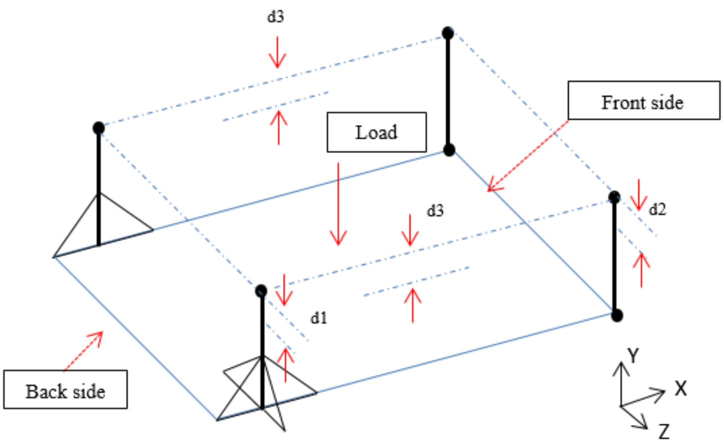



**Figure 5.** Bending Test configuration

Dial Test Gauge (DTI's) is placed at front, center and rear sides of the model to measure the deflection at $d_1$, $d_2$ and $d_3$, respectively. The deflection when load is applied incrementally is recorded in a Spreadsheet Bendsht.xls, as shown in figure 6. The spreadsheet is used to calculate load which then used to plot load-deflection diagram. The corresponding bending stiffness is eventually be obtained from the diagram

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DATE | | MODEL BENDING TEST | | | | | |
| | | MODEL= | | | | | |
| | | CONDITION= | | | | | |
| LOAD (grams) | LOAD N | D1 Deflection at front | D2 Deflection at rear | D3 Deflection at centre/load | D(av)= (D1+D2)/2 | D3-D(av) | LOAD N |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |
| | 0 | | | | 0 | 0 | 0 |

**Figure 6.** Spreadsheet Bendsht.xls

The test is repeated by removing few other panels from the SSS model. Bending stiffness that recorded in various conditions of incomplete SSS model can be developed and further compared with a complete model condition (continuous load paths).

*3.1.1. Bending Model Test Implementation.* The following test procedure is proposed for bending model test:

1. Test the model with all parts assembled (complete model) by applying load at the middle floor (start with 200g, 400g, 600g, 800g, 1000g and 1200g)
2. Measure four deflections of the model as shown in figure 5.
3. Repeat steps 1 and 2 without a windshield frame.
4. Repeat steps 1 and 2 without a windshield frame and front parcel shelf
5. Use the Spreadsheet Bendsht.xls to determine bending stiffness of the model for each model conditions (slope of the graph gives the stiffness in N/mm).

### 3.2. Torsion Model Test

To set up the torsion test, few modifications on the SSS model have to be made. As shown in figure 7, support at P4 is removed and the other supports remain.

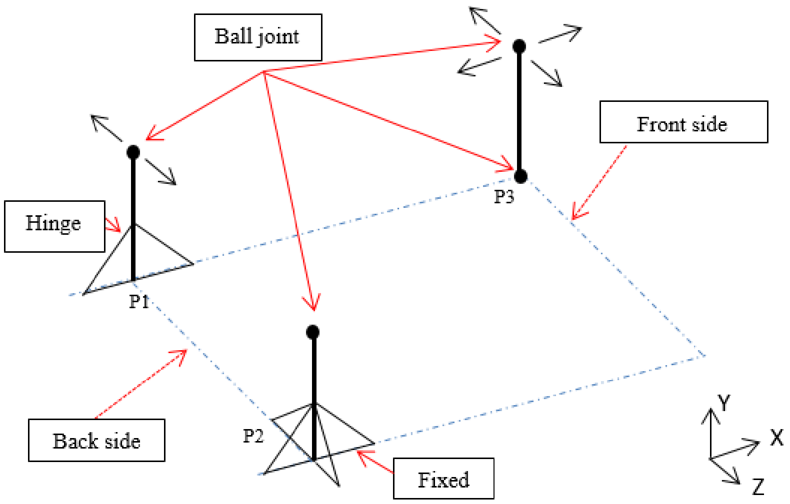



**Figure 7.** Boundary condition for torsion test

To transmit torsion load to the SSS structure, load is applied at the top side of point P4 as shown in figure 8. Dial Test Gauge located around each corner of rear and front sides are used to calculate the deflections $d_1$, $d_2$, $d_3$ and $d_4$. Spreadsheet Torsionsht.xls is introduced to record the distances between gauges $d_1$ and $d_2$ and between gauges $d_3$ and $d_4$. The spreadsheet is also used to record the deflections of $d_1$, $d_2$, $d_3$ and $d_4$ and finally calculate the global torsion stiffness of the proposed SSS model.

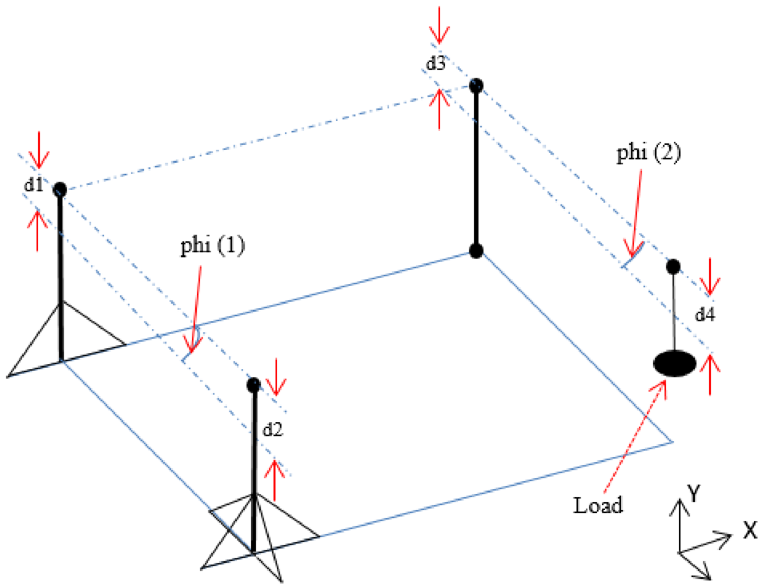



**Figure 8.** Data characterization for torsion test

*3.2.1 Torsion Model Test Implementation.* The following test procedure is proposed to predict responses of the model when subjected with torsion loading:

1. Measure the distances between gauges $d_1$ and $d_2$ and between gauges $d_3$ and $d_4$ that across the model.
2. Apply load at point P4 of a complete SSS structure.
3. Measure the deflection at each corner of the model ($d_1$, $d_2$, $d_3$ and $d_4$).
4. Add an incremental load at point P4.
5. Measure the corresponding deflections for each increment.
6. Use the Spreadsheet Torsionsht.xls to record all the measurements.
7. Repeat steps 2 to 6 without a windshield frame.
8. Repeat steps 2 to 6 without a windshield frame and rear bulkhead
9. Use the Spreadsheet Torsionsht.xls to determine torsion stiffness of the model for each condition.

## 4. Results and Discussion

4.1. Bending Model Test Results

Figures 9, 10 and 11 show bending stiffness calculated by Spreadsheet Bendsht.xls for each SSS model condition. Figure 12 compares relative bending stiffness of the model for each condition. The bending stiffness for complete model, without a windshield frame and without a windshield frame and front parcel shelf is 353.8 N/mm, 218.6 N/mm and 33.37 N/mm, respectively. It can be observed that the bending stiffness reduces approximately 38 % compared to complete body stiffness when windshield is excluded. The bending stiffness decreases considerably (more than 90%) when both windshield and front parcel shelf are removed from the SSS model.

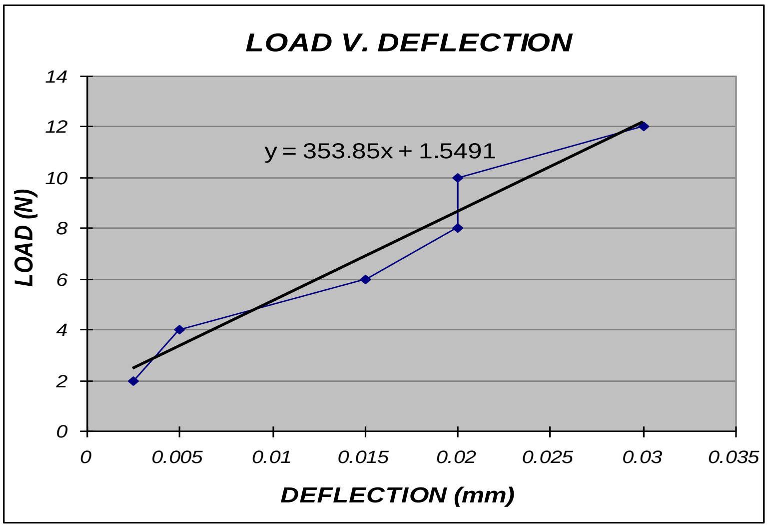



**Figure 9.** Bending stiffness of SSS model (complete model)

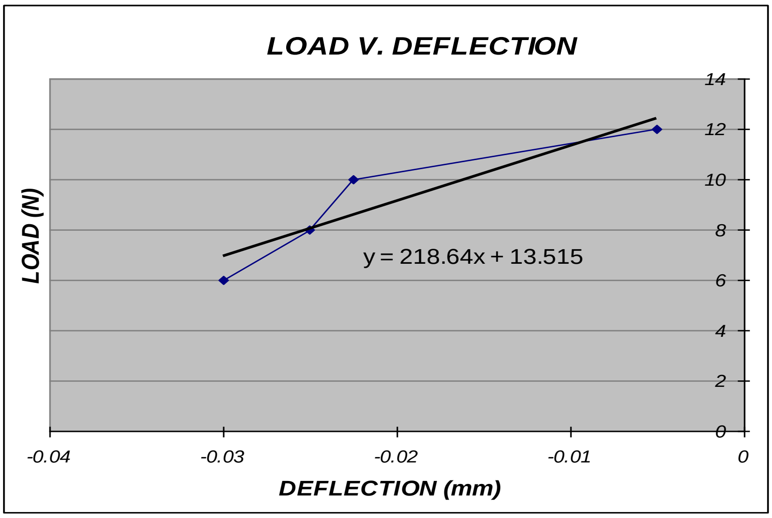



**Figure 10.** Bending stiffness of SSS model (without windshield)

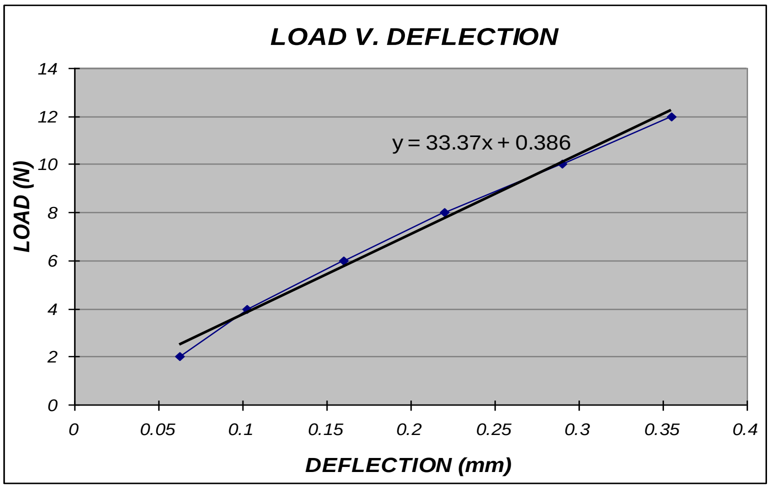



**Figure 11.** Bending stiffness of SSS model (windshield and front parcel shelf)

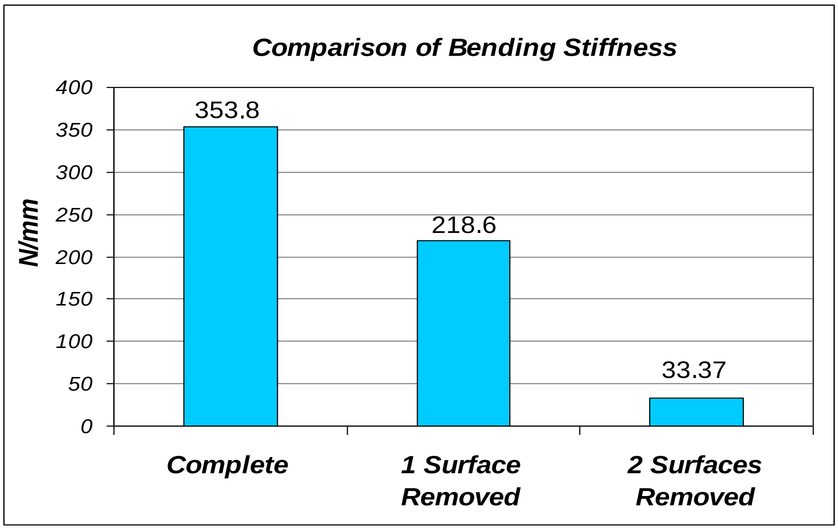



**Figure 12.** Comparison of bending stiffness

It is quite hard to observe responses (deformation mode) within the model due to the bending load created by the given weights. A pronounced response (slight deflection) only can be observed when front parcel shelf is removed from the model and load is applied by hand at the area close to the front parcel shelf as highlighted in figure 13.

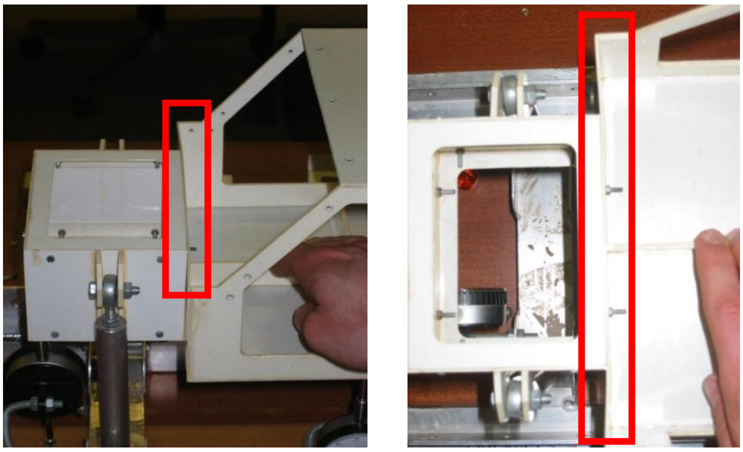


**Figure 13.** Reaction of the SSS model

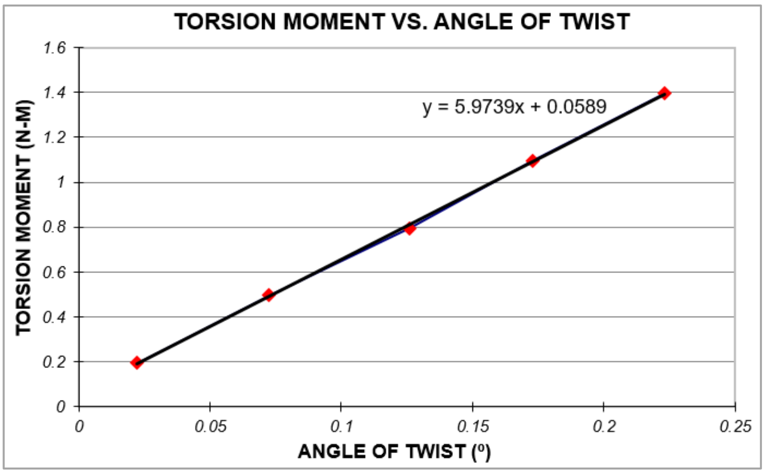
The results of bending model test show that not every subassembly within the structure is important to withstand the global bending stiffness of the vehicle. Theoretically, windshield does not contribute to sustain bending load. On the other hand, the front parcel shelf is one of active subassembly to sustain bending load. In fact, the parcel shelf is very important to carry the fender boom reactions out to the side frame. Therefore, the boom reacts by out-of-plane forces on the bulkhead when parcel shelf is removed. This gives flexibility to the cantilever beam support of the fender.

## 4.2. Torsion Model Test Results

Figure 14 shows the example of experimental data analyzed by the Spreadsheet Torsionsht.xls and the corresponding torsion stiffness calculated for the model with complete SSS structure.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | | | | | | | | | | | | | | | |
| | | | MODEL TORSION TESTS | | | | | MODEL= | Sedan | | | | | | |
| MODEL CONDITION | DISTANCE | LOAD | TORSION | TORSION | d1 | d2 | DISTANCE | PHI(1) | d3 | d4 | DISTANCE | PH(2) | PHI(2)-PHI(1) | STIFFNESS | TORSION |
| Complete | BETWEEN | | MOMENT | MOMENT | Defl. diagonally | Defl on | BETWEEN | | Defl opposite | Defl near | BETWEEN | | | | MOMENT |
| | SUPPORT | | T | | opposite load | load side | DTI'S 1&2 | | d4 | load point | DTI'S 3&4 | | | | T |
| | & LOAD | grams | gram-mm | N-M | mm | mm | mm | radians | mm | mm | mm | radians | degree | N-M/degree | N-M |
| | mm | | | | | | | | | | | | | | |
| | 150 | 133 | 19950 | 0.19571 | -0.02 | 0.058 | 173 | 0.000451 | 0.003 | 0.15 | 175 | 0.00084 | 0.022295676 | 0.000 | 0.19571 |
| | | 337 | 50550 | 0.495896 | -0.12 | 0.2 | | 0.00185 | -0.005 | 0.54 | | 0.003114 | 0.072454795 | 6.844 | 0.495896 |
| | | 541 | 81150 | 0.796082 | -0.15 | 0.29 | | 0.002543 | 0 | 0.83 | | 0.004743 | 0.126022327 | 6.317 | 0.796082 |
| | | 745 | 111750 | 1.096268 | -0.17 | 0.38 | | 0.003179 | -0.005 | 1.08 | | 0.0062 | 0.173079621 | 6.334 | 1.096268 |
| | | 949 | 142350 | 1.396454 | -0.23 | 0.5 | | 0.00422 | -0.03 | 1.39 | | 0.008114 | 0.223146007 | 6.258 | 1.396454 |

(a) Spreadsheet Torsionsht.xls for complete SSS structure




(b) Torsion Moment vs. Angle of twist for complete SSS structure

**Figure 14.** Results of a complete SSS model

Figures 15 and 16 show the graph provided by the spreadsheet to calculate torsion stiffness of the model without windshield frame and without both windshield frame and real bulkhead, respectively. Figure 17 compares torsion stiffness for each SSS conditions. It can be observed the torsion stiffness for a complete SSS model, without windshield frame and without windshield frame and rear bulkhead is 5.9739 Nm/degree, 1.6981 Nm/degree and 1.4188 Nm/degree, respectively.

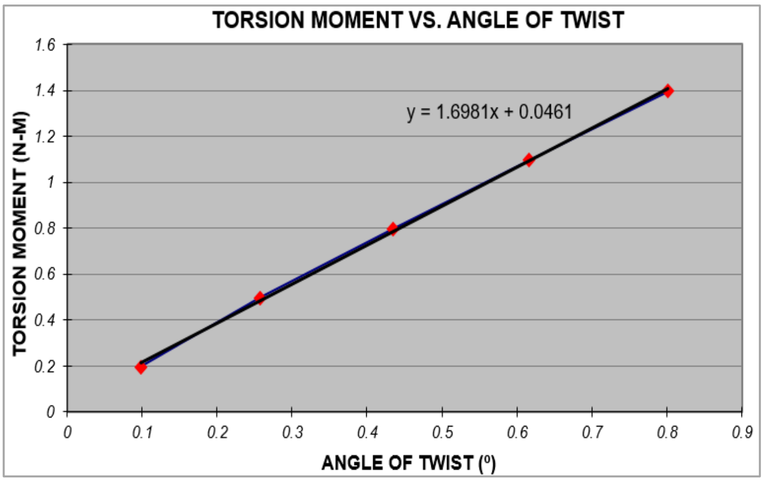



**Figure 15.** Torsion Moment vs. Angle of Twist for the model without windshield frame

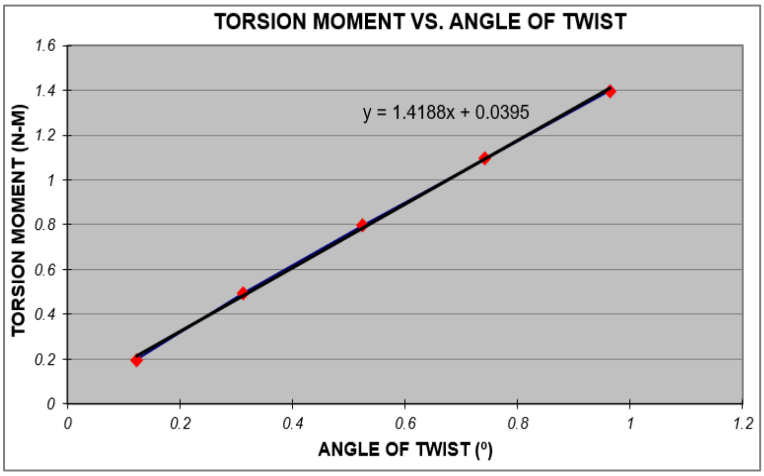



**Figure 16.** Torsion Moment vs. Angle of Twist for the model without windshield frame and rear bulkhead

Referring to the results, the torsion stiffness decrease considerably when only one subassembly is removed from a complete body. It can be seen the torsion stiffness drops by 71.6% when windshield frame is removed. This is because the structure becomes an open box and the shear panel load path for torsions breaks down when one load path is removed from a complete SSS model [1]. The reaction forces in other panels become zero when one of the edge forces disappears. Eventually the complementary forces also reduce to zero hence results in flexibility of the structure in torsion. The side frame then acts as a lever to twist the other assemblies.

The results in addition show that the decrement of torsion stiffness is not too significant when 2 panels are removed (windshield frame and rear bulkhead). As has been mentioned, the structure becomes an open box (flexible) when one panel is removed. Removing more panels certainly will reduce the torsion stiffness further, however, not significant since the flexibility is already developed and experienced by an open box condition of the SSS structure. Figure 18 shows the reaction of the SSS model (without windshield frame) when subjected to torsion load. It can be observed in figures 18(b) and 18(c) that the reaction experienced by the roof panel is significant compared to the original condition in Figure 18(a). The capability of the proposed vehicle model test to demonstrate that the vehicle structure is less stiff when subjected to torsion loading compared to bending load in an open section condition is also established.

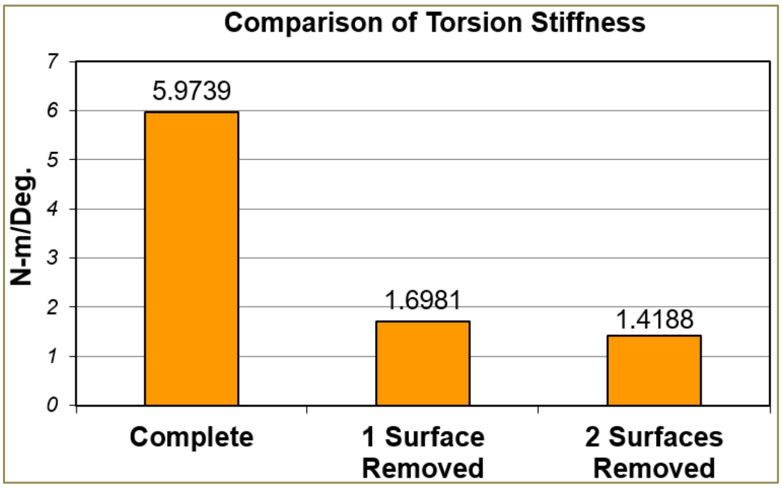
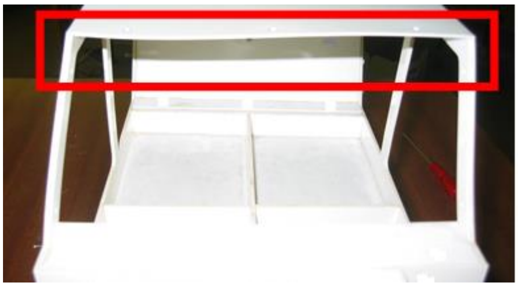
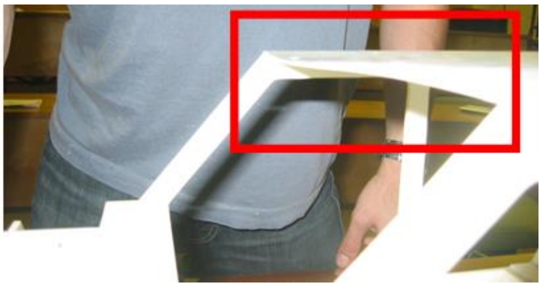



**Figure 17.** Torsion stiffness comparison between different conditions of SSS model

(a) Condition before torsion load is applied



(b) Condition after torsion load is applied (front view)



(c) Condition after torsion load is applied (left side view)

**Figure 18.** Conditions of SSS model subjected by torsion load

## 5. Conclusion

Vehicle model test of sedan model is proposed using SSS approach in this paper. The model consists of SSS structures, supports and basement frame (including the measurement tools). The corresponding bending and torsion experimental procedures are then established in this work to validate the capability of the proposed model to transmit road loading to the SSS structures. The results show that the effects of bending and torsion loads can be successfully demonstrated by the proposed vehicle model. The preliminary bending test implementation shows that the front parcel shelf is one of active subassemblies to sustain bending load. The torsion test implementation then shows that the sedan model is less stiff in torsion in an open section condition; the torsion stiffness decrease considerably when only one of the SSS subassemblies is removed from a complete body. It can be observed that the proposed vehicle model is capable to give an overview and understanding on structural integrity of vehicle structures easier compared to the conventional theoretical approach. Therefore, the proposed model is beneficial in teaching and learning process of SSS subject at any academic level. The capability can be further enhanced by integration with FEM to speed up the design process of automotive vehicle.

## 6. References

[1] J. C. Brown, A. J. Robertson, Serpento S. T., "Motor Vehicle Strcutures: Concepts and Fundamentals," Cranfield University, UK: *Butterworth Hennemann Publication*, 2002

[2] J. Palowski, "Vehicle Structures," Cranfield University, 1986
[3] A. Noordin, "Development of Simple Structural Surfaces of Automotive Vehicle Model Structure," B. Sc. Thesis, Universiti Tun Hussein Onn Malaysia, 2014
[4] F. T. S. Ruzali, "Development of Torsion and Bending Experimental Modules of the Simple Structural Surfaces (SSS)," B. Sc. Thesis, Universiti Tun Hussein Onn Malaysia, 2014
[5] M. Roots et al., "The Contribution of Passenger Safety Measures to Structural Performance in Sports Racing," *MSC World Users Conference, Newport Beach Ca.*, 1995
[6] E. J. Beitler and B. Lockhart, "Design For You," *New York: John Wiley & Sons, Inc.*, 1969
[7] M. H. Hussen,"Modeling of Simple Structural Surfaces (SSS) of Sedan Model," B. Sc. Thesis, Universiti Tun Hussein Onn Malaysia, 2015
[8] N. Mustafa@Othman, "Analysis of the Simple Structural Surfaces (SSS) of Sedan Model," B. Sc. Thesis, Universiti Tun Hussein Onn Malaysia, 2016

**Acknowledgments**
The authors wish to convey a sincere gratitude to UniversitiTun Hussein Onn Malaysia (UTHM) and Ministry of Higher Education (MOHE) for providing the financial means during the preparation to complete this work under Fundamental Research Grant Scheme (FRGS), Vot 1547.