Topology Optimization of EV Underbody Considering Unpaved Road Vibration

2016.12.13

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Outline

- Motivation
- Setup Road Scenario
- Specification of EV Underbody Model
- Topology Optimization (Eigenvalue Maximization)
- Result & Conclusion

Motivation

1) Still lots of roads over the world are '**Unpaved**'
   - EV should be considered also on the unpaved condition

<The percentage of paved roads 2015>

http://www.dangerousroads.org/rankings23/4941-countries-with-lowest-of-paved-roads.html

2) Resonant frequency in EV will get lower than conventional vehicle
   - Influence of EV Battery, weight is '**Increased**'

CO2 배출량 (g/km)	배기량 (cc)	공차중량 (kg)
114	1,598	1,195

SM3 1.6 GTe

회 충전주행거리 (km)	배너리 정격전압 (전류용량)(V)	공차중량 (kg)
135	360V(74Ah)	1,580

SM3 Z.E

$$\text{Bending Resonant } w_n = \frac{22.4}{\sqrt{48}}\left(\frac{l}{L}\right)^{1.5}\sqrt{\frac{K}{M}}$$

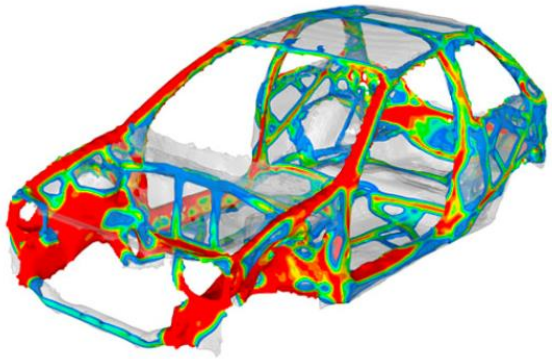
Increased M
->Resonant Freq. Decrease

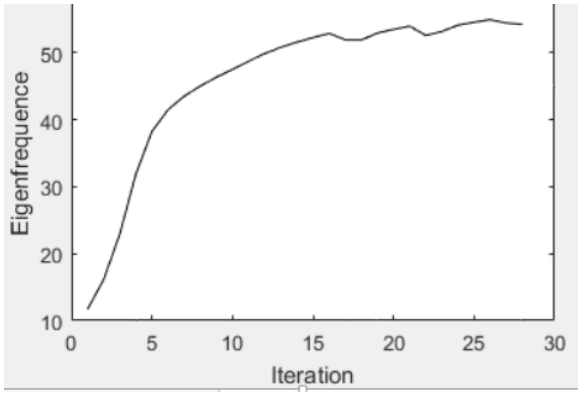
Renault Samsung Motors Official Site

EV vehicles are more exposed by Resonance condition !

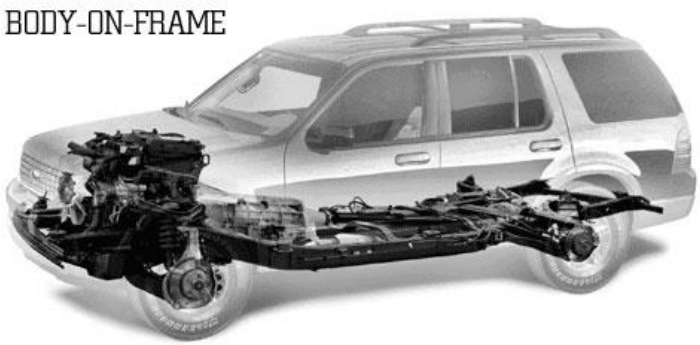
Motivation

3) Perform ‘Maximum Eigenvalue Topology Optimization’ (EV Underbody)
   - By the same mass -> **get the most optimized design**





4) Optimization Target Vehicle -> ‘Body-on-Frame EV’
   - Optimizing Area **: EV Underbody**



Setup Road Scenario

Setup Road Scenario

Extracting Road Profile

1) Extract Unpaved Road Surface '**Profile**'
   - Make a different scenario based on road condition

Vägverket

Publication 2000:31E

Whole-body vibration when riding on rough roads

4.4 Analysis of road roughness

The deviation of the road surface from a horizontal plane can be described by the wavelengths and amplitudes of the roughness, see Figure 10. The very shortest roughness wavelengths are classed as *microtexture*, which is determined by the properties of the aggregate and binder in the surface. Somewhat longer wavelengths are classed as *macrotexture*, which is determined by such things as the shape of the aggregate and the particle size distribution. Longwave deviations are quite simply designated as *roughness* [2], often caused by more or less extensive settlement, frost heave or ice lenses in or under the road structure in the winter.

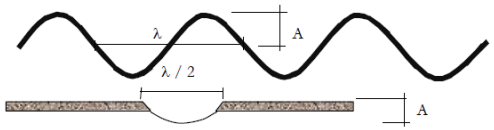


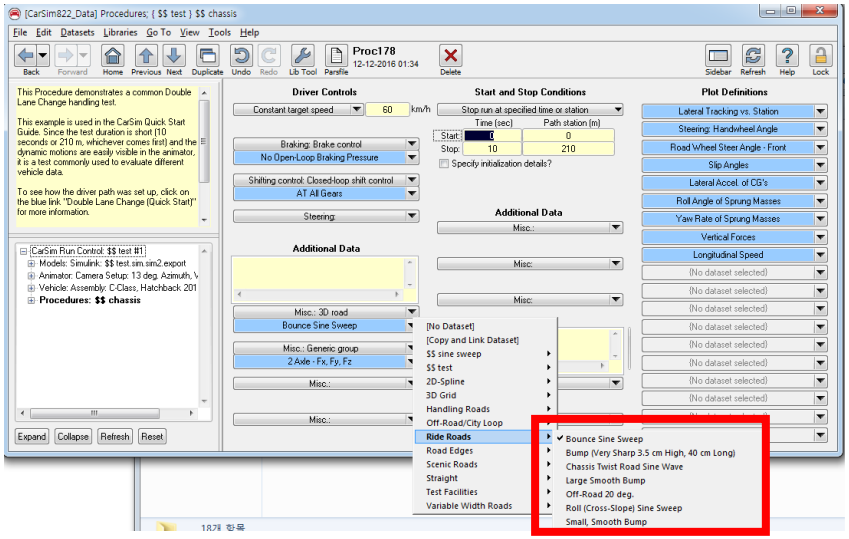
Figure 10 Wavelength (λ) and amplitude (A). Above at corrugation, below at a pothole.

➡ **But**, the math formulations are too simple to setup various scenario & Explanation about considering friction is ambiguous

Substituent Method ➡ CarSim® Mechanical Simulation

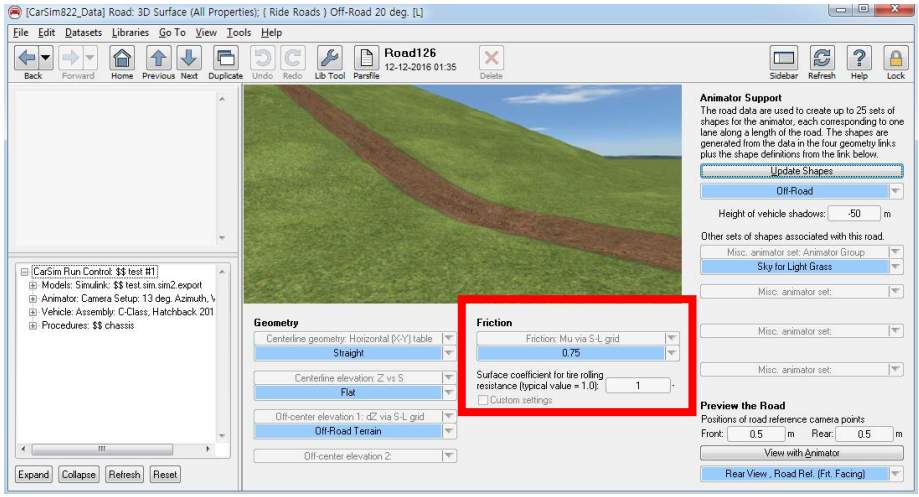
Setup Road Scenario

Extracting Road Profile

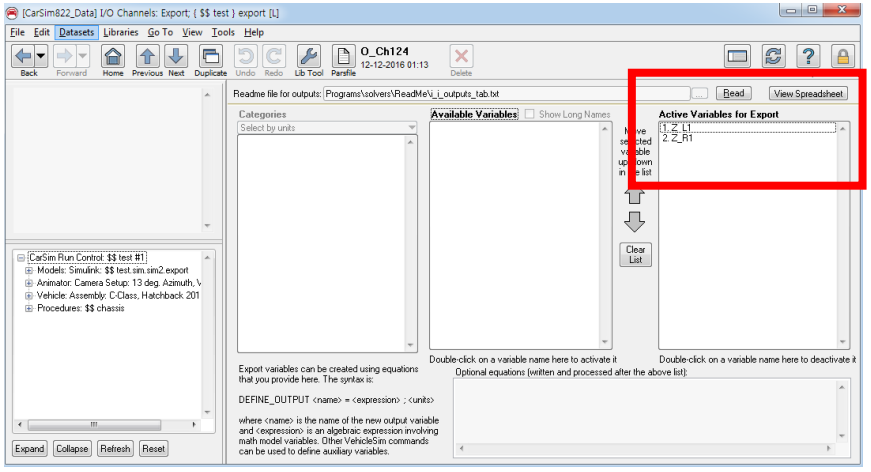


<1> Choose the road type

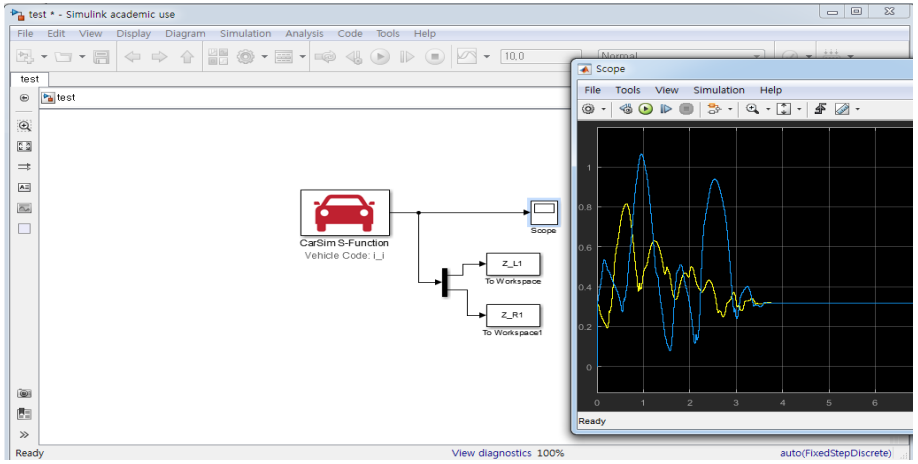
2) Extracting Procedure



<2> Specify road characteristic in detail (Friction etc.)



<3> Export Output variables (Wheel displacement)



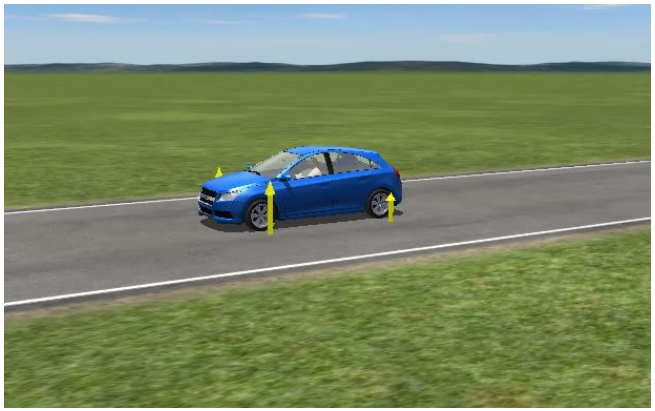
<4> Send to Simulink , Save data

Setup Road Scenario

Extracting Road Profile

<1> Bounce Sine Sweep

<2> Chassis Twist Road



3) Road Scenario

<3> Off road terrain

- Z_L1_offroad_0.2.xlsx
- Z_L1_offroad_0.7.xlsx
- Z_L1_sinesweep_0.2.xlsx
- Z_L1_sinesweep_0.7.xlsx
- Z_L1_twist_0.2.xlsx
- Z_L1_twist_0.7.xlsx
- Z_long_0.7.xlsx
- Z_R1_offroad_0.2.xlsx
- Z_R1_offroad_0.7.xlsx
- Z_R1_sinesweep_0.2.xlsx
- Z_R1_sinesweep_0.7.xlsx
- Z_R1_twist_0.2.xlsx
- Z_R1_twist_0.7.xlsx

Setup Road Scenario

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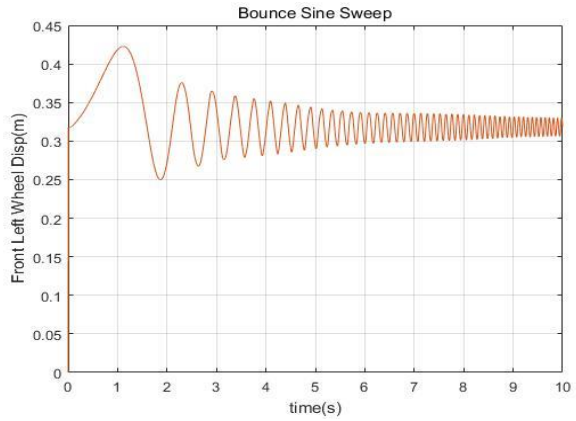
4) Road Analysis

Extracting Road Profile

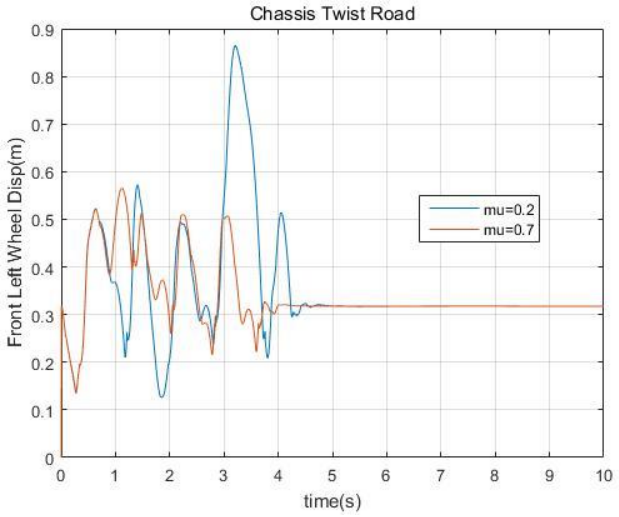
Displacement difference by Friction? Set Mu = 0.7, Mu = 0.2

<1> Bounce Sine Sweep

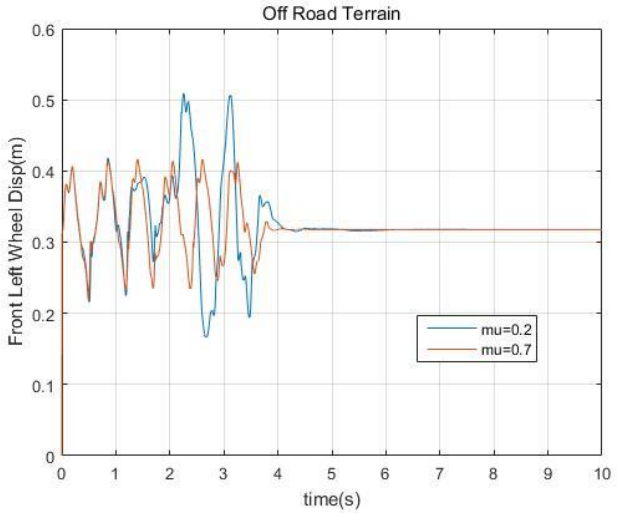


Friction value is working as variable at Scenario <2>, <3>

<2> Chassis Twist Road



<3> Off road terrain



IVERSITY

Setup Road Scenario

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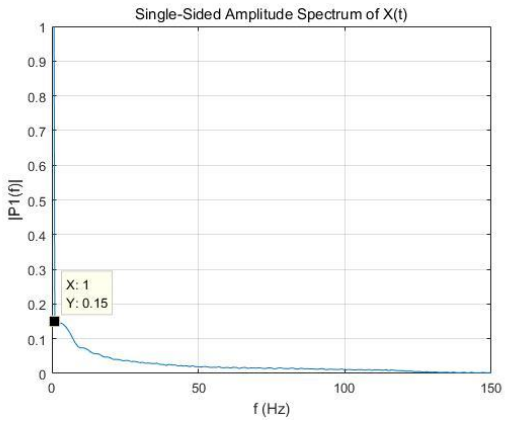
Extracting Road Profile

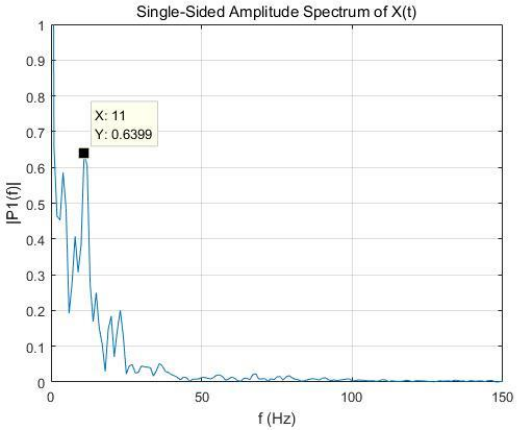
4) Road Analysis

Perform Road's Fast-Fourier Transform (FFT) Analysis
- To compare road's frequency with that of EV Model.

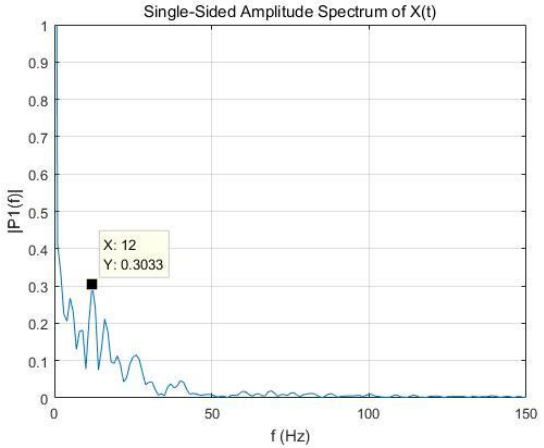
<1> Bounce Sine Sweep



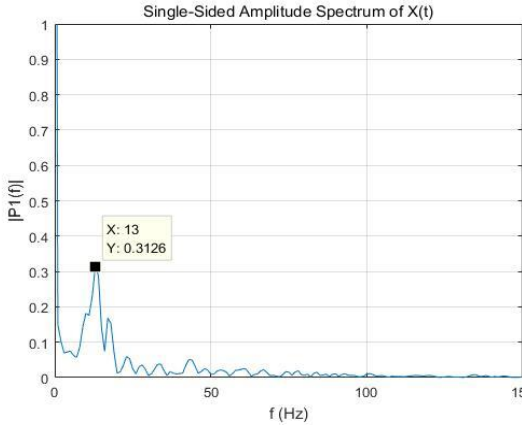
<2>Chassis Twist mu = 0.2



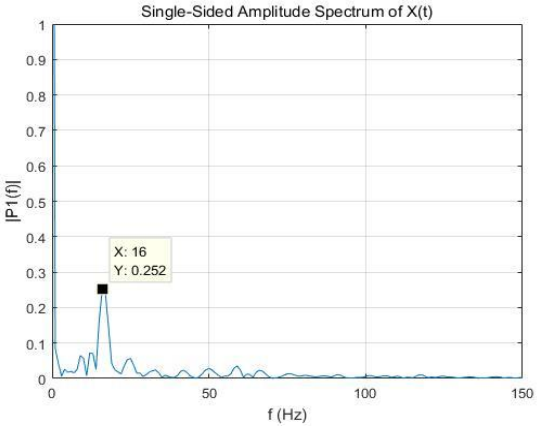
<3> Chassis Twist mu = 0.7



<4> Off-road mu = 0.2



<5> Off-road mu = 0.7



Unpaved Road prevail frequency
-> **11Hz ~ 16Hz !!**

Specification of EV Underbody Model

Specification of EV Underbody Model

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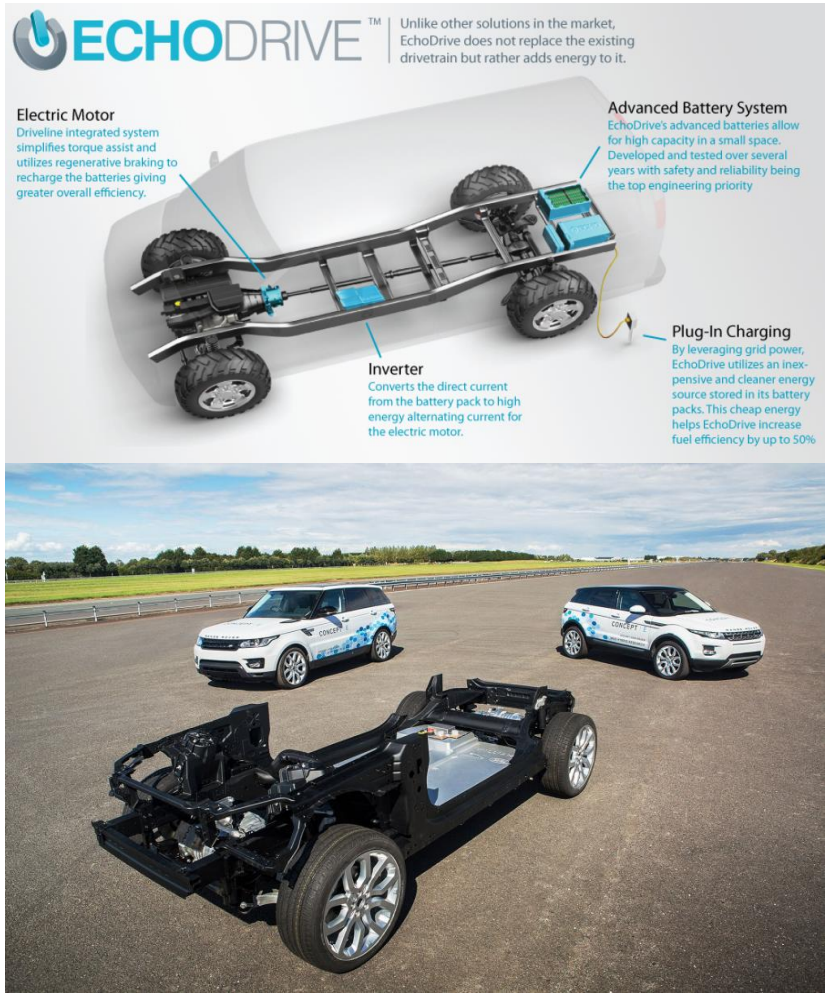
Benchmarked Underbody Model
-> Mercedes – Benz G Class

Dimensions

More Exterior Dimensions

Overall height	76.9 in
Overall length	187.6 in (including spare tire, excluding brush guard)
Overall width	80.9 in(with mirrors)
Coefficient of drag	TBD
Wheelbase	112.2 in
Curb weight	5,724 lbs



Specification of EV Underbody Model

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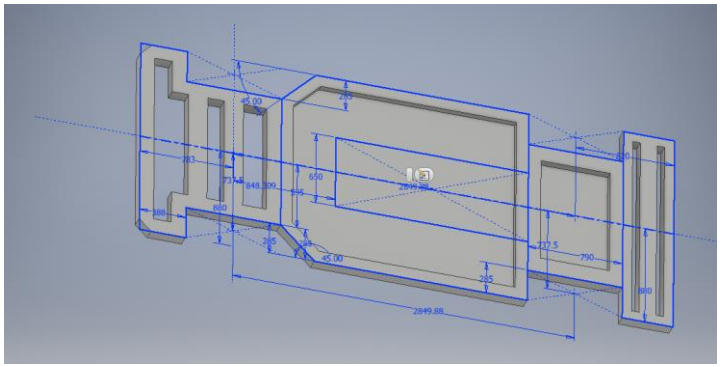
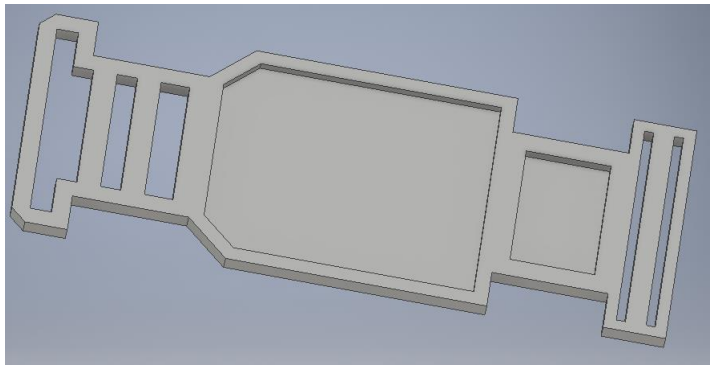
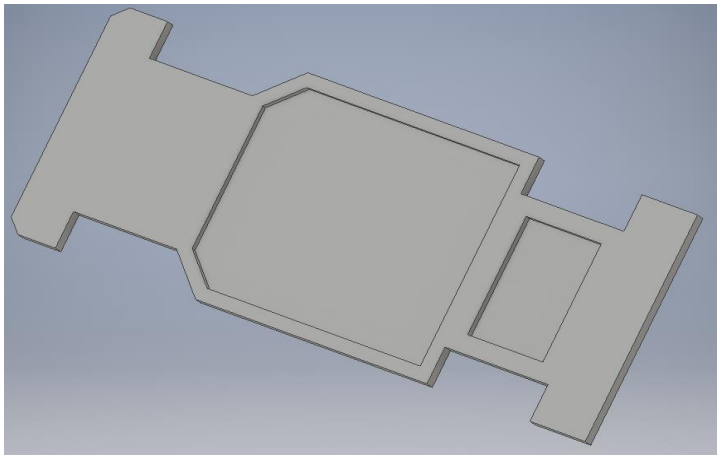
Modeling Tool -> Autodesk Inventor 2016



Real Model
(For Modal Analysis)



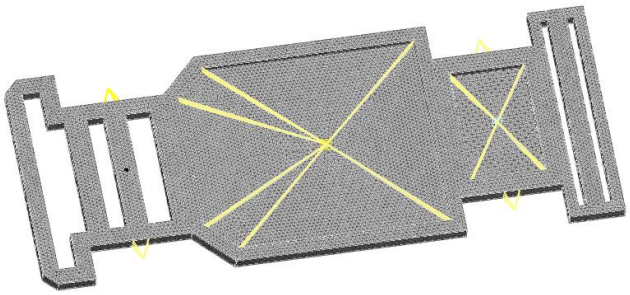
Design Domain Model
(For Topology Optimization)

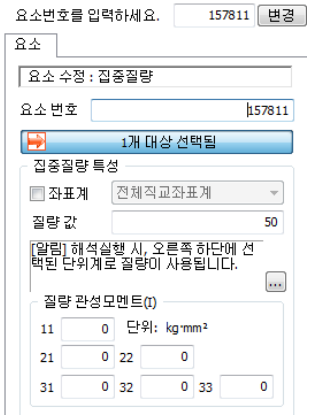


midas NFX

Specification of EV Underbody Model

Modal Analysis (Real Model)



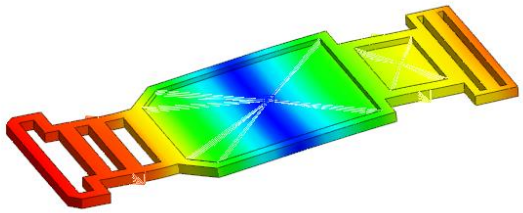


Recall that Unpaved Road prevail frequency is 11Hz ~ 16Hz !!

-> Resonance could happen easily

Modal Analysis

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES
1	0.000000e+000	0.000000e+000	0.000000e+000
2	4.788317e-007	6.919767e-00	[illegible]
3	9.674034e+003	9.835667e+00	1.565395e+001
4	1.497929e+005	3.870309e+00	6.159788e+001
5	2.342013e+005	4.839435e+002	7.702199e+001
6	4.526793e+005	6.728145e+002	1.070818e+002
7	5.290715e+005	7.273730e+002	1.157650e+002
8	7.253579e+005	8.516795e+002	1.355490e+002
9	7.600859e+005	8.718291e+002	1.387559e+002
10	1.002024e+006	1.001012e+003	1.593160e+002

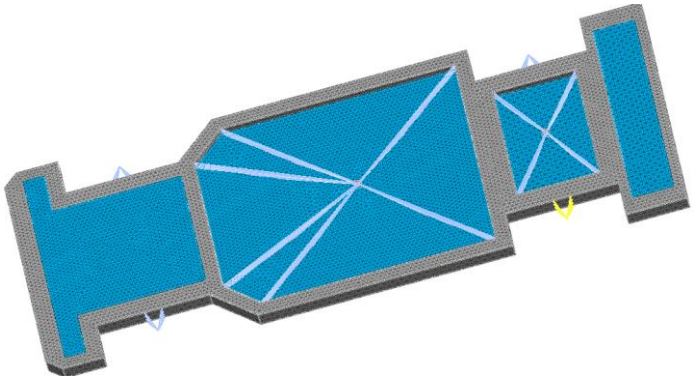


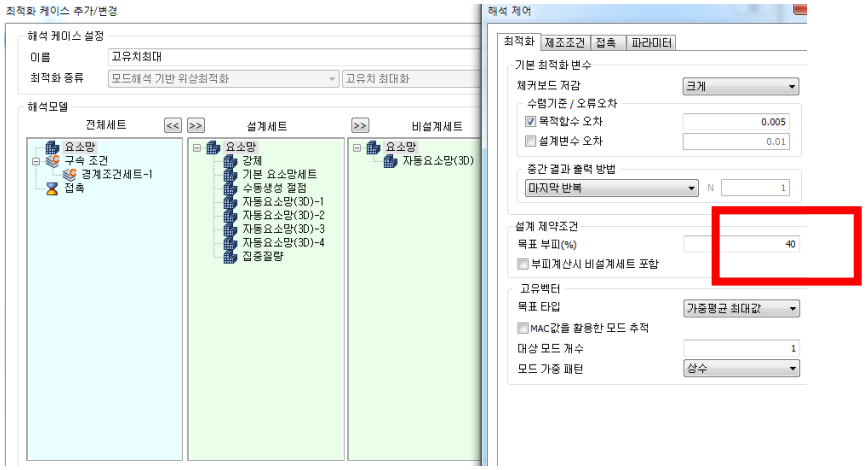
Topology Optimization Process

Topology Optimization (Eigenvalue Maximization)

Topology Optimization (Eigenvalue Maximization)

Recall $\frac{\sqrt{\lambda}}{2\pi} = f(Hz)$ (eigenvalue property)

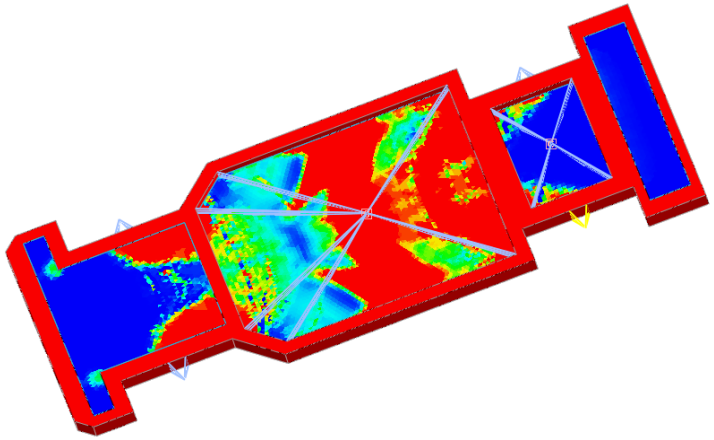


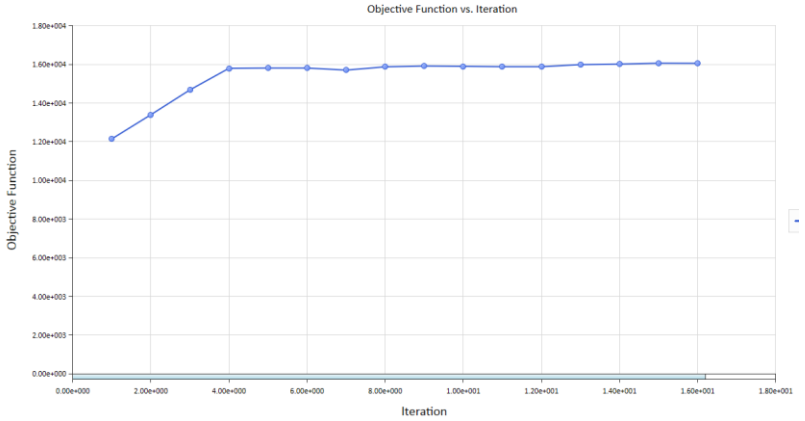


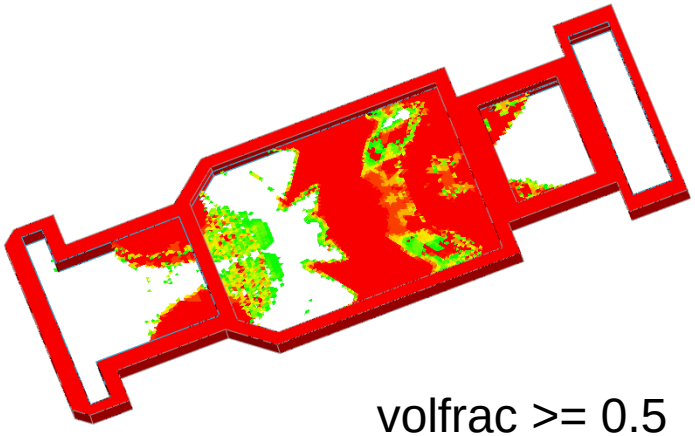
Gray : Non - Design Domain
Blue : Design Domain

Eigenvalue Maximization

Topology Optimization (Eigenvalue Maximization)







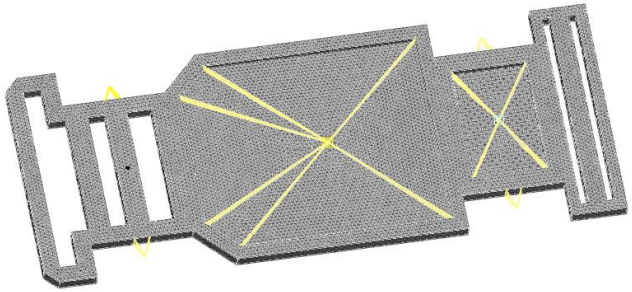
volfrac >= 0.5

Maximization Completed !!

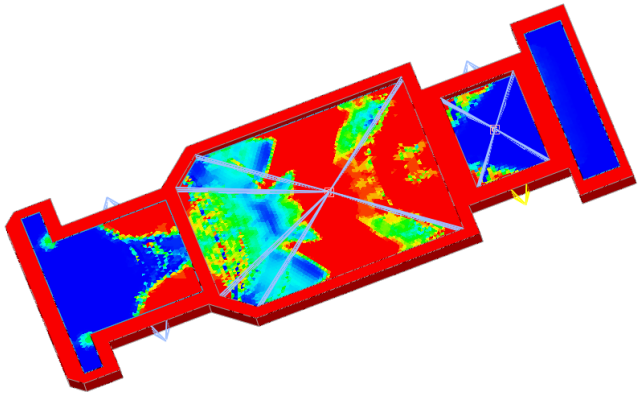
Conclusion

Result & Conclusion

Recall $\frac{\sqrt{\lambda}}{2\pi} = f(Hz)$ (eigenvalue property)



Natural Frequency
15.65 Hz (Real Model)



Natural Frequency
20.13 Hz (Optimized Model)
-Eigenvalue : 1.6e4 !

20.13Hz is bigger than 11Hz~16Hz (Unpaved Road Freq)
- Adequate design for avoiding resonance !!

Result & Conclusion

Limitation

- Model is not sophisticated (We need to input more condition)
- Investigated in only 3 road Scenario
- In reality, Vehicle Natural frequency should be analyzed in comprehensive point.
- Battery Weight and EV body-on-frame dimension could be quite different

Thank you for your attention

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