USE OF SECONDARY ENERGY ABSORBING STRUCTURES FOR IMPROVED SELF PROTECTION PERFORMANCE – EXPERIENCES DURING THE DEVELOPMENT OF A CHASSIS BASED VEHICLE

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ABSTRACT

Secondary Energy Absorbing Structures (SEAS) have been discussed in literature in the context of improving geometric compatibility between larger vehicles like SUVs and cars. While compatibility related work is still in a research phase, development of the vehicles for self protection remains a priority. Vehicles also have to be designed to meet set targets against consumer group tests like Euro NCAP.

A Secondary Energy Absorbing Structure on a Crossover kind of vehicle was evaluated to see the effect on self protection. Through the evaluation it was realized the SEAS can actually be optimized for improving the self protection and lead to reduced weight of the chassis frame. This concept was optimized to achieve weight savings in EuroNCAP load case.

This paper presents the results of evaluations, analysis of the reasons why SEAS is expected to lead to weight savings in a typical offset frontal crash along with the optimization work carried out for achieving weight savings.

INTRODUCTION

In case of crash scenario for effective occupant protection, the structural crash behavior of the vehicle has to fulfill requirements like controlled energy absorption, structural integrity of the passenger compartment, limited intrusions in passenger cell and so on. These crash safety requirements resulted in significant weight addition on passenger car structures over last decade. Figure 1 show the weight spiral for European compact cars [1] where vehicle weight has significantly increased due to stringent legal/consumer group safety requirements and change in customer demands for growing vehicle size and comfort. However, this increased vehicle mass adversely impacted vehicle fuel efficiently and CO2 emissions due to increased energy consumption.

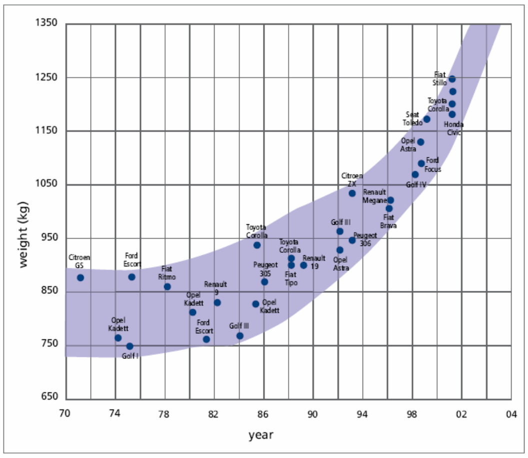

Figure 1. Weight spiral for European compact cars (Source: “Aluminium in Cars” Report by European Aluminium Association)

Today various light materials are being getting evaluated to reduce the weights of vehicle structures example include Aluminum, Magnesium Titanium etc. However the required weight reduction is not going to realized only through substitution of heavy materials by lighter ones unless it supported by appropriate new design and manufacturing design concepts. In this paper the concept of secondary energy absorbing device (SEAS) is being proposed which helped to achieve light weight design for chassis frame for body over chassis type crossover vehicle. In past Secondary Energy Absorbing Structures (SEAS) have been discussed in literature in the context of improving geometric compatibility between larger vehicles like SUVs and cars [3]. However no standard procedure has been defined yet to evaluate the compatibility aspects. The occupant protection in test conditions like ODB64 and FF56 is still area of focus for crash safety engineers. In this study emphasis was put on achieving weight reduction through introduction of new design concepts rather than using high strength steels and advanced manufacturing techniques like laser welding. The vehicle design was evaluated against EuroNCAP ODB64 crash performance requirements. (Refer EuroNCAP Frontal Impact Testing Protocol Version 5 October 2009)

FRONTAL CRASH PERFORMANCE OF BODY OVER CHASSIS FRAME VEHICLES

In frontal crash accident scenario for body over chassis frame vehicle, chassis frame acts as main load bearing member. The front end of the chassis frame is designed to absorb significant amount of energy of impact (It is observed that in most cases chassis frame contributes up to 60% of energy by vehicle for vehicles providing reasonably good occupant protection). The general design strategy for chassis frame for crash application is depicted in Figure 2

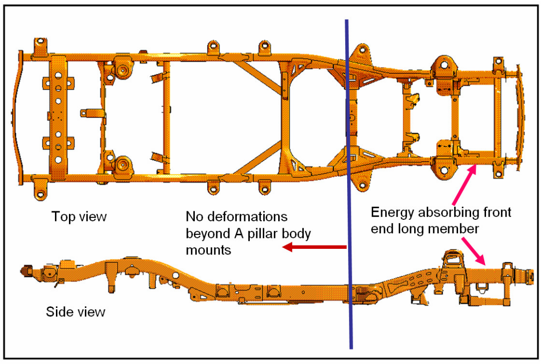

Figure 2. Chassis frame design strategy for offset frontal impact scenario

The chassis frame front long members are designed for optimum energy absorption targeting axial collapse mode. Once frame front end is collapsed during the early phase of crash, no deformations are intended beyond A pillar body mount area to ensure the structural integrity of passenger compartments without any significant structural intrusions. (Refer Figure 2) The special attention is required while designing frame stiffness in front crank area such that while frame front long member is deforming for energy absorption, front crank area should not deform. Second aspect is that frame should not interact with foot well or firewall area due to crank area deformations and struck side wheel should move straight rearward resting against side sill (rocker panel) rather interacting with weak footwell area.

CHASSIS FRAME DEFORMATIONS IN FRONT SWAN NECK AREA IN FRONTAL IMPACTS

While designing chassis frame for frontal crash applications especially for offset frontal impacts major challenge is to achieve required crash performance with minimum possible structural weight for chassis frame. While designing the chassis frame under consideration for frontal crash requirements large weight addition was resulted on chassis frame long members in front swan neck area. This was typically because while chassis frame front end is deforming, large bending moment (My) acts on frame front swan neck area leading to tendency of vertical frame bending of the frame in swan neck area. This is due to the vertical offset between frame long member part in frame front and in swan neck area (Refer Figure 3).

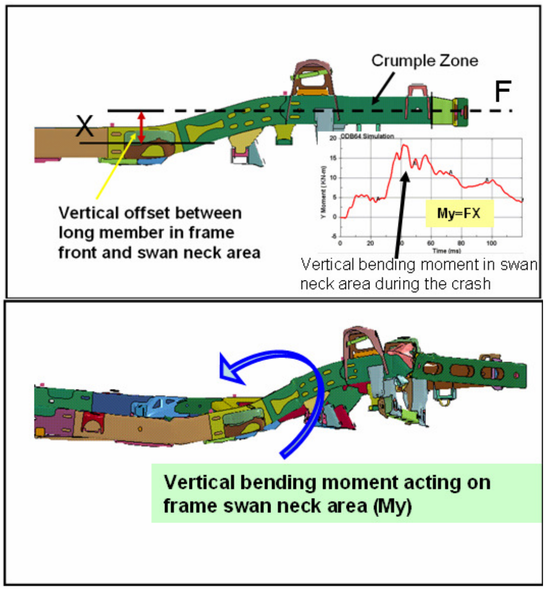

Figure 3. Frame deformations in front swan neck area due to vertical bending moments.

Apart from vertical bending in swan neck area, the chassis frame also deforms laterally in front swan neck area. This lateral bending of the chassis frame is due to moment Mz acting on the frame due to loads through front wheel as shown in the Figure 4.

Hence in order to reduce weight of the chassis frame in swan neck area the concept of SEAS was thought as a solution to this problem. It was expected that SEAS would reduce vertical bending moment acting on frame swan neck area thereby reducing reinforcement requirement in swan neck area. The proposed SEAS do not contribute to reduce lateral bending of the frame in swan neck area. The controlled lateral bending in swan neck area is desirable and helps to achieve energy absorption during the crash. However vertical bending of the frame is not at all desirable as it causes large loads on body structure leading to unstable passenger compartment of the vehicle during the crash.

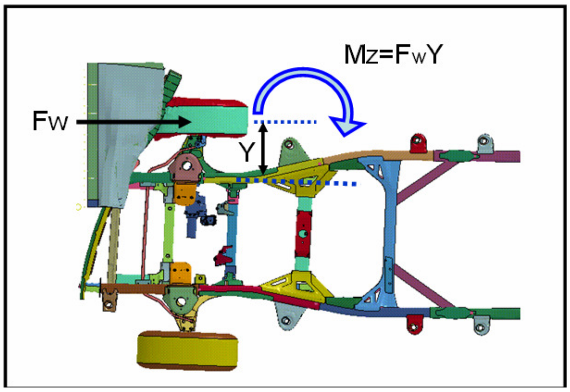

Figure 4. Lateral frame deformations in front swan neck area due to Mz bending moments.

SECONDARY ENERGY ABSORBING STRUCTURE (SEAS) FOR CHASSIS FRAME

Figure 5 shows schematic of SEAS concept which is expected to reduce vertical bending moment on chassis frame crank area by providing parallel load path for crash energy management.

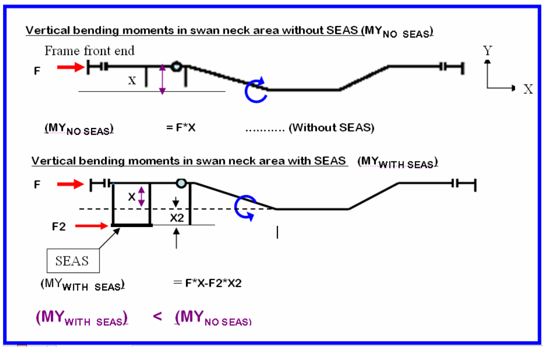

Figure 5. Effect of SEAS on reducing vertical bending moment in swan neck area.

In case of chassis frame design without SEAS, impact load (F) through long member results in vertical bending moments ($M_{Y\ NO\ SEAS}$) = F*X in frame crank area.
With introduction of SEAS, additional moment F_2*X2 acts in opposite direction resulting in ($M_{Y\ SEAS}$) < ($M_{Y\ NO\ SEAS}$) as shown in the Figure 5

As mentioned earlier the proposed SEAS do not affect lateral bending behavior of the frame in swan neck area

SIMULATION RESULTS FOR CHASSIS FRAME DESIGN WITH AND WITHOUT SEAS-VALIDATION OF SEAS CONCEPT

The chassis frame design which was analyzed as a part of this study is depicted in Figure 6.

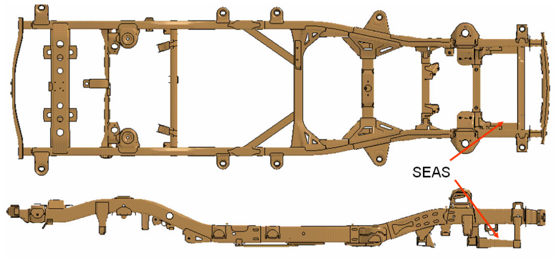

Figure 6. Chassis frame design studied for EuroNCAP ODB56 structural crash CAE.

This proposed design was analyzed in CAE for with and without SEAS (secondary energy absorbing structure) configurations. The forces and moments at long member, SEAS and front crank (swan neck) area (Refer Figure 7) were studied during the study in with and without SEAS configuration.

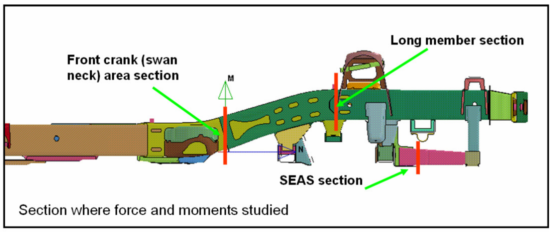

Figure 7. Frame front and crank (swan neck) area where forces and moments were studied.

The forces acting in longitudinal directions at long member and at SEAS cross section are shown in Figure 8.

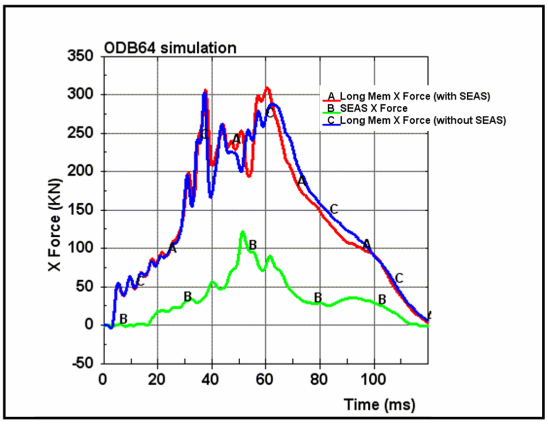

Figure 8. The forces acting in longitudinal directions at long member and at SEAS

It can be seen from the Figure 8 that current SEAS design offers average 70 KN resistance parallel to frame long member which offers average 250 KN resistance during this period. Thus SEAS acts as additional load path during early phase of crash, absorbing additional energy for chassis frame which is shown in Figure 9.

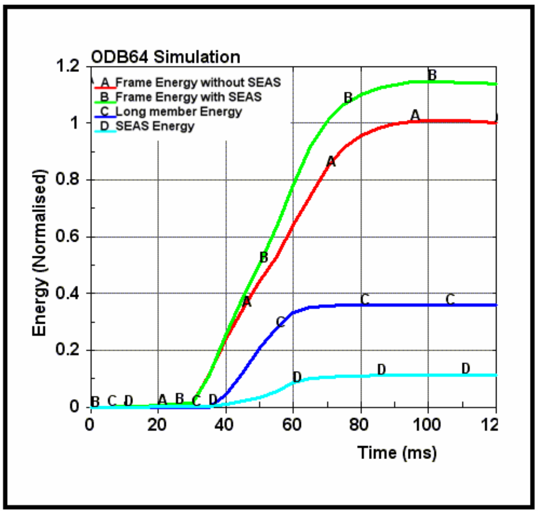

Figure 9. The Energy absorbed by chassis frame with and without SEAS design configurations

It can be seen that approximately 15% more energy absorption is observed for chassis frame with addition of SEAS. It helps to reduce inertia loading on the structure in later phase of crash.

Figure 10 shows the bending moments acting on chassis frame in front crank (swan neck area) area in with and without SEAS design configuration**.**

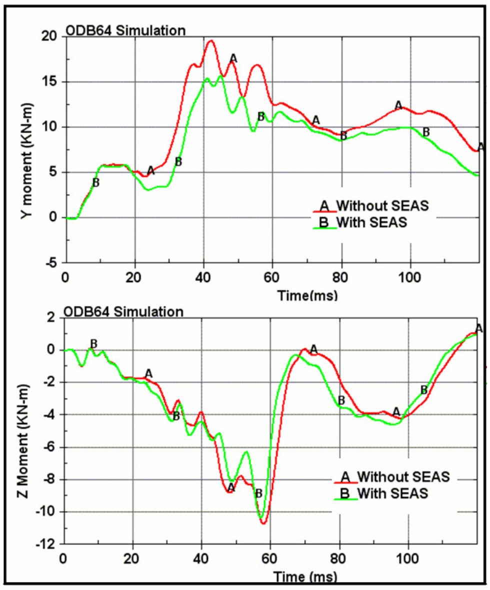

Figure 10. -Bending moments acting on chassis frame in front crank (swan neck area) area in with and without SEAS configuration.

It clearly seen that the bending moments about Y axis significantly reduces in case of design configuration with SEAS in place. This reduces the tendency for vertical bending of chassis frame in front crank (swan neck area). The vertical bending of the chassis frame is not desirable as it increases tendency of vehicle pitching leading to increased loading on BIW structure (risk of more intrusions passenger compartment.)

Figure 11 shows the comparison of vehicle deformation pattern in with and without SEAS design configuration along with frame Z bending measured at frame front swan neck area. It is clearly seen that without SEAS in place the Z bending in the swan neck area has increased by 10 % resulting in increased loading in Body structure causing high deformation in BIW cantrail area near C pillar (Refer Figure 11). More structural intrusions were observed in passenger compartment in without SEAS case. This difference in intrusion values is similar to order of difference that observed for Z bending of frame in swan neck area.

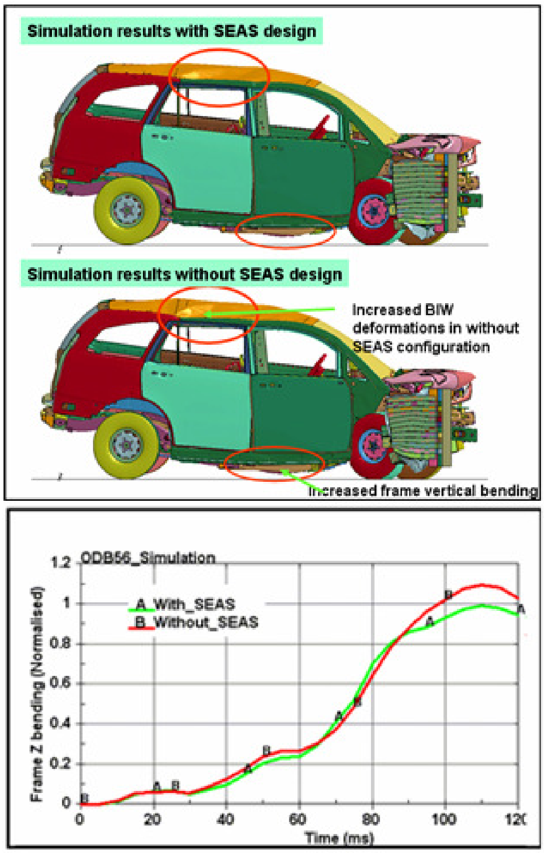

Figure 11. Comparison of vehicle deformation pattern in with and without SEAS design configuration.

The deceleration pulse of the vehicle measured at vehicle B pillar bottom is shown in Figure 12. The peak deceleration observed to be increased by approx. 10 g in case of design without SEAS configuration. This result clearly show that concept of SEAS definitely help to achieve better crash energy management of the vehicle leading to reduced vehicle intrusions and shock levels transferred to occupants. Thus simulation results have clearly highlighted the benefits of SEAS concept and its potential for lighter weight design for crash energy management.

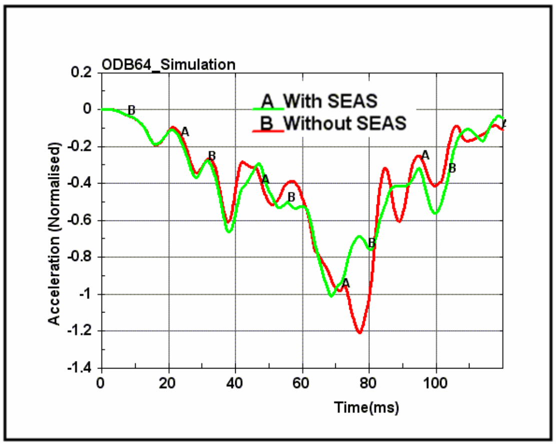

Figure 12. Comparison of vehicle deceleration pulse with and without SEAS design

WEIGHT SAVING ACHIEVED WITH SEAS CONCEPT

The concept of SEAS explained earlier helped to reduce chassis frame reinforcement's weight that were required around front swan neck area to meet structural targets for EuroNCAP offset frontal impact test at 64 kmph. Using proposed SEAS concept, through CAE based design optimization, almost 15 kg weight was saved in frame front swan neck area. The weight of the SEAS assembly in the final chassis frame design is 8 kg. Thus effectively 7 kg weight was saved in chassis frame design.

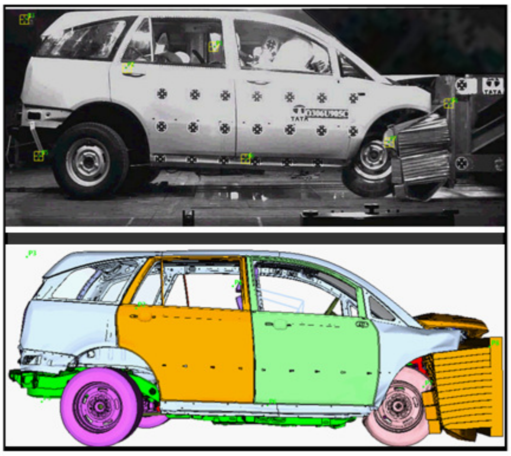

Figure 14. Comparison of vehicle structural deformation in EuroNCAP offset frontal impact test (test vs. CAE prediction).

The provision of SEAS device also helped to reduce 5 kg weight in BIW A pillar and cantrail area as SEAS helped to reduce impact loading on BIW as vertical bending deformations of chassis frame in front swan neck are controlled . Overall concept of SEAS saved 12 kg weight on complete vehicle to meet structural targets of EuroNCAP offset frontal test. The final vehicle design met target EuroNCAP crash performance as shown in Figure 14

CONCLUSIONS:

In the present study the concept of secondary energy absorbing device (SEAS) is proposed and it's benefits are demonstrated through full vehicle crash simulation results. The proposed SEAS concept reduces vertical bending moments in chassis frame swan neck area during the frontal impact scenario thus providing opportunities for light weight design concepts for chassis frame design. The proposed SEAS concept is implemented in Crossover vehicle program and approximately 12 kg weight reduction is achieved for complete vehicle for offset frontal crash requirements. The proposed SEAS concept also likely to improve the compatibility aspects of the vehicle crash performance which is not evaluated in this study.

REFERENCES

[1] Aluminium in Cars" Report by European Aluminium Association 2009, www.aluminium.org

[2] T Dutton, S Iregbu, R Sturt, A kellicut, B Cowell and K Kavikondala," The effect of forming on the crashworthiness of the vehicles with hydroformed frame siderails" SAE 1999

[3] Chung Kyu Park, Robert Thomson,Aleksandra Krusper, Cing Dao (steve) Kan,"The influence of subframe geometry on a vehicles frontal crash response ", ESV Paper 09-0403

[4]LSTC "LSDYNA User's manual version 971 May 2007, Livermore Software Technology Corporation.