# Analysis and Correlation for Body Attachment Stiffness in BIW

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**ABSTRACT**

It is known that automotive body structure must have sufficient stiffness at the suspension attachments and the powertrain mounts to take advantage of the isolation provided by bushings and to improve the flexibility of bushing rate tuning. So, to get the sufficient stiffness at the attachments is one of the major NVH targets in most car makers.

In this paper, F.E. analysis and correlation process of body attachment stiffness are described and reliable frequency ranges for the analysis are discussed. During the correlation process some factors were suspected to have influences on test results and their effects are simulated and discussed.

On the assumption that full body model is well correlated, reliability of partial model is reviewed and computer's resources are compared.

## 1. Introduction

It is known that there are various sources of vibration in automotive vehicle, and engine excitations and forces from road are important sources. Also, the vibration paths to body are mainly powertrain mounts, strut attachment points, subframe and cross member attachment points, etc. Body structure must have sufficient stiffness at these attachments and mounts to take advantage of the isolation provided by bushings and to improve the flexibility of bushing rate tuning. So, body attachment stiffness is one of the major NVH targets in design and therefore to evaluate attachment stiffness in F.E analysis is important to meet the design target.

In this paper, reliable frequency ranges of F.E. analysis of body attachment stiffness using BIW full model were compared to test. During the correlation process some factors were suspected to have influences on test results and their effects were simulated and discussed.

On the other hand, using BIW full model demands too much modeling time and many analysis resources. In some cases, there is only partial model to analyze instead of full model. In this point of view, it is meaningful to discuss reliable frequency ranges of analysis of partial model.

Process of attachment stiffness evaluation was carried out using partial model of BIW to compare the analysis resources and reliabilities of results.

## 2. Modeling for evaluation on attachment stiffness

### Selection of the body attachments

Using MSC.Patran, full BIW was made of about 130,000 elements. The body attachments are 4 points of subframe attachments, engine mount, transmission mount and 1 point at front strut attachments in front part of body and 1 point at rear cross member attachments and 1 point at rear strut attachments in rear part. The stiffness was evaluated in both Y and Z direction. If the test results show almost same stiffness between left-hand (LH) and right-hand (RH) attachment, only one side attachment stiffness was evaluated. But the stiffness of subframe front attachment was evaluated on both LH and RH attachment. [Fig. 1]

### Modeling at bolt-and-nut joint

The fixed nut at bolt-and-nut joint of rear cross member attachments was modeled as shell elements and the joint was connected with rigid elements. [Fig. 2]

Subframe front attachments were connected using movable nut. So all nodes of area of movable nut that contacts with adjacent panels were connected with rigid elements. [ Base model of Fig. 4 ]

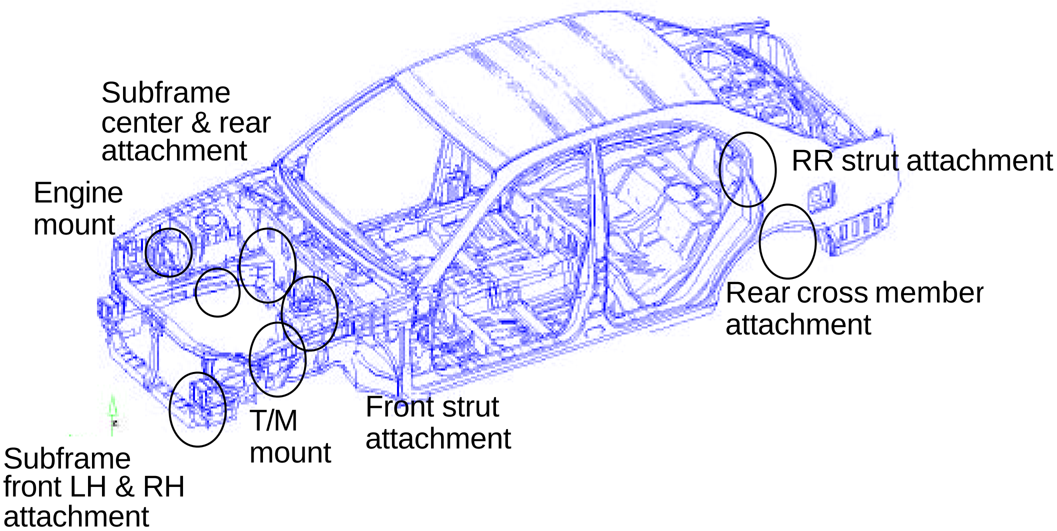



Fig. 1 BIW and attachment for point inertance analysis

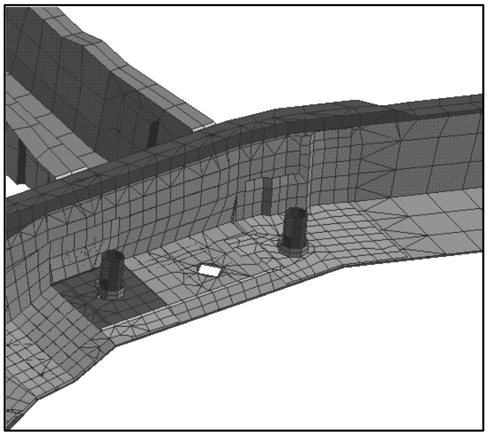
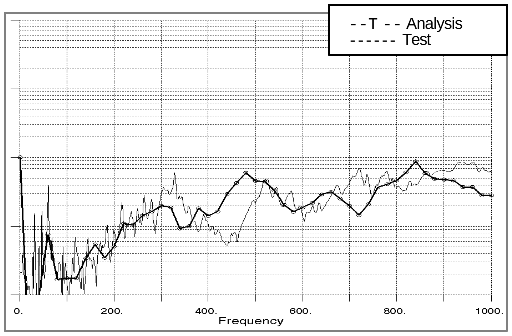


Fig. 2 Example model for point inertance analysis
(RR cross member)

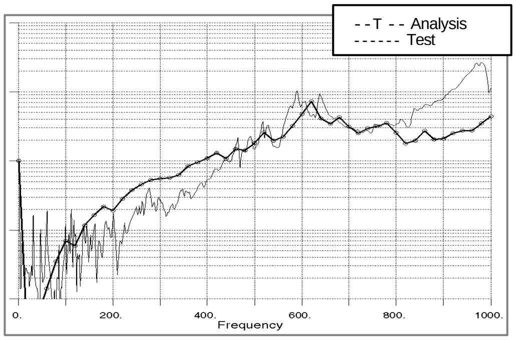
## 3. Results of analysis for attachment stiffness

To evaluate the body attachment stiffness, point inertance analysis was performed using solution 108 of MSC.Nastran v70.5 and 20 hertz of frequency resolution was determined from trial and error.

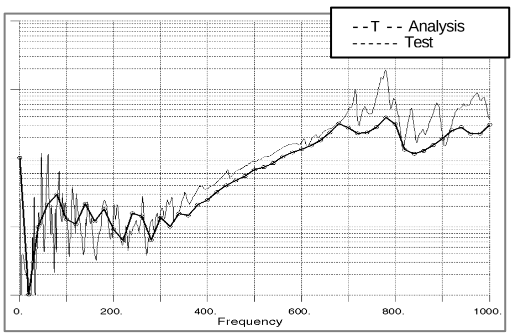
Figure 3 presents some parts of point inertance analysis results. Analysis data coincide with measured data up to 800 hertz at most attachment points including subframe attachment center, engine mount, transmission mount, front strut attachment and rear cross member attachment. Reliable frequency range at subframe front LH attachment is 600 hertz.



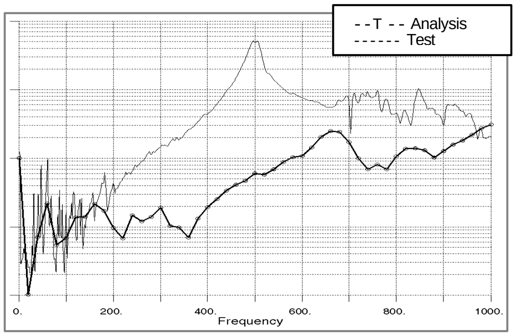

(a) Engine mount



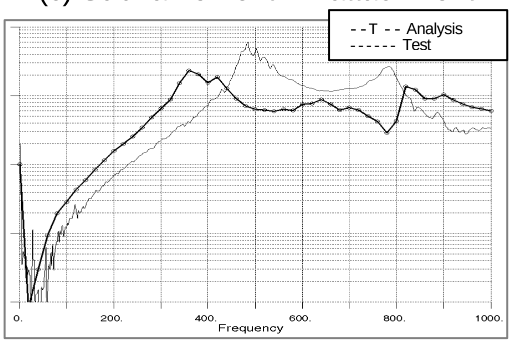

(b) Front strut attachment



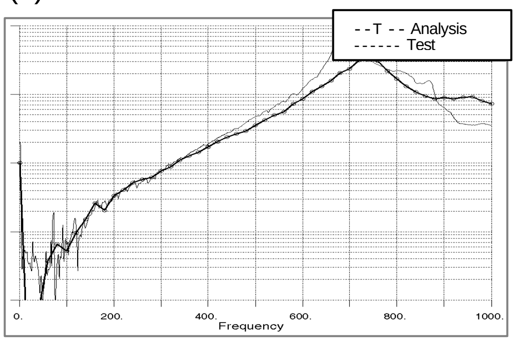

(c) Subframe front LH attachment




(d) Subframe front RH attachment




(e) Rear strut attachment




(f) Rear cross member attachment

Fig. 3 Point inertance results in Z direction at some attachment points

**Results of analysis at attachment with fixed nut**

Attachment structures used in this analysis are mainly divided in two types. One is fixed nut type and the other is movable nut type. And, it has different analysis results due to these nut types. That is, analysis result of subframe center attachment or rear cross member attachment with fixed nut has same characteristic comparing with test results. But this characteristic cannot be applied to the movable nut type any more as follows.

**Results of analysis at attachment with movable nut**

Although the test results are significantly different between subframe front LH and front RH attachment, the analysis results are not. [ Fig. 3(c) and (d) ] We assumed that the difference between test results or the difference between test and analysis results is due to movable nut type of attachment structure.

Subframe front attachment consists of bolt-and-nut joint with movable nut. So, according to what torque is applied to joint, area of actual thickness – that means stiffness – of panel will be changed. To describe this phenomenon in analysis, rigid elements were connected between movable nut plate and front side member panels, and then the number of rigid elements was changed [ Fig. 4 ]

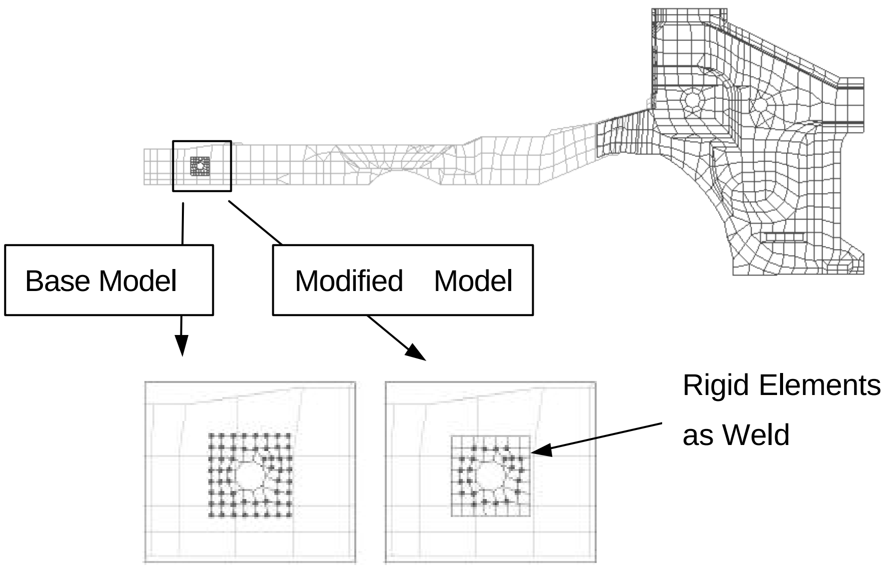



Fig. 4 Difference between base model and modified model at subframe front LH attachment

In base model, movable nut plate was connected to front side member through the whole area which means joint has strong connection. In modified model, the connection was accomplished only around the hole.

At first, it was predicted that the change of connection strength of local area will influence only some peaks at high frequencies, but it turned out that the level of curve - which means stiffness level - is influenced throughout the most frequencies. [Fig. 5] This tendency of analysis results is same as that of the test results.

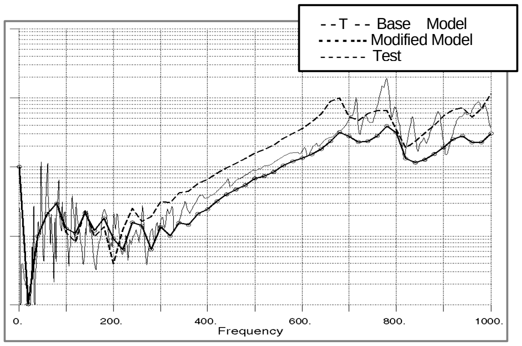



Fig. 5 Results of base model and modified model in Z direction at subframe front LH attachment

From above results, it could be inferred that joint at subframe front LH attachment was strongly connected rather than RH attachment in test.

It is not desirable that the attachment stiffness depends on connection strength due to torque that is applied to joint. If these phenomena are occurred in the field, it will bring about serious problems such as inconsistent results of test. Therefore it is proper to use fixed nut rather than movable nut to avoid above phenomena.

**Results of analysis at rear strut attachment**

It appears the stiffness of analysis result is lower than the test at rear strut attachment. [Fig. 3(e)] This result was occurred because the 2 rigid elements describing welds had been missed. When the missed rigid elements in base model were added into modified model [Fig. 6], the analysis result almost coincided with test result [Fig. 7].

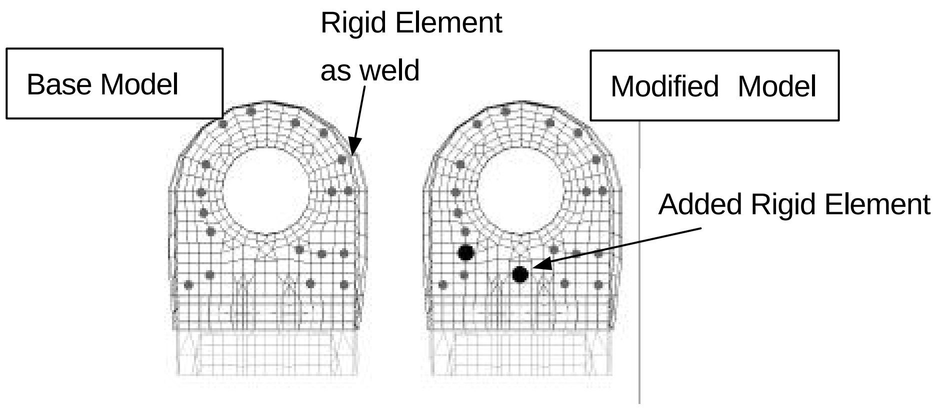



Fig. 6 Difference between base model and modified model at rear strut attachment

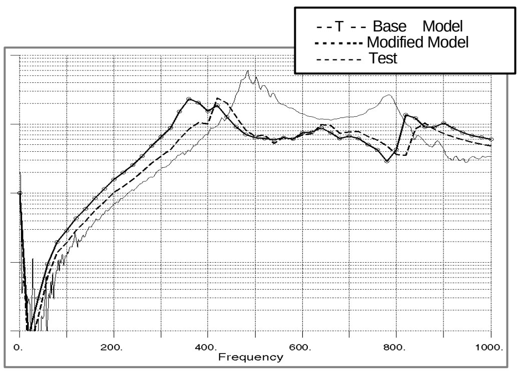



Fig. 7 Results of base model and modified model in Z direction at rear strut attachment

Basically weak structure like rear strut attachment that has large plain area will cause relatively significant difference between before and after adding rigid elements. Test or analysis should be performed carefully on weak structure because many factors such as weld, mass, etc. may cause large error.

**4. Analysis using partial model**

Because analysis using BIW full model demands large system resources including

CPU time and disk usage, it could be efficient method to use partial model. But this method cannot secure reliability of result at low frequency global modes. So whether partial model is appropriate or not will be important.

To examine an efficient method using partial model, BIW was divided into front and rear part and also each partial model was transformed into 3 or 4 cases. Point inertance analysis result of each case was compared with that of BIW full model.

**Front partial model**

The analysis of model case A ~ D for front part was carried out. Figure 8 shows model case A ~ D. Body stiffness at 7 attachments and mounts was evaluated in case A and B, 6 in case C and 1 in case D.

The boundary condition is free or fixed along the section and solution 108 and solution 111 were used to get the point inertance result.

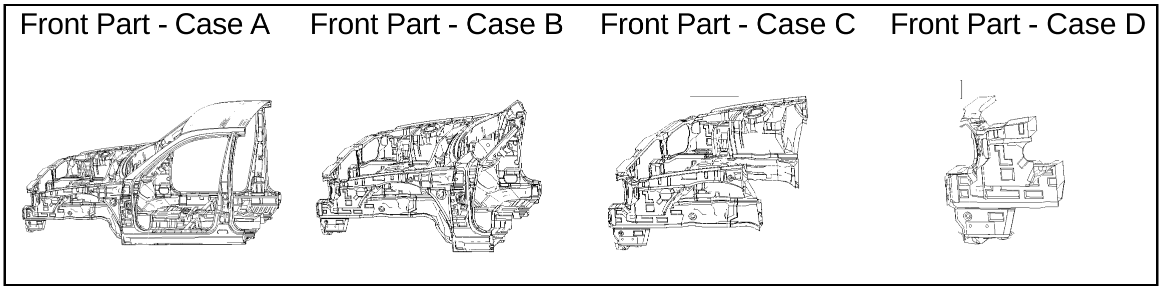



Fig. 8 Partial models to compare the resources and reliable frequency region

**Result of analysis using front partial model**

Figure 9(a) shows some results of point inertance analysis of each case and table 1 shows computer's resources in solution 108 analysis and table 2 shows in solution 111. The CPU time in solution 108 is 45 % in case A, 21 % in case B and 6 % in case C compared with full BIW model. Also, the CPU time in solution 111 is 139 % in case A and 26 % in case B compared with full BIW model in solution 108. The CPU time in solution 108 in case A is less than a half of full BIW analysis. It took long time in solution 111 in case A than full BIW analysis because of modes calculation. The case B has similar CPU time in solution 108 or solution 111.

Reliable frequency ranges depends on the attachments and directions. Table 3 shows the reliable range in each case compared with full BIW analysis. The number in the table means low limit of the reliable frequency range.

In general, the curve of case A coincides with full BIW above 100 hertz and the case B above 200 hertz except subframe rear attachment. Reliable range of subframe rear attachment is reduced to above 300 hertz because it is located near the boundary. In the case C, reliable range is above 400 hertz only at subframe front attachment. The case D has no reliable range.

Therefore, if it needs reliable range above 100 hertz, it is desirable to use case A in solution 108 and above 200 hertz to use case B in solution 111.

On the other hand, in comparison of results between fixed boundary condition and free boundary condition, the range that has same results will be the reliable range of frequency in partial model analysis. [ Fig. 9 ]

Table 1. Analysis resources in each case of front part ( solution 108 )

| | | CPU time(sec.) | Disc Usage(GB) |
|---|---|---|---|
| Full BIW | | 42,241 | 20.179 |
| Case A | Free | 18,978 | 12.406 |
| | Fix | 19,321 | 12.377 |
| Case B | Free | 9,014 | 7.494 |
| | Fix | 8,634 | 7.442 |
| Case C | Free | 2,316 | 2.859 |
| | Fix | 1,987 | 2.830 |
| Case D | Free | 292 | 0.226 |
| | Fix | 276 | 0.222 |

Table 2. Analysis resources in each case of front part ( solution 111 )

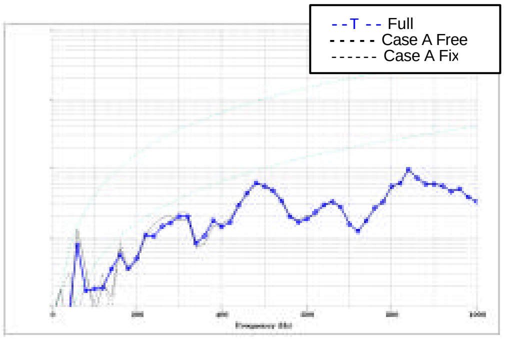
| | | CPU time(sec.) | Disc Usage(GB) |
|---|---|---|---|
| Case A | Free | 58,559 | 18.986 |
| | Fix | 47,127 | 18.867 |
| Case B | Free | 10,937 | 6.983 |
| | Fix | 7,666 | 6.340 |
| Case C | Free | 1,980 | 1.277 |
| | Fix | 1,137 | 1.236 |

Table 3. Reliable frequency ranges in each case of front part comparing with full BIW ( Low limit of frequency, hertz )

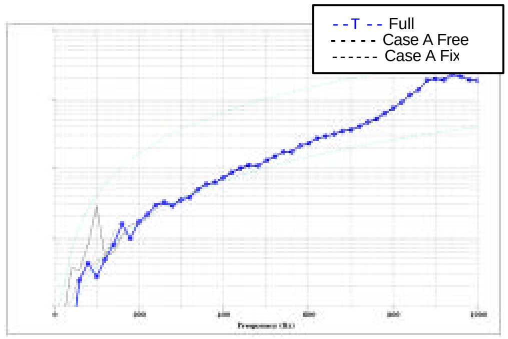
| Attachment points | Case A | Case B | Case C | Case D |
|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| T/M mount | Z | 100 | 200 | × | _ |
| | Y | 100 | 200 | × | _ |
| Engine mount | Z | 150 | 200 | 800 | _ |
| | Y | 100 | 200 | 500 | _ |
| Front strut | Z | 100 | 200 | × | _ |
| | Y | 100 | 200 | × | _ |
| Subframe front LH | Z | 100 | 200 | 300 | × |
| | Y | 150 | 200 | 400 | × |
| Subframe front RH | Z | 100 | 250 | 350 | _ |
| | Y | 150 | 200 | 400 | _ |
| Subframe center RH | Z | 100 | 200 | × | _ |
| | Y | 100 | 150 | × | _ |
| Subframe rear LH | Z | 200 | 300 | _ | _ |
| | Y | 200 | 300 | _ | _ |

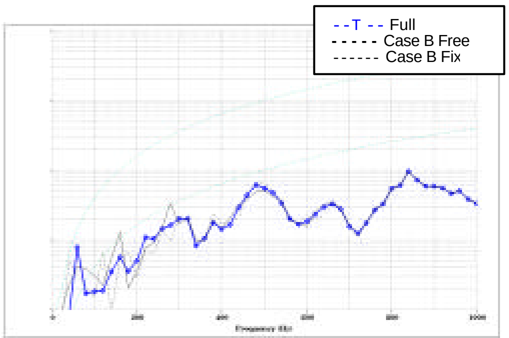
( × : No reliable range within 1k hertz )



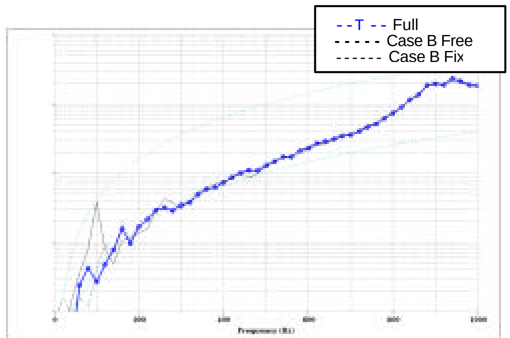

Front Part - Case A



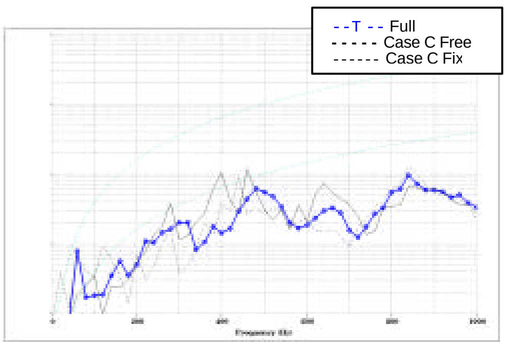

Rear Part - Case A

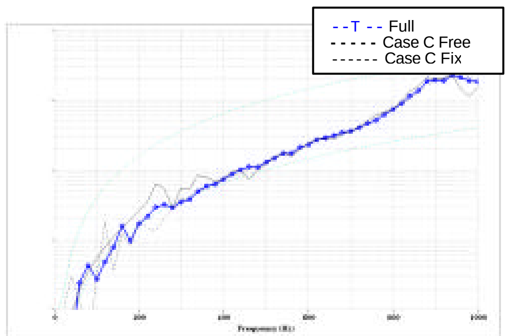



Front Part - Case B




Rear Part - Case B




Front Part - Case C　　Rear Part - Case C

(a) Engine mount of front part　　(b) Rear cross member attach. of rear Part

Fig. 9 Point inertance results in Z direction

in each case of front and rear part

**Rear partial model**

Analysis of case A ~ C for rear part was carried out. Figure 10 shows model case A ~ C. Body stiffness at 2 attachments was evaluated in case A ~ C.

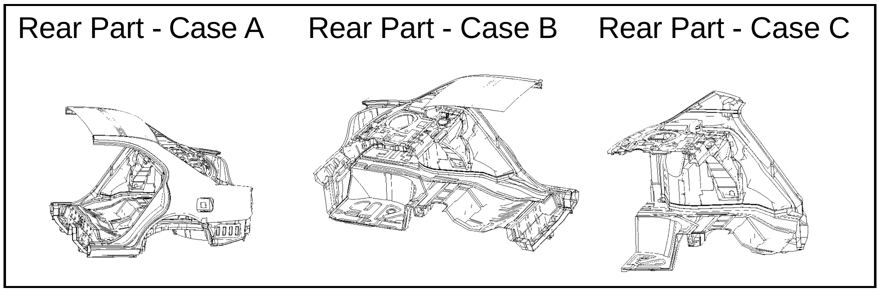



Fig. 10 Partial models to compare the resources and reliable frequency region

**Result of analysis using rear partial model**

Figure 9(b) also shows some results of point inertance analysis of each case. Table 4 shows computer's resources in solution 108 analysis and table 5 shows in solution 111. The CPU time in case A is 24 % in solution 108 and 80 % in solution 111 compared with BIW full model. In the case B, CPU time is 8 % in solution 108 and 15 % in solution 111 compared with full BIW model.

Table 6 shows the reliable frequency range in each case compared with full BIW analysis.

In the case A, low limit of frequency becomes 100 ~ 200 hertz. In the case B and C, low limit of frequency will be 100 ~ 400 hertz in Z direction but there is no reliable range in Y direction. So, the case A is the best to get a reliable range above 100 hertz.

Table 4. Analysis resources in each case of rear part ( solution 108 )

| | | CPU time(sec.) | Disc Usage(GB) |
|---|---|---|---|
| Full BIW | | 41,709 | 9.169 |
| Case A | Free | 9,839 | 3.433 |
| | Fix | 9,825 | 3.431 |
| Case B | Free | 3,268 | 1.782 |
| | Fix | 2,776 | 1.749 |
| Case C | Free | 1,859 | 1.101 |
| | Fix | 1,821 | 1.072 |

Table 5. Analysis resources in each case of rear part ( solution 111 )

| | | CPU time (sec.) | Disc Usage(GB) |
|---|---|---|---|
| Full BIW | | _ | _ |
| Case A | Free | 33,297 | 12.659 |
| | Fix | 33,163 | 12.014 |
| Case B | Free | 6,509 | 4.206 |
| | Fix | 5,888 | 3.993 |
| Case C | Free | 2,655 | 1.776 |
| | Fix | 1,762 | 1.220 |

Table 6. Reliable frequency ranges in each case of rear part comparing with full BIW ( Low limit of frequency, hertz )

| Attachment points | | Case A | Case B | Case C |
|---|---|---|---|---|
| Rear strut | Z | 100 | 100 | 100 |
| | Y | 200 | 900 | 900 |
| Rear cross member | Z | 200 | 250 | 400 |
| | Y | 200 | 600 | × |

( × : No reliable range within 1k hertz )

## 5. Conclusion

From the point inertance analysis of subframe attachments, strut attachments and powertrain mounts, it was verified that results coincide with test result up to 600 hertz and F.E. model is appropriate to evaluate on the body attachment stiffness.

Analysis result of rear cross member attachment with fixed nut coincided with test results. But body stiffness of attachment with movable nut such as subframe front is changed due to area of actual thickness that is influenced by applied torque to bolt-and-nut joint in test or analysis.

Also, weak structure such as rear strut attachment that has large plain area will cause relatively significant influences on the stiffness between before and after adding rigid elements describing welds.

Using partial model, computer's resources can be reduced. The reliable range of frequency is above 100 ~ 200 hertz if front partial model includes hinge pillar or rear partial model includes rear structure of center pillar. In comparison of results between fixed boundary condition and free boundary condition, the range that has same results will be the reliable range of frequency in partial model analysis.