Altair Technology Conference 2018

Truck Ride Comfort Analysis by using Compose and MotionSolve

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ATC 2018

Truck Ride Comfort Analysis

1. Purpose

1) Truck ride comfort modeling and analysis by using Compose and MotionSolve
2) ISO 8608 road modeling, ISO 2631 comport evaluation by Compose

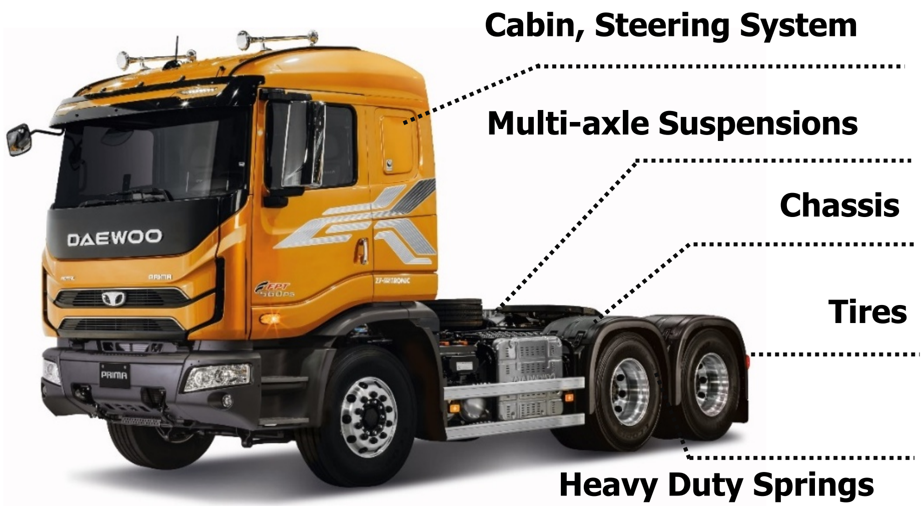
2. Truck Line-up

1) Simple modeling and analysis are needed for the various vehicle variations

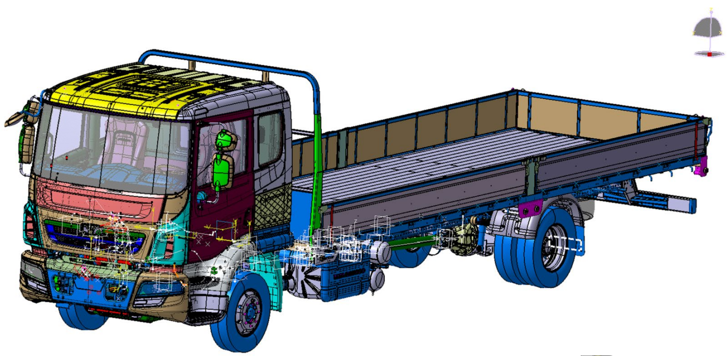
Construction Dump/Mixer	   
Tractor	  
Cargo	    

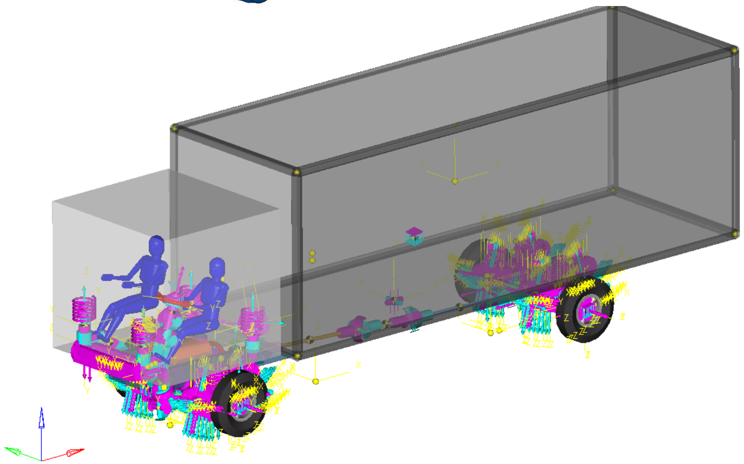
3. Truck Library

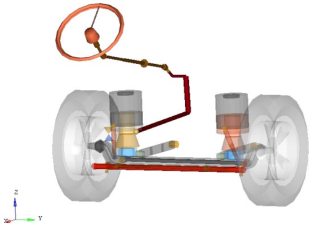
❖ Truck Library is a collection of essential and ancillary heavy vehicle components for assembling and testing trucks virtually.



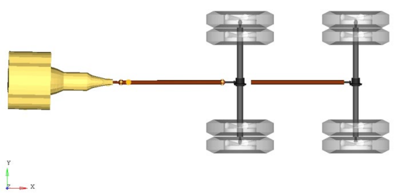
[Truck Library]



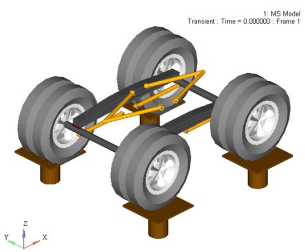




Steering system



Driveline



Test Rigs

[4x2 Cargo(MCV) w/ Truck Library]

4. Ride Comfort Analysis

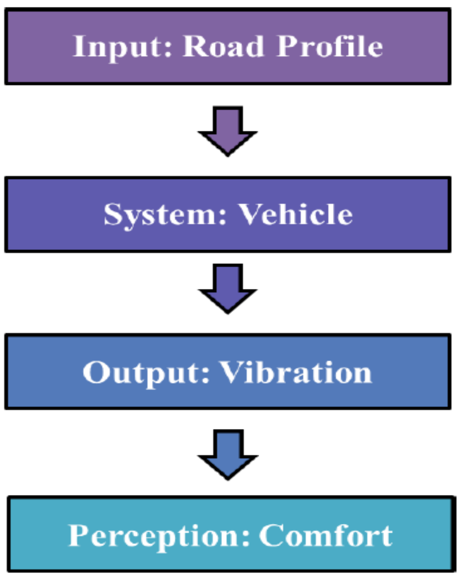
1) Post Shaker Simulation(Road Simulator)

① Input : To reproduce a road, the road profile is defined to be delayed from the front tires to the rear tires according to the vehicle speed

② System : Vehicle Model, Post Shaker Model

③ Output : The acceleration results at the driver seat floor

④ Perception : The evaluation of the acceleration results according to the comfort criteria

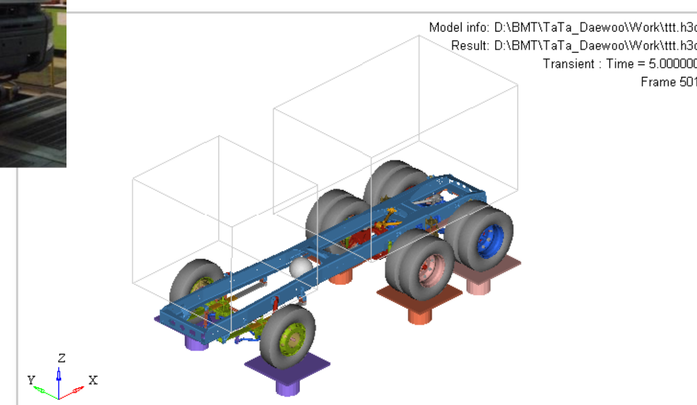


[Ride Comfort Analysis]

◆ R/S Sine Sweep Test

[R/S TEST]

+



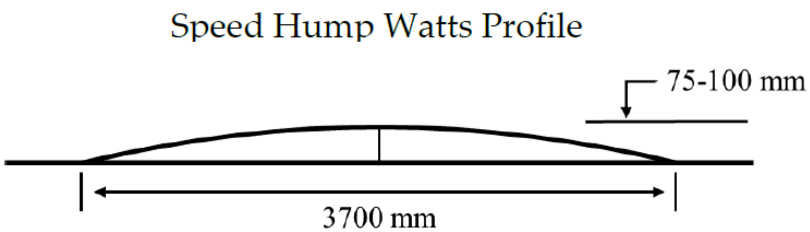
[6-Post Simulation]

4. Ride Comfort Analysis

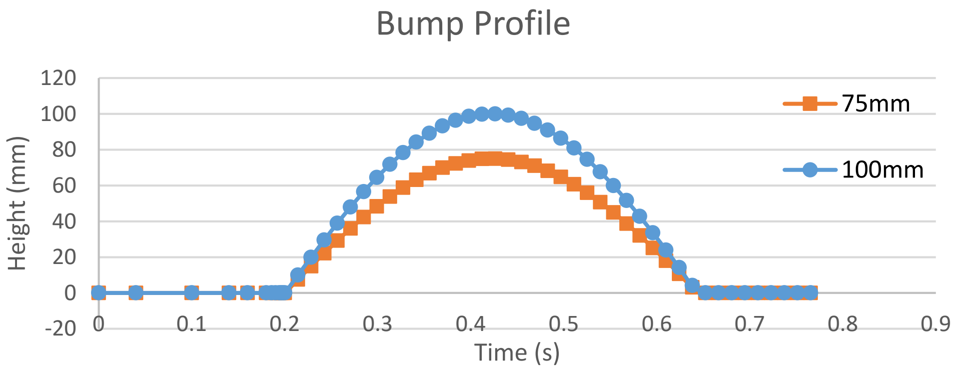
2) Input

① Bump Road

- Using Watts Profile Bump at ITE Journal (Institute of Transportation Engineers)
  (The bump profile which is safe for most vehicle at 25~30kph speed)
- The vehicle frequency response characteristic can be reliably displayed.
- This can show vehicle natural frequency response characteristic.



[Speed Bump]



[Bump road modeling – 30kph]

4. Ride Comfort Analysis

2) Input

② Road Profiles for ISO 8608

- The main factors determining the shape of the road surface are spatial frequency and amplitude.
- ISO 8608 road class (A~H) modeling according to the road roughness

$$z_R(x) = \sum_{i=1}^{N} A_i \sin(\Omega_i x - \varphi_i)$$

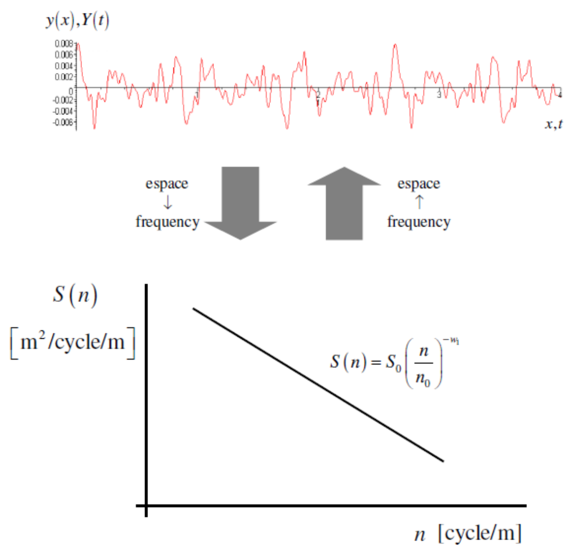
$$A_i = \sqrt{\Phi(\Omega_i)\frac{\Delta\Omega}{\pi}},$$

$$\Delta\Omega = \frac{\Omega_N - \Omega_i}{N-1},$$

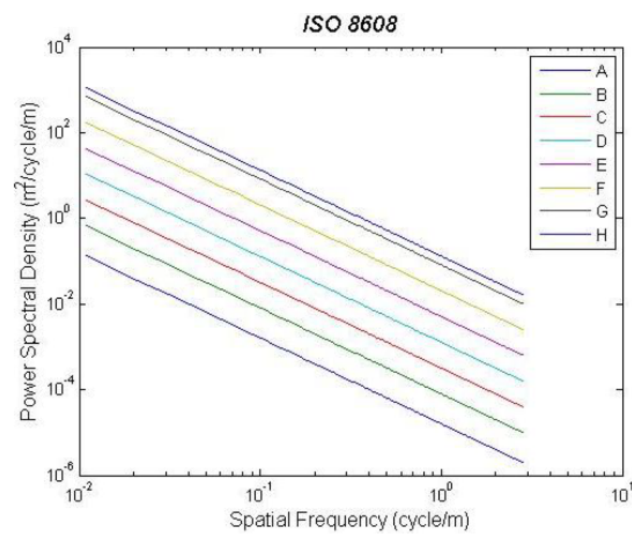
$$\begin{aligned} f(\mathrm{Hz}) &= \Omega[\mathrm{cycles/m}] \cdot V[\mathrm{m/s}] \\ &= \frac{1}{l_{wn}} \cdot V \end{aligned}$$

$$S_y(n) = S(n_0)\left(\frac{n_0}{n}\right)^2, \quad n \le n_0$$

$$S_y(n) = S(n_0)\left(\frac{n_0}{n}\right)^{1.5}, n \ge n_0$$



[PSD와 Spatial Signal의 관계]



[ISO 8608에 따른 도로 거칠기 분류]

4. Ride Comfort Analysis

2) Input

③ ISO Road Modeling by Compose

– Random Road Profile : Random road modeling according to the ISO 8608 road class

[Compose Modeling]

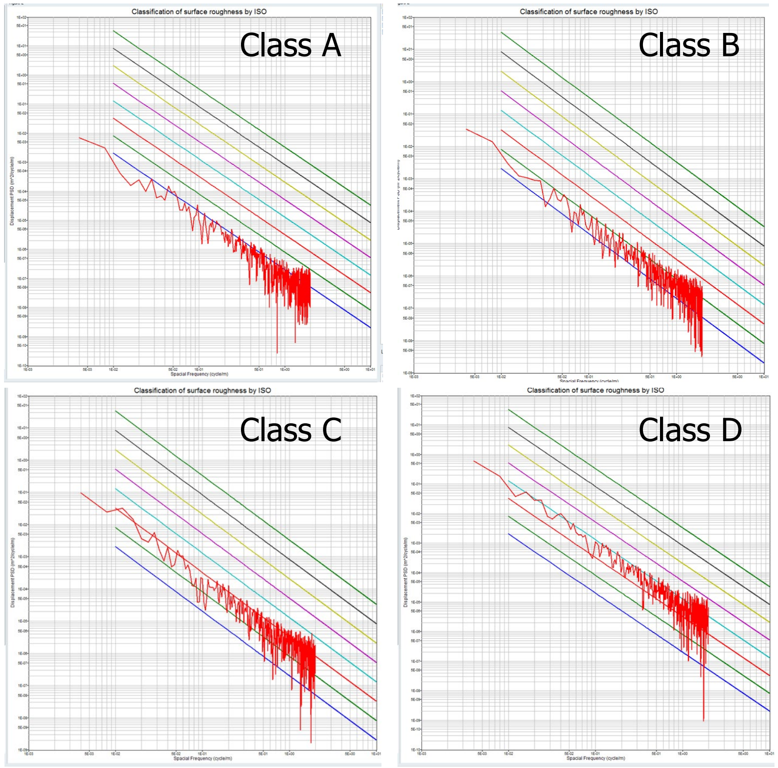
4. Ride Comfort Analysis

2) Input

④ ISO Road Profiles for Simulation

- ISO Class A (h_{max}= ±15mm) : very good
- ISO Class B (h_{max}= ±25mm) : good
- ISO Class C (h_{max}= ±50mm) : average
- ISO Class D (h_{max}= ±100mm) : poor

[Road Profile for Simulation]



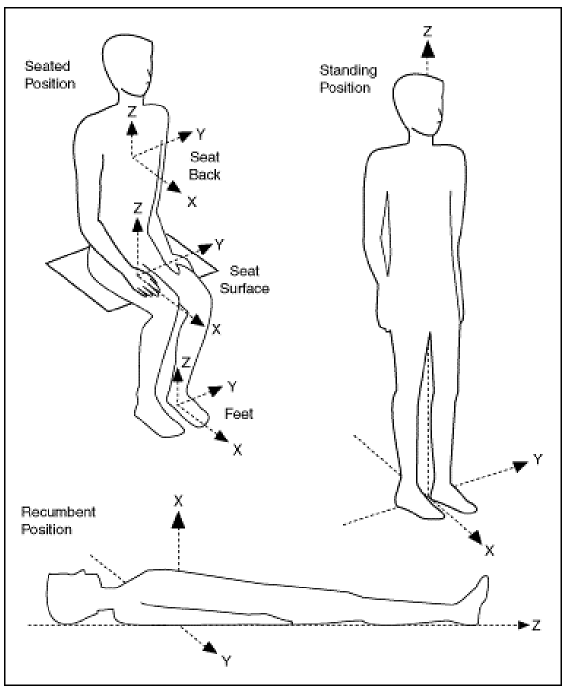
[ISO Classification]

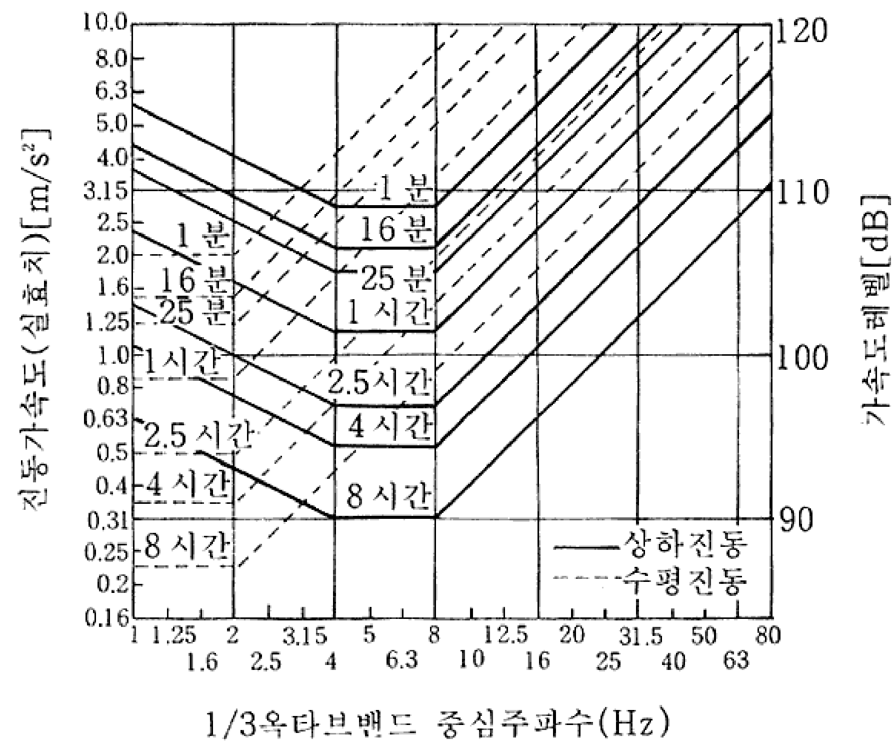
4. Ride Comfort Analysis

3) Perception

① ISO 2631 (Evaluation of Human Exposure to Whole-Body Vibration)

- The entire body vibration exposure limits for the horizontal and vertical vibrations established by using the experimental results of human body vibration
- The vibration acceleration and the exposure time vary depending on the frequency.
- Critical Frequency : 4~8 Hz(Vertical), 1~2 Hz(Longitudinal, Lateral)





4. Ride Comfort Analysis

3) Perception

② ISO 2631 Comfort Graph by Compose

- Ride comfort evaluation
- PSD and RMS values for each frequency are calculated with acceleration output value and calculate ISO 2631 Comfort Graph to evaluate Ride Comfort
- ISO Road Class, Velocity standards need to be established for vehicle types(Dump, Cargo, Tractor)

* 1/3 octave frequency bands

$$f_1 = 0.89 f_c \quad f_2 = \sqrt[3]{2} f_1 = 1.26 f_1 = 1.12 f_c$$

* PSD in each band

$$\Delta E\left(\ddot{z}^2\right) \cong \frac{S_{\ddot{z}}(f_1) + S_{\ddot{z}}(f_c)}{2}(f_c - f_1) + \frac{S_{\ddot{z}}(f_c) + S_{\ddot{z}}(f_2)}{2}(f_2 - f_c)$$

* RMS acceleration in each band

$$a_i = \sqrt{\Delta E(\ddot{z}^2)}$$

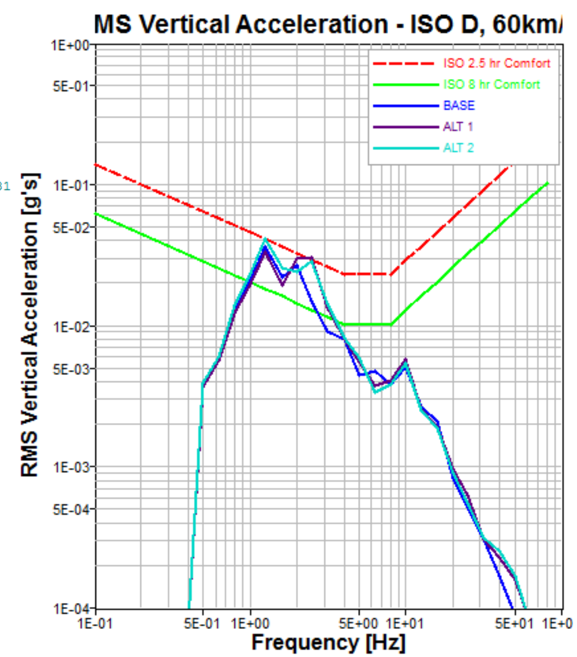
* RMS weighted acceleration

$$a_0 = \left[\sum_i (w_i a_i)^2\right]^{1/2}$$

[ISO 2631 Equations]

```
% Wheel center frequencies...
whzc = [.1 .125 .16 .2 .25 .315 .4 .5 .63 .8 1. 1.25 1.6, ...
        2 2.5 3.15 4 5 6.3 8 10 12.5 16 20 25 31.5 40 50 63 80];

% upper and lower frequency bands..
f1 = .89*whzc;
f2 = 1.12*whzc;

% calculate ISO 2631 fatigue boundaries
% wc is vector of center frequencies of 1/3 octave bands, Hz
wc = [.1, 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8, 10, 12.5, 16, 20, 25, 31

% ISO 2631 2.5 hr fatigue boundary in m/s^2 (VERTICAL ACCEL)
fat25FV = [4.284, 1.4, 1.26, 1.12, 1, .9, .8, .71, .71, .71, .71, ...
           .9, 1.12, 1.4, 1.8, 2.24, 2.8, 3.55, 4.5, 5.6, 7.1];

%
% ISO 2631 2.5 hr comfort boundary in g's (VERTICAL)
%
comf25 = (fat25FV/3.15)/9.81;

% comf8 is the 8 hour reduced comfort boundary in g's
comf8 = comf25/2.254;

% ISO standard weights for vertical acceleration
wgtV = [.0312, .0486, .079, .121, .182, .263, .352, .418, .459, .477, ...
        .482, .484, .494, .531, .631, .804, .967, 1.039, 1.054, 1.036,...
        .988, .902, .768, .636, .513, .405, .314, .246, .186, .132];

for i = 8:length(whzc)
    ii = find((F >= f1(i)) & (F <= f2(i)));
    RMS(i) = sqrt(trapz(F(ii), P(ii)));
end

% weighted rms acceleration values
wgtrms = RMS.*wgtV;
wgtrms2 = wgtrms.^2;
```

[Compose - ISO 2631]



[RMS Results]

5. Quarter Car Model

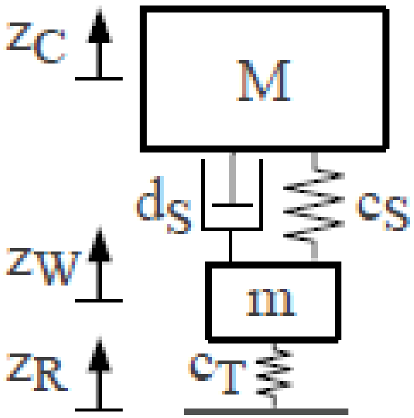
1) Quarter Car

① Definition

- Two-degree-of-freedom model that can adequately express vertical motion of sprung mass and unsprung mass for road excitation
- Evaluation of suspension parameters effect on ride frequency
- Natural Frequency : 1~2 Hz(Sprung Mass), 10Hz(Unsprung Mass)

② Equations of Motion

$$M\ddot{z}_C = F_S + F_D - Mg$$
$$m\ddot{z}_W = F_T - F_S - F_D - mg$$



Suspension Forces
Wheel Load

$$F_S = F_S^0 + c_S(z_W - z_C),\ F_D = d_S(\dot{z}_W - \dot{z}_C),\ F_T = F_T^0 + c_T(z_R - z_W)$$

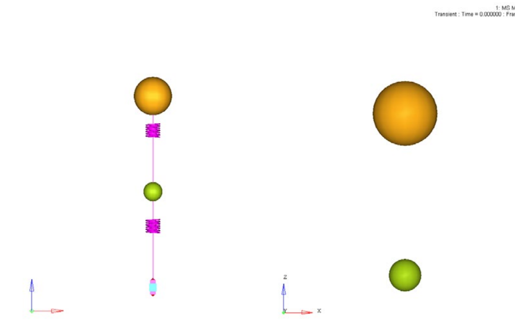
where, z_R : the irregularities of the road
c_S : the stiffness of the suspension
d_S : the damping of the suspension
c_T : the stiffness of the tire

5. Quarter Car Model

2) Compose vs. MotionSolve

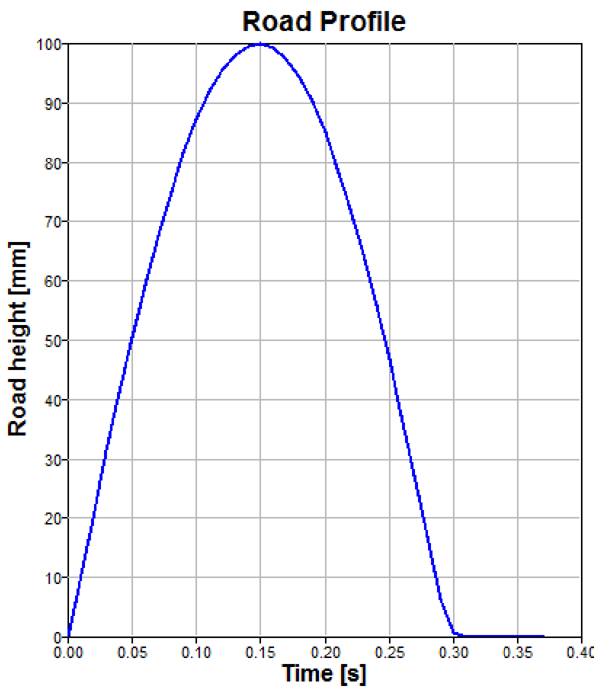
① Correlation between Compose and MotionSolve

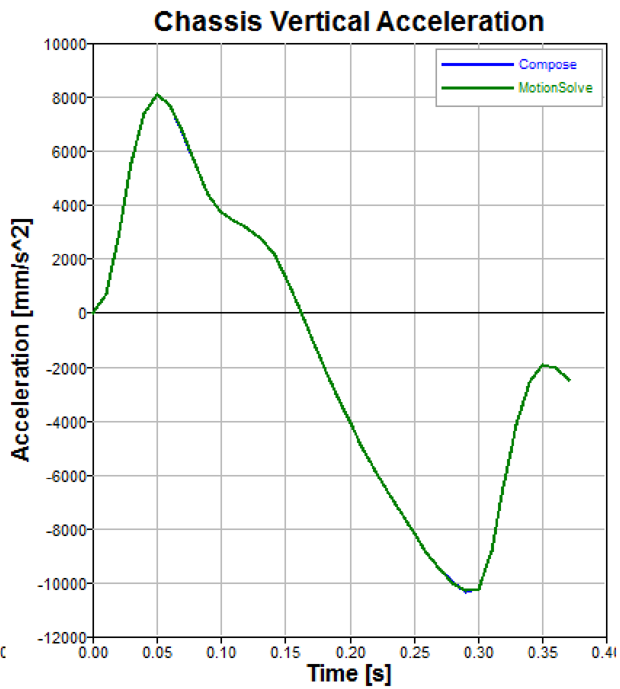
– Comparison of sprung mass acceleration and FFT for the road excitation

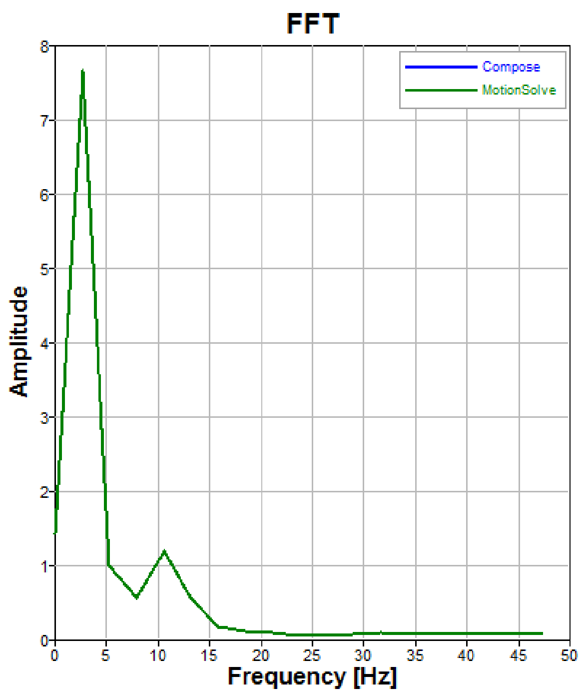


[MotionSolve Modeling & Result]

② Bump Road : Compose and MotionSolve results are well matched







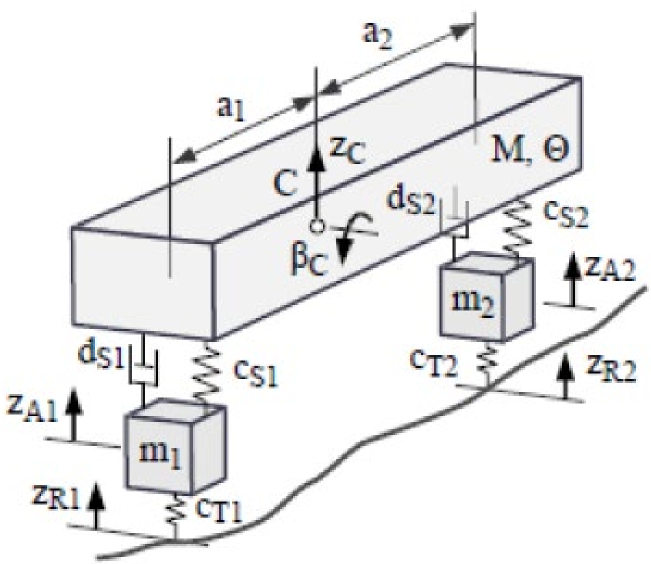
6. Half Car Model

1) Half Car

① Definition

- Four degree-of-freedom model that can express pitch motion
- Sprung Mass의 Bounce Motion, Pitch Motion, Unsprung Mass(Front, Rear)의 Bounce Motion
- To reduce pitch motion, the spring rate and natural frequency of the front must be slightly smaller than rear.
- The optimum ratio depends on the wheelbase, average speed, and road wavelength

② Equations of Motion



$$M\ddot{z}_C = F_1 + F_2 - Mg, \qquad m_1\ddot{z}_{A1} = -F_1 + F_{T1} - m_1 g$$

and

$$\Theta\ddot{\beta}_C = -a_1F_1 + a_2F_2, \qquad m_2\ddot{z}_{A2} = -F_2 + F_{T2} - m_2 g$$

Suspension Forces
Wheel Load

$$F_1 = \overbrace{Mg\frac{a_2}{a_1+a_2}}^{F_{S1}^0} + c_{S1}[z_{A1} - (z_C - a_1\beta_C)] + d_{S1}[\dot{z}_{A1} - (\dot{z}_C - a_1\dot{\beta}_C)]$$

$$F_2 = \underbrace{Mg\frac{a_1}{a_1+a_2}}_{F_{S2}^0} + c_{S2}[z_{A2} - (z_C + a_2\beta_C)] + d_{S2}[\dot{z}_{A2} - (\dot{z}_C + a_2\dot{\beta}_C)]$$

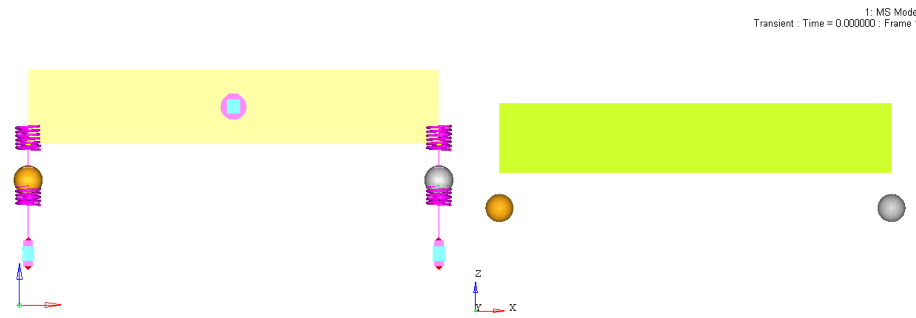
$$F_{T1} = F_{S1}^0 + m_1 g + c_{T1}(z_{R1} - z_{A1}),\ F_{T2} = F_{S2}^0 + m_2 g + c_{T2}(z_{R2} - z_{A2})$$

6. Half Car Model

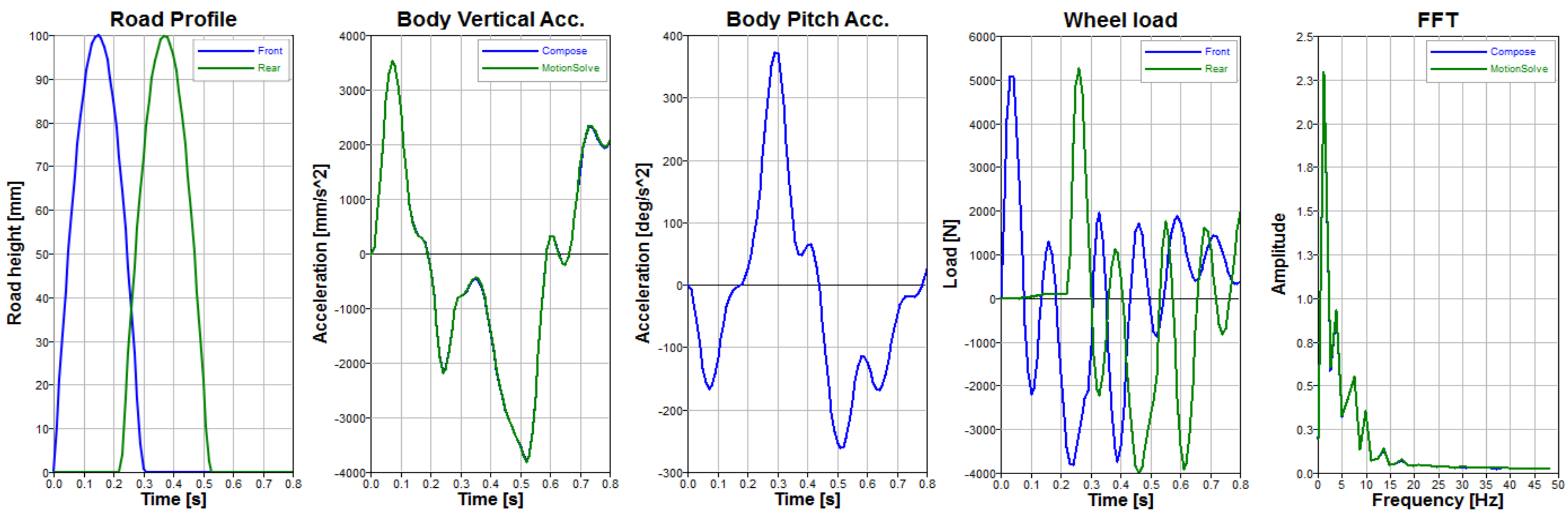
2) Compose vs. MotionSolve

③ Bump Road

: Compose and MotionSolve results match.



[MotionSolve Modeling & Result]

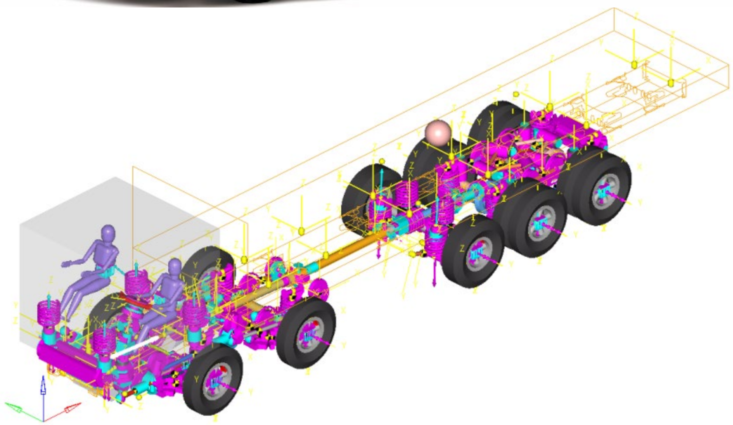


7. Full Vehicle Model

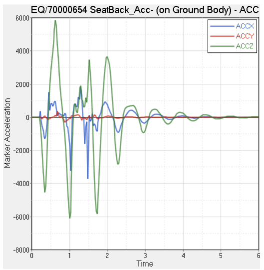
1) Vehicle Model : HCV(Heavy-duty Commercial Vehicle), 10x4 Cargo

2) Road Simulator : 10 Post Shaker modeling which is possible for bump and ISO road excitation

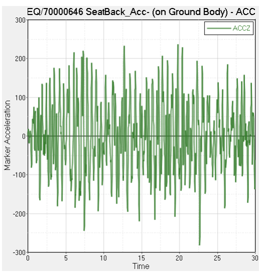
Full Vehicle Dynamic Model

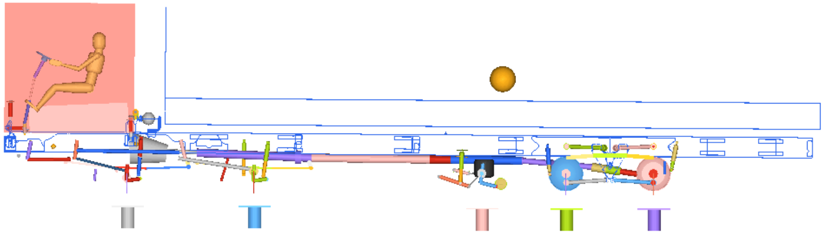


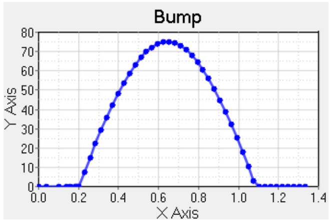
10 Post Road Simulator



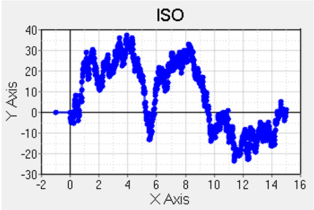
Output







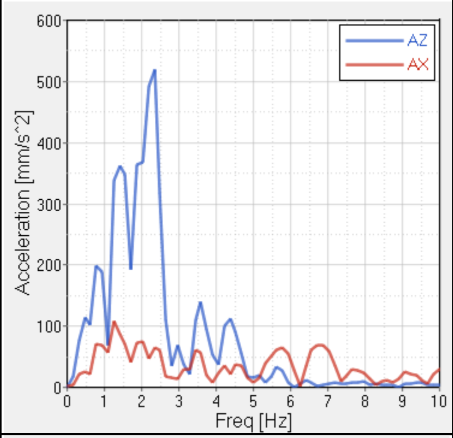
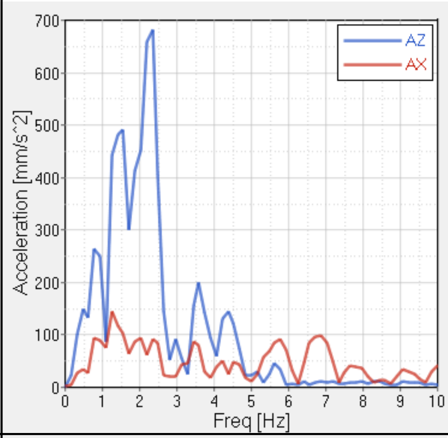
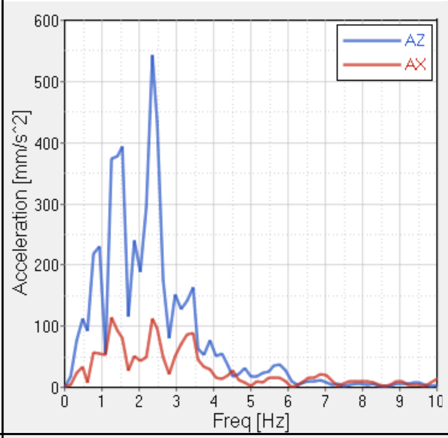
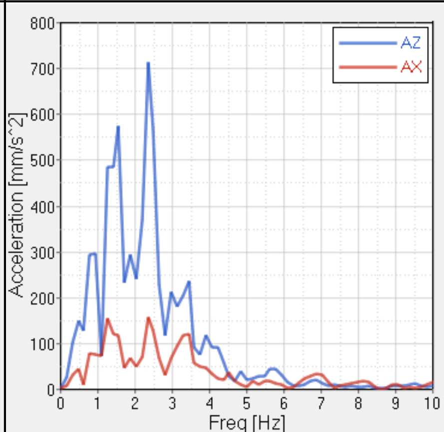
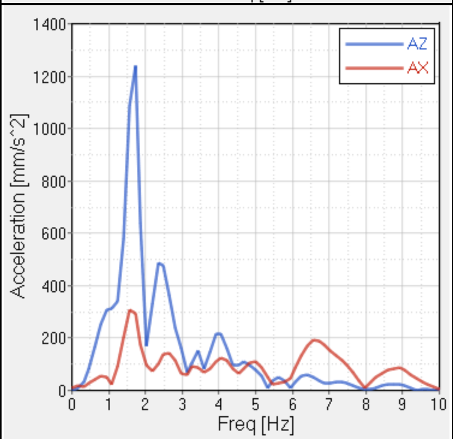
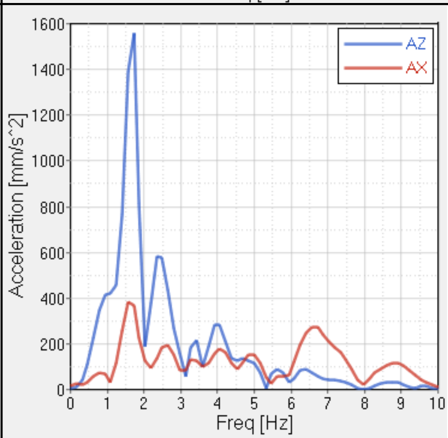
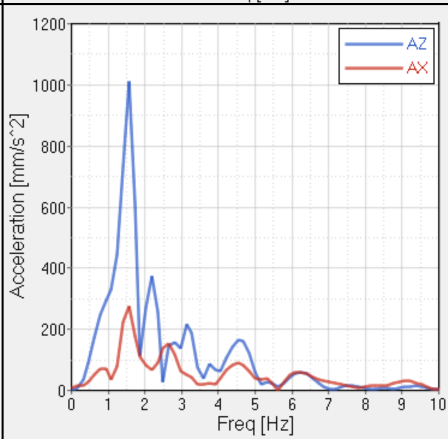
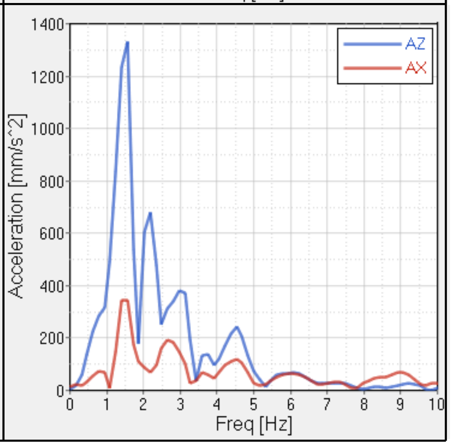
Input



7. Full Vehicle Model

3) Bump Road Results

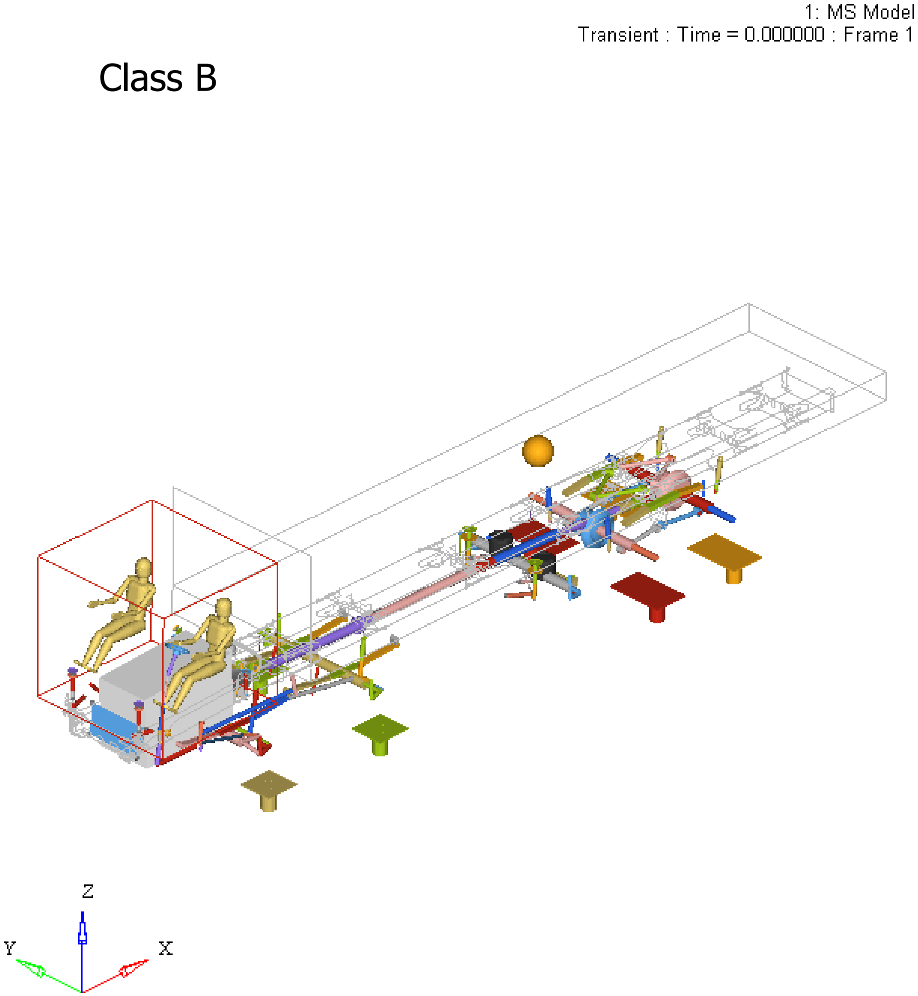
– CAB acceleration FFT results (empty and loaded condition) for bump height 75mm and 100mm

	Unladen, 75mm	Unladen, 100mm	Laden, 75mm	Laden, 100mm
15kph				
30kph				

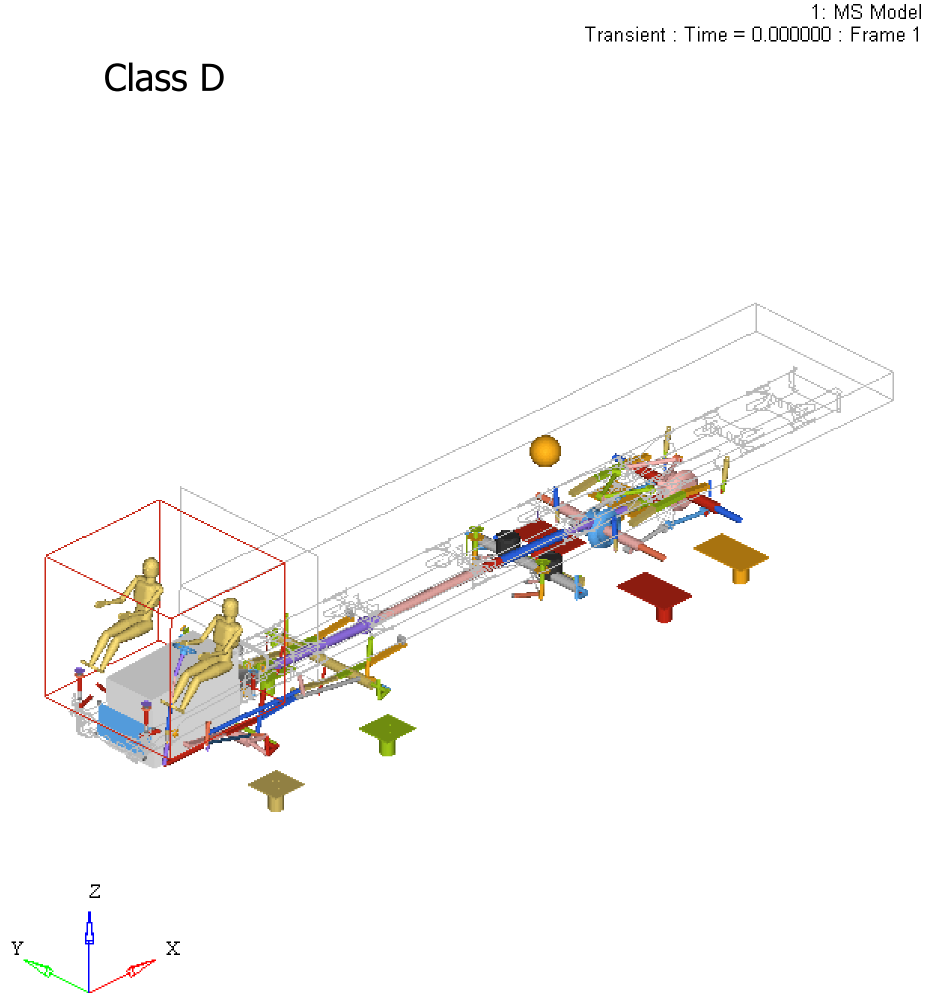
❖ ISO Road Simulation [Animation]

➢ Empty vehicle, 60km/h, Class B & D

Class B



Class D

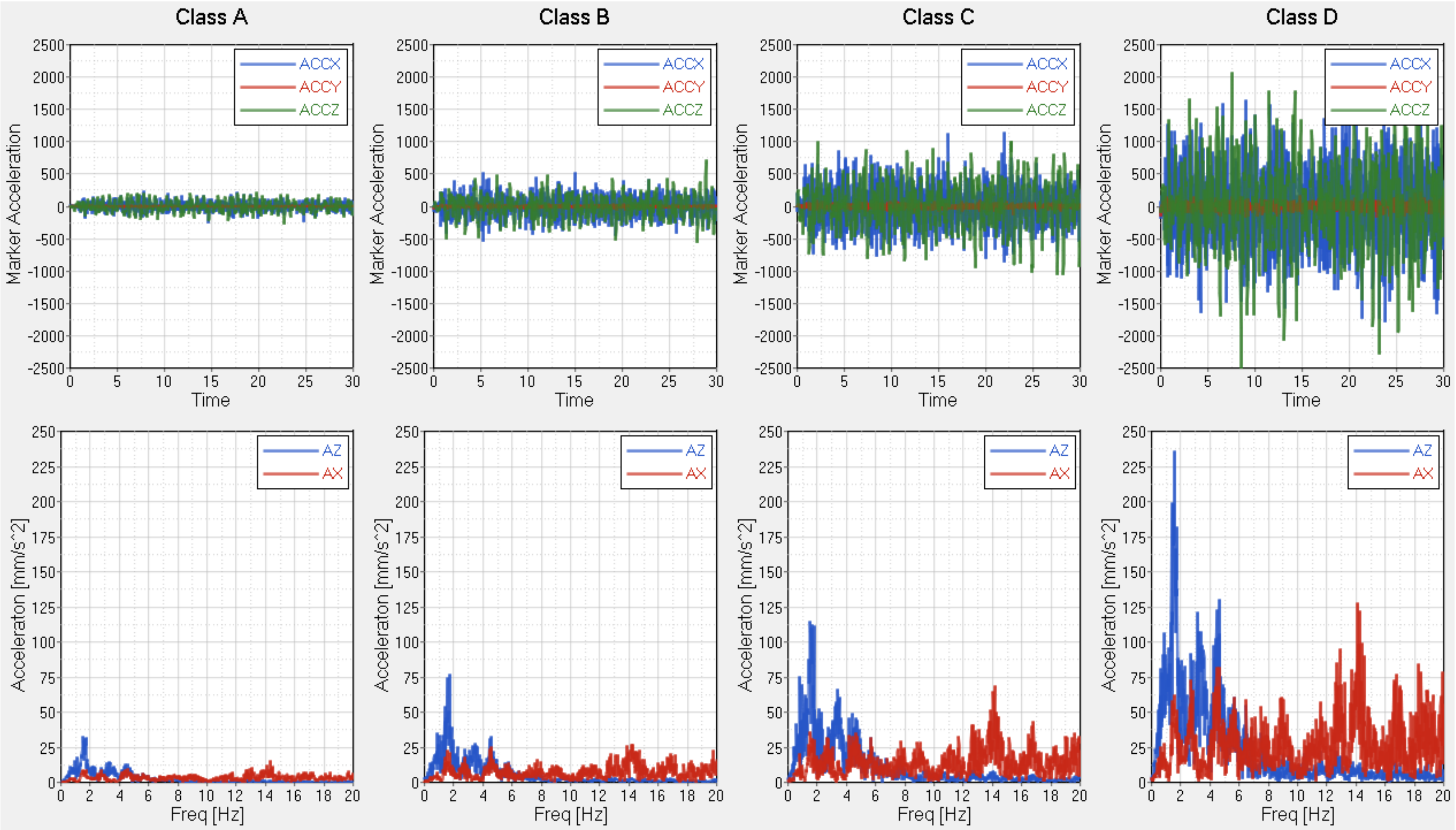


7. Full Vehicle Model

4) ISO Road Results

① ISO Class A~D

– As the road grade goes from A to D, the driver's seat acceleration value increases

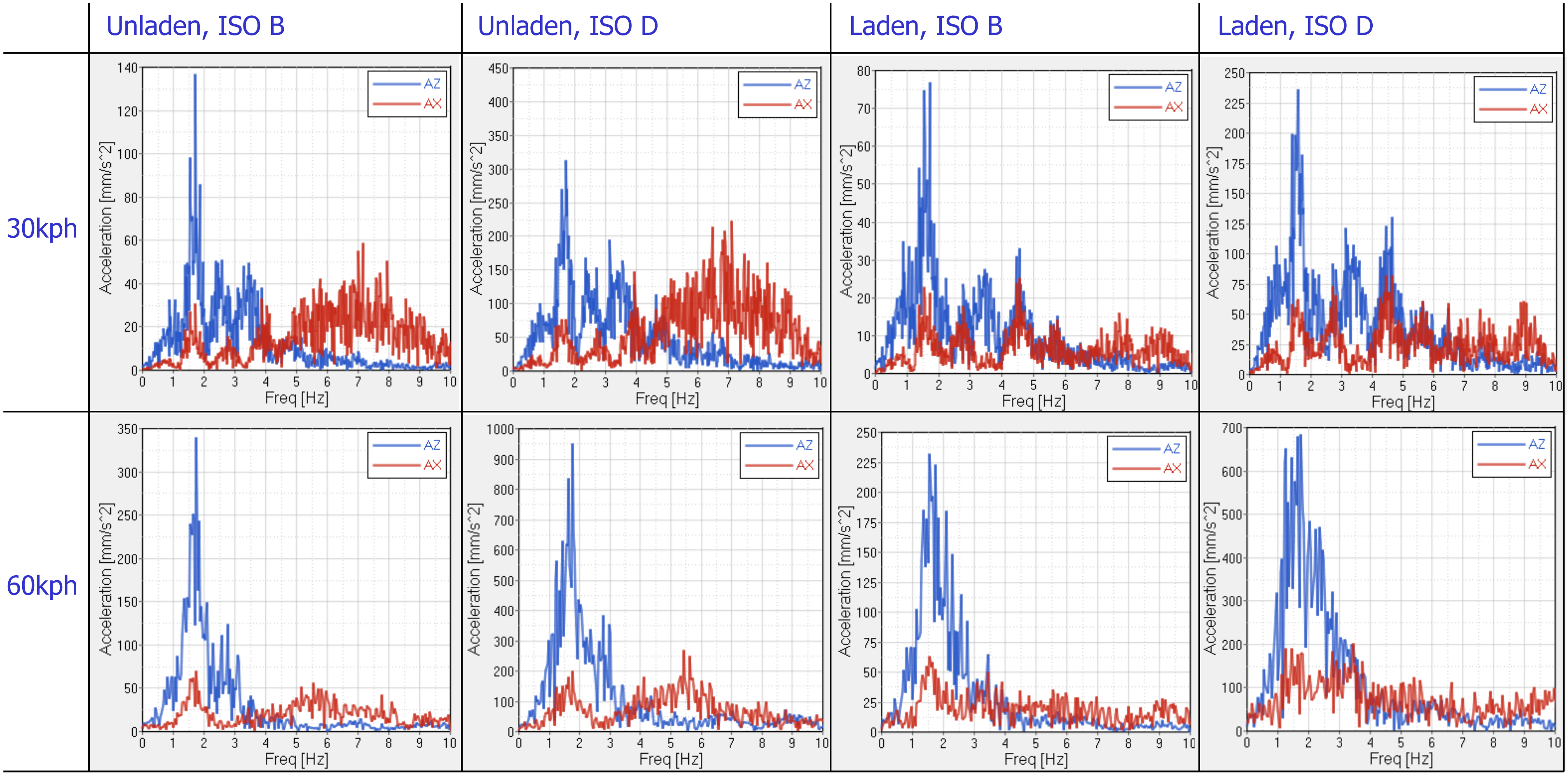


[CAB acceleration for road classes, FFT results]

7. Full Vehicle Model

4) ISO Road Results

② CAB acceleration FFT results(empty and loaded condition) for ISO Road B, D class

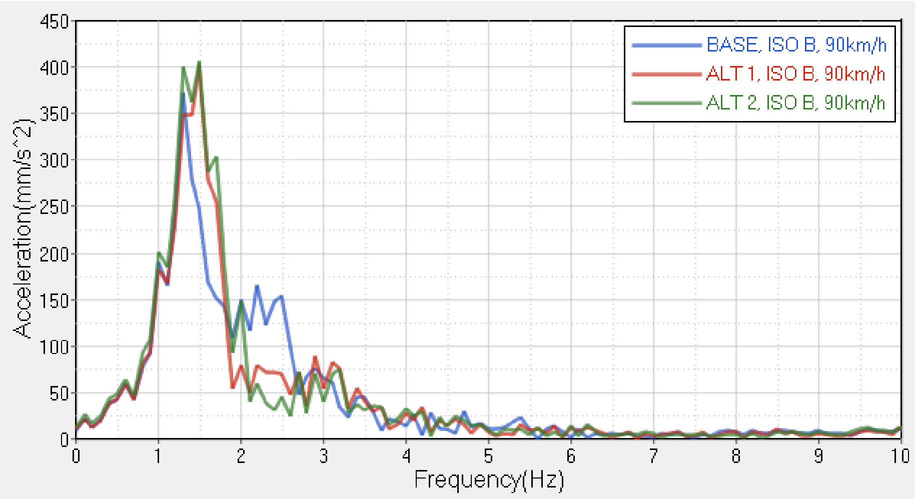


8. Ride Comfort for Full Vehicle

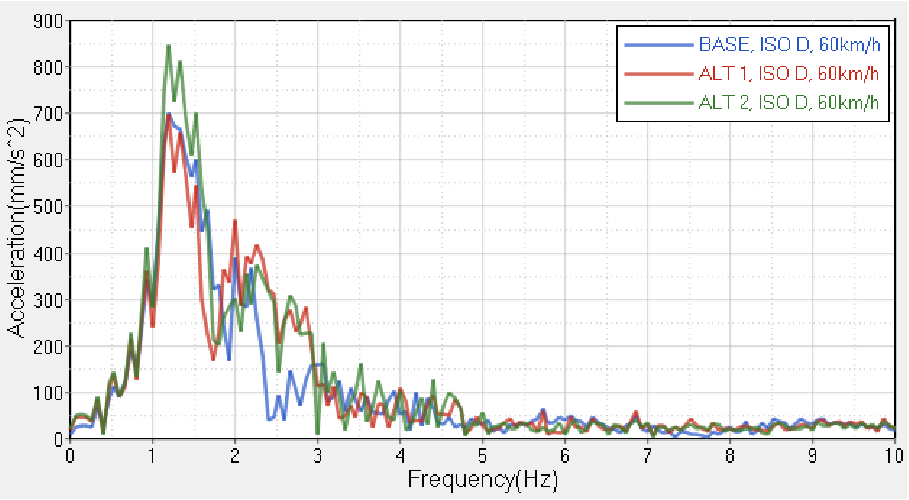
1) Design Change

① CAB Floor Acceleration(Az)

- In the design change (ALT 1, 2) review, the difference in the acceleration results are differ for each frequency.
- It is difficult to evaluate the ride comfort only by the FFT result



[CAB Floor Acceleration(Az) – ISO B, 90km/h]



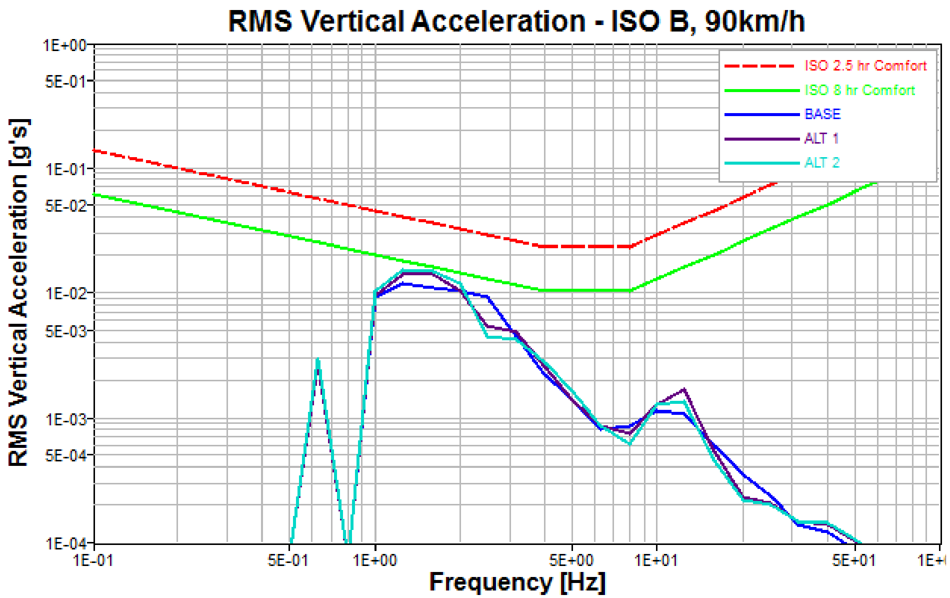
[CAB Floor Acceleration(Az) – ISO D, 60km/h]

8. Ride Comfort for Full Vehicle

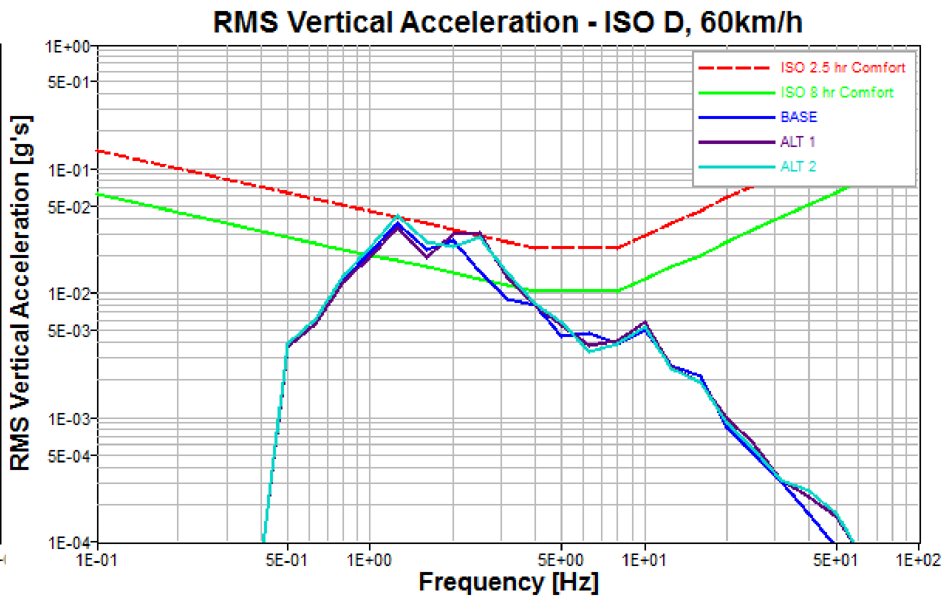
1) Design Change

② Ride comfort evaluation (ISO 2631 Standard)

- The acceleration RMS(root mean square) value is weighted by frequency and the result is evaluated. (Comfort time by the frequency differs depending on human body)
- ISO B road, 90km/h : 8hr Comfort line is satisfied.
- ISO D road, 60km/h : For 1Hz~3Hz frequency range, 2hr Comfort line is almost satisfied.



[ISO 2631 Vibration Standard– ISO B, 90km/h]



[ISO 2631 Vibration Standard– ISO D, 60km/h]

Truck Ride Comfort Analysis

8. Ride Comfort for Full Vehicle

- Golden Car : U.S.A road roughness measuring standard
  Reference Quarter Car Model at International Roughness Index(IRI)

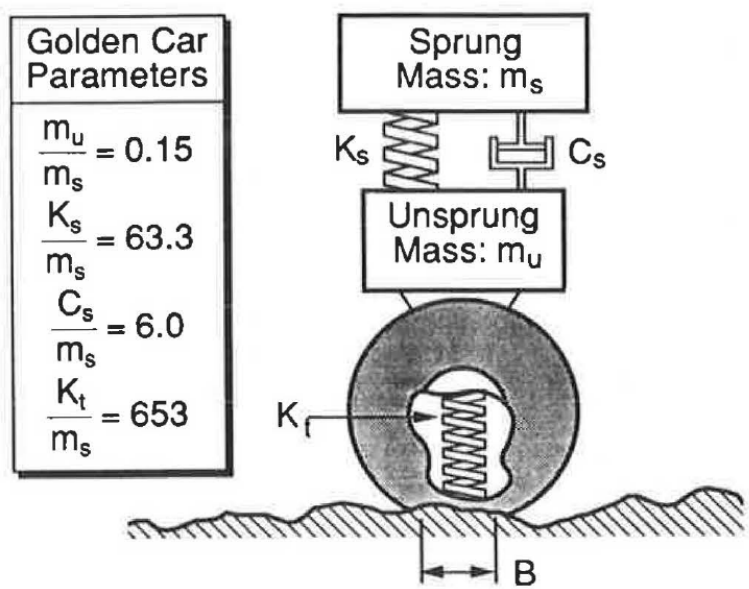
2) Evaluation stadard

① ISO 2631

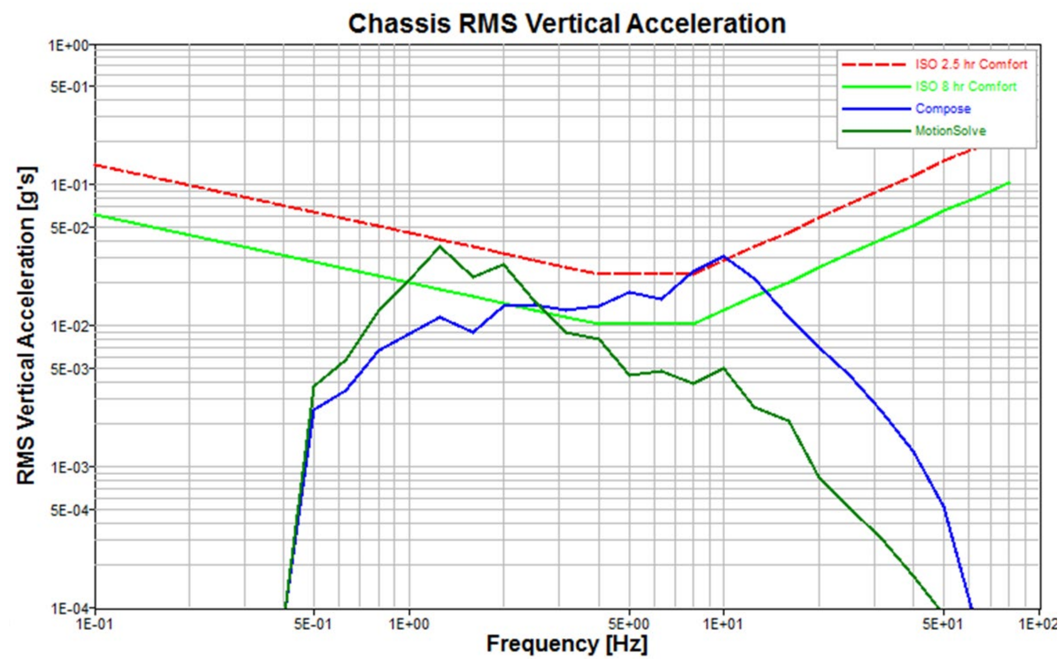
- It is necessary to establish criteria for evaluating the ride quality of each vehicle grade(Cargo, dump, tractor, etc.) for ISO road rating, vehicle speed, Comfort diagram (8hr, 2.5hr, 1hr ...) (ex : Golden Car*)

② Suspension Performance

- Vibration Isolation(Transmissibility Ratio), Suspension Travel(Rattle Space), Road Holding



[Golden Car Parameters]



[ISO 2631 Standard – Golden Car vs. Truck(ISO D, 60km/h)]

9. Conclusion

1) Ride comfort analysis modeling
   ① Modeling the road excitation and vehicle using Compose and MotionSolve
   ② ISO 8608 road implemented with Compose is used as input of MotionSolve and Compose vehicle model
   ③ Quarter Car, Half Car Model Correlation (Compose vs. MotionSolve)

2) Ride comfort evalulation
   ① ISO 2631 Vibration Standard Graph Modeling by Compose
   ② MotionSolve analysis result (Output acceleration) are imported into Compose model and evaluating ride comfort MotionSolve
   → Update required to draw ISO 2631 Graph (Compose) from HyperGraph

10. Next plan

1) Establishment criteria for ride comfort
   – Vehicle-specific criteria for ISO road classes and vehicle velocity
2) Vehicle Correlation
   – Road simulator test using test equipment and analysis correlation
3) Suspension Parameter Optimization
   – Vibration Isolation, Suspension Travel, Road Holding

◆ R/S Sine Sweep Test

[R/S TEST]