Powering Innovation That Drives Human Advancement

LS-DYNA中纯电动汽车电池刮底仿真

Simulation of BEV battery bottom-scraping in LS-DYNA

王应奇 2025.05.20

Content

- Background---The different requirements for vehicle equilibrium between high velocity crash and bottom scraping
- The Methods of achieving vehicles equilibrium
  1. Dynamic relaxation
  2. Switching deformable to rigid
  3. Replacing nodes after simulating vehicle equilibrium once
- Summary

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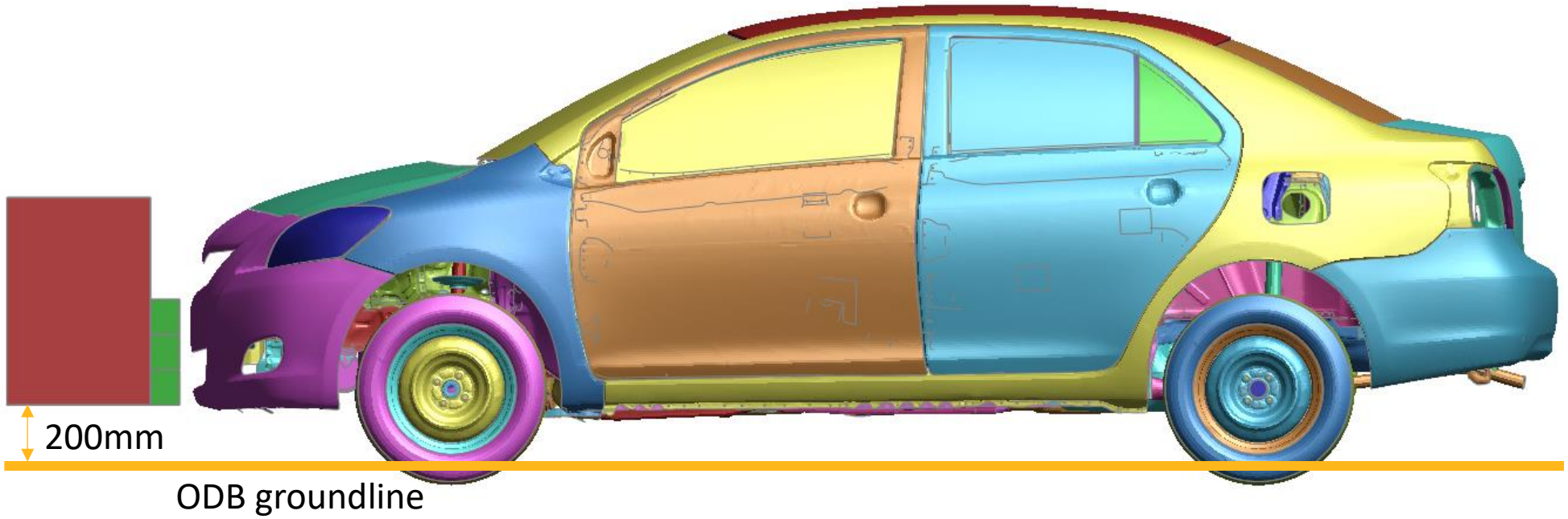
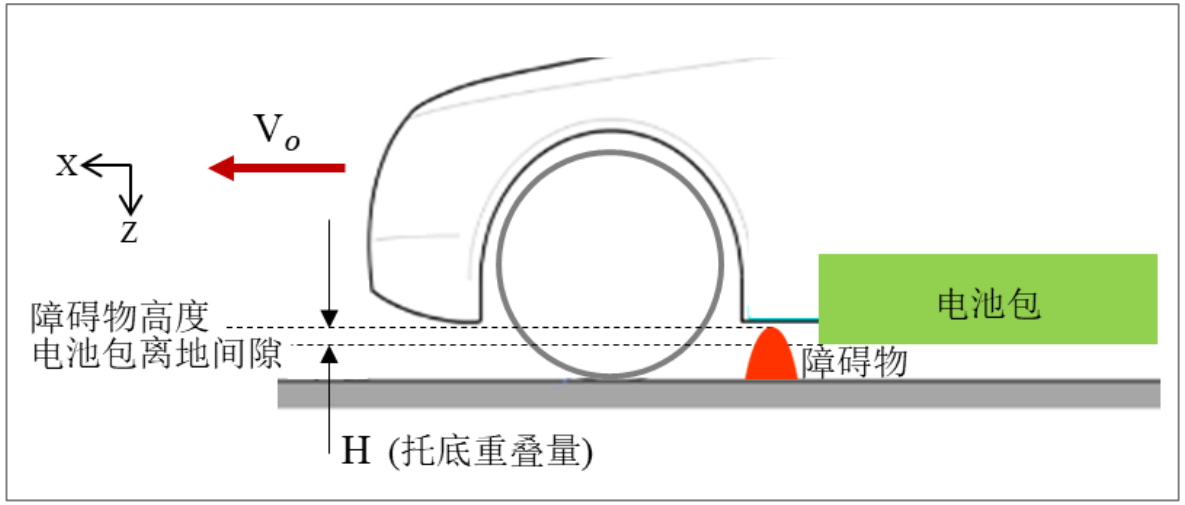
Background---High velocity crash simulation ignore equilibrium

- Currently, in the high velocity crash simulation model, the state of the suspension is not compressed. When positioning the height of the barrier, it needs to be based on the groundline.
- For FFB, ODB, MPDB and other cases, there is no load in Z-direction, and the crash time is approximately 100ms. From an engineering perspective, the above simplification of uncompressing is acceptable.

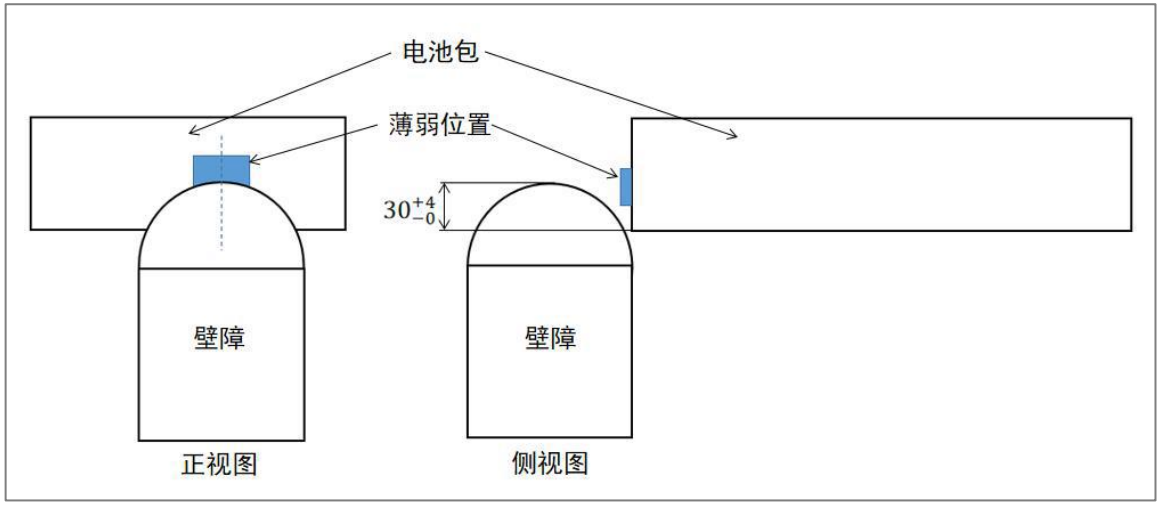


Background---Bottom scraping simulation requires equilibrium

- During the bottom scraping case, the vehicle is subjected to a load of Z-direction force. That the velocity decreases means that the time of the case increases. The simplification of the suspension for high velocity crash is no longer applicable.
- For the simulation of the bottom scraping, the vehicle needs to be in equilibrium, and the suspension model should contain information such as compression deflection and force.



Bottom scraping



Schematic diagram of spherical barrier positioning

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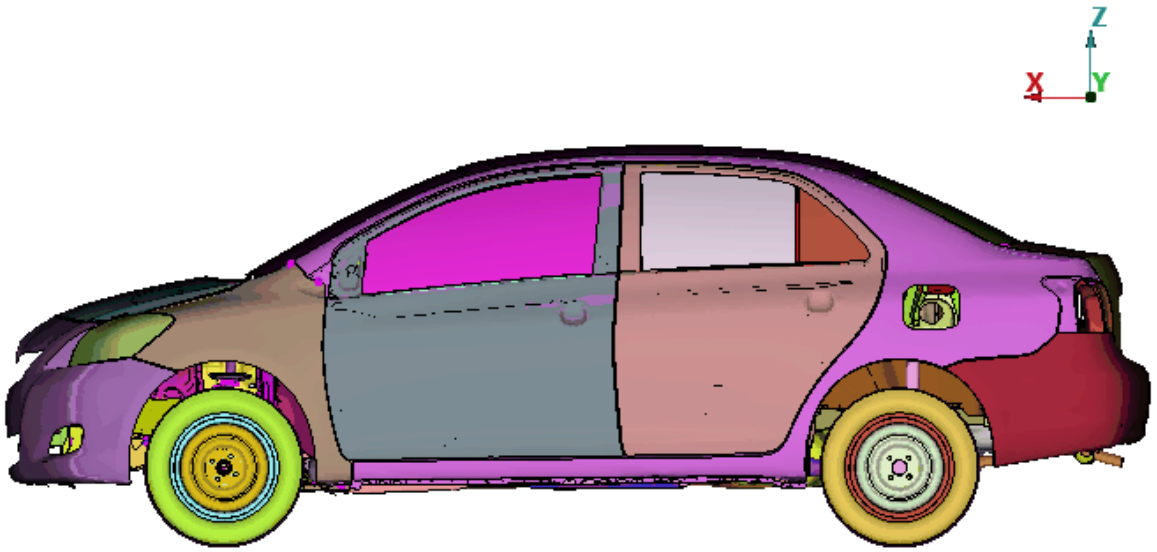
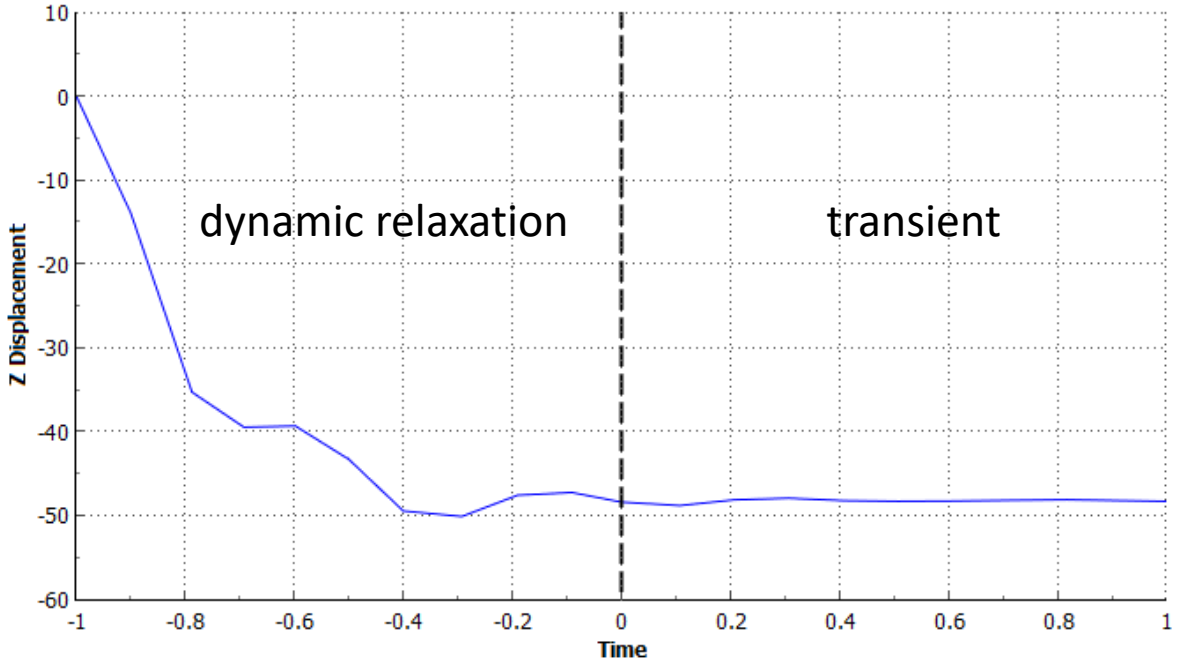
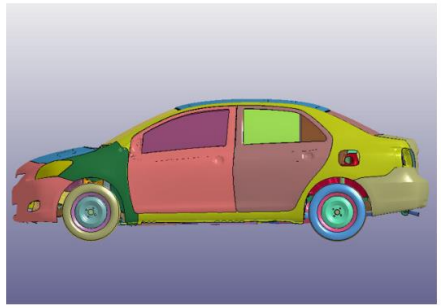
The Methods of achieving vehicles equilibrium---Dynamic relaxation method

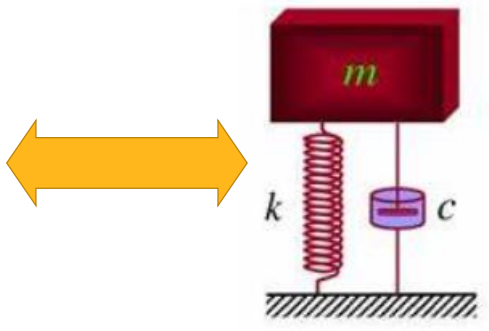
- Before conducting transient analysis, add dynamic relaxation to let the vehicle reach the equilibrium position first.
- The dynamic relaxation phase requires 0.5 to 1.0 second and needs much computing resources. The detailed reasons are on the following page.





The Methods of achieving vehicles equilibrium---Dynamic relaxation method





- Simplify the vehicle to a single-DOF vibration system: $m\ddot{d} + c\dot{d} + kd = mg$
- Then, The vibration period: $T = 2\pi\sqrt{m/k}$, $C_{cr} = 2\sqrt{mk}$
- When the actual damping coefficient c takes different values: $c = 0$ Undamped free vibration. $c > C_{cr}$ Overdamping, no vibration, equilibrium after multiple cycles. $c < C_{cr}$ Underdamped, vibration and attenuation occur simultaneously, equilibrium after multiple cycles. $c = C_{cr}$ Critical damping, the system will return to equilibrium after approximately one vibration period.
- Even if it is set to critical damping, it still takes at least one vibration period to reach equilibrium.

-----From LS-DYNA Theory Manual

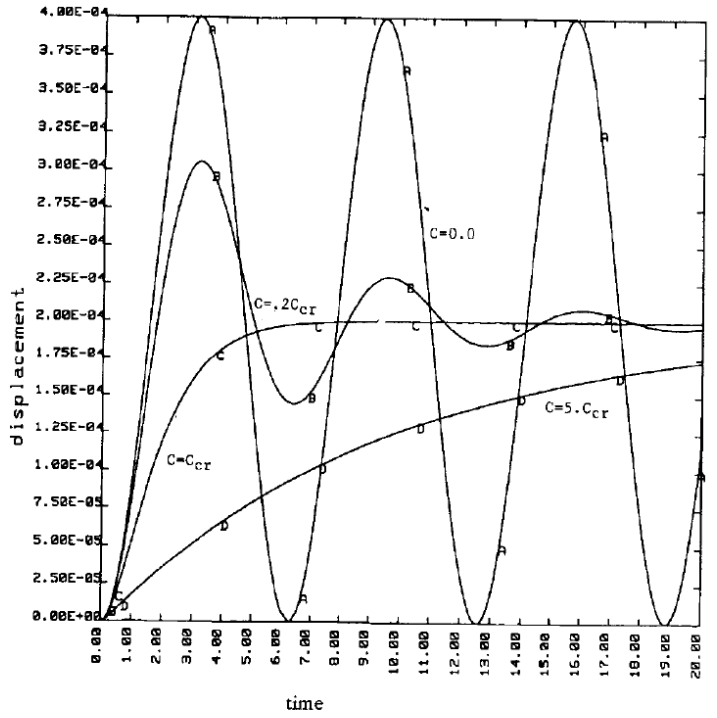
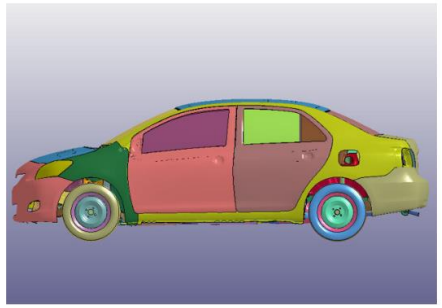
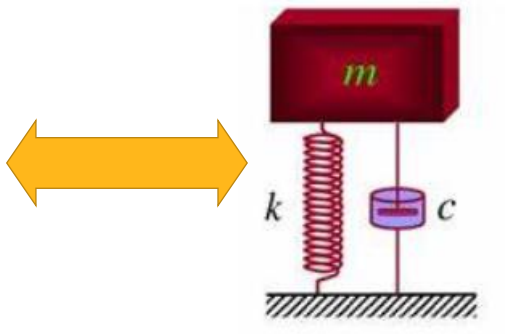


Figure 34.1. Displacement versus time curves with a variety of damping coefficients applied to a one degree-of-freedom oscillator.

The Methods of achieving vehicles equilibrium---Dynamic relaxation method





- Take the 2010 Toyota Yaris as an example. According to the model from NHTSA:
- The total stiffness of the suspension k ≈ 72 N/mm,
- The total mass is 1078 kg. Assuming the sprung mass m ≈ 1000 kg,
- Then the frequency f = 1.35 Hz, the vibration period T = 0.74 s.
- At least 0.74 s is needed to reach equilibrium.

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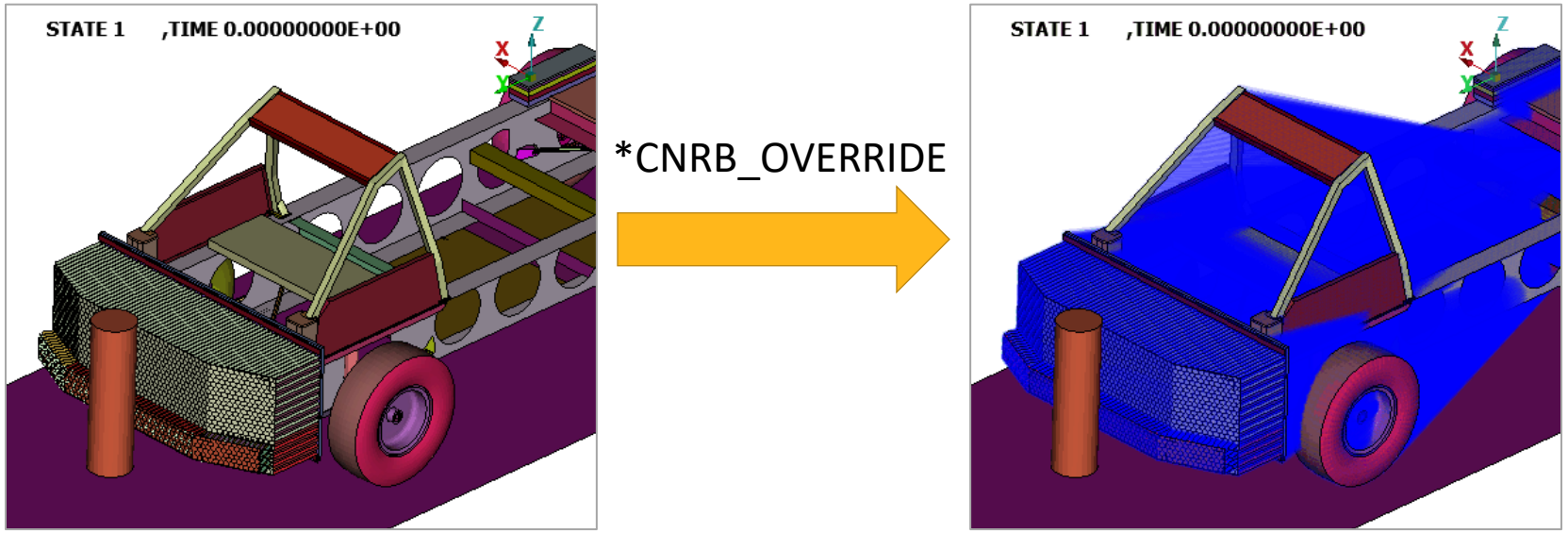
The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- In LS-DYNA, two keywords are provided for the switching between deformable and rigid,

1. *CONSTRAINED_NODAL_RIGID_BODY_OVERRIDE. Based on the input to generate a *CONSTRAINED_NODAL_RIGID_BODY to achieve the rigidity effect. However, Element Processing cannot be skipped. The saved computing resources are limited, and it is not suitable for use at this case.



2. *DEFORMABLE_TO_RIGID_AUTOMATIC. It will Skip Element Processing to save computing resources. Please pay attention to the instruction on the following page when using this keyword.

The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- When using *DEFORMABLE_TO_RIGID_AUTOMATIC, the following situations need to be pay attention. Improper usage may lead to errors.
  - 1. The deformable body has connection with *CONSTRAINED_NODAL_RIGID_BODY.
  - 2. When the nodes of the deformable body are called by *CONSTRAINED_EXTRA_NODES.
  - 3. The deformable body is simultaneously connected to more than one rigid bodies.
  - 4. *CONSTRAINED_RIGID_BODYS
  - 5. *CONSTRAINED_JOINT_TYPE
- The switching between deformable and rigid is not easy to use for the whole vehicle model.

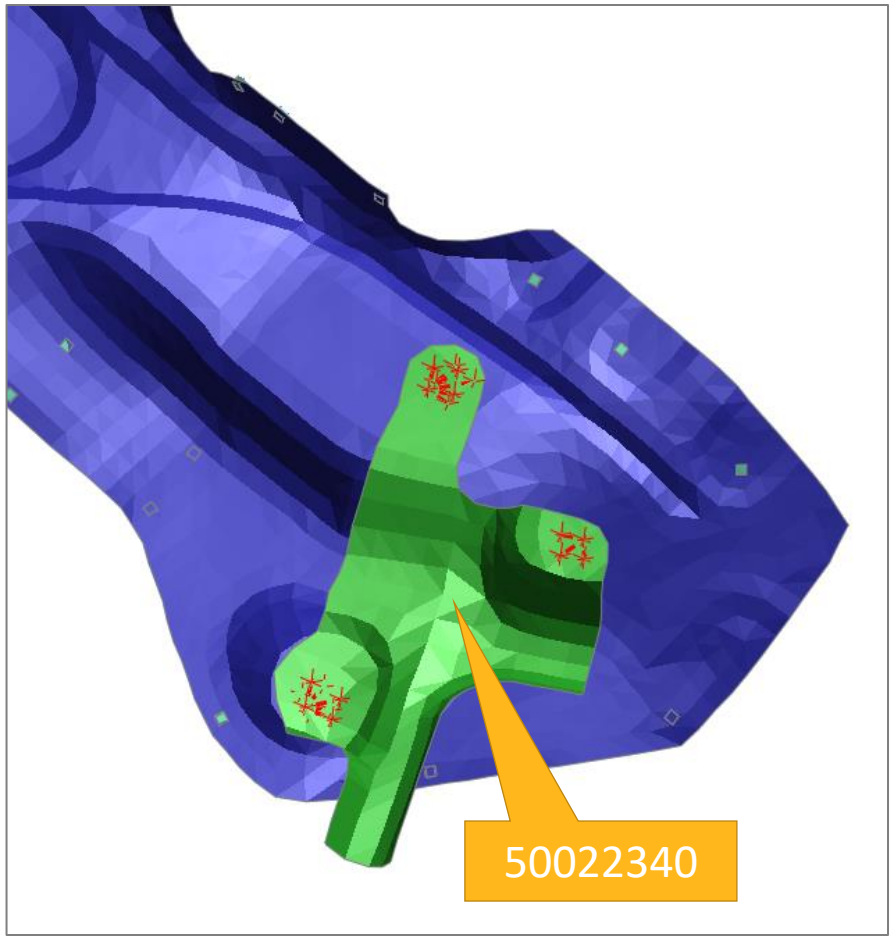
The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- When switching a deformable to rigid body and if the deformable body is connected to *CONSTRAINED_NODAL_RIGID_BODY,

```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
          1          0        0.0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf      dtmax       d2r        r2d     offset
          0          0         0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50022340          0       PART
$
```

- the *CONSTRAINED_NODAL_RIGID_BODY connected to it will be merged.

```
*** Automatic material switch at time      7.65000E-07
    Switch case 1

Nodal rigid body ID: 50010374 is merged with part ID: 50022340

Nodal rigid body ID: 50010372 is merged with part ID: 50022340

Nodal rigid body ID: 50010373 is merged with part ID: 50022340
```



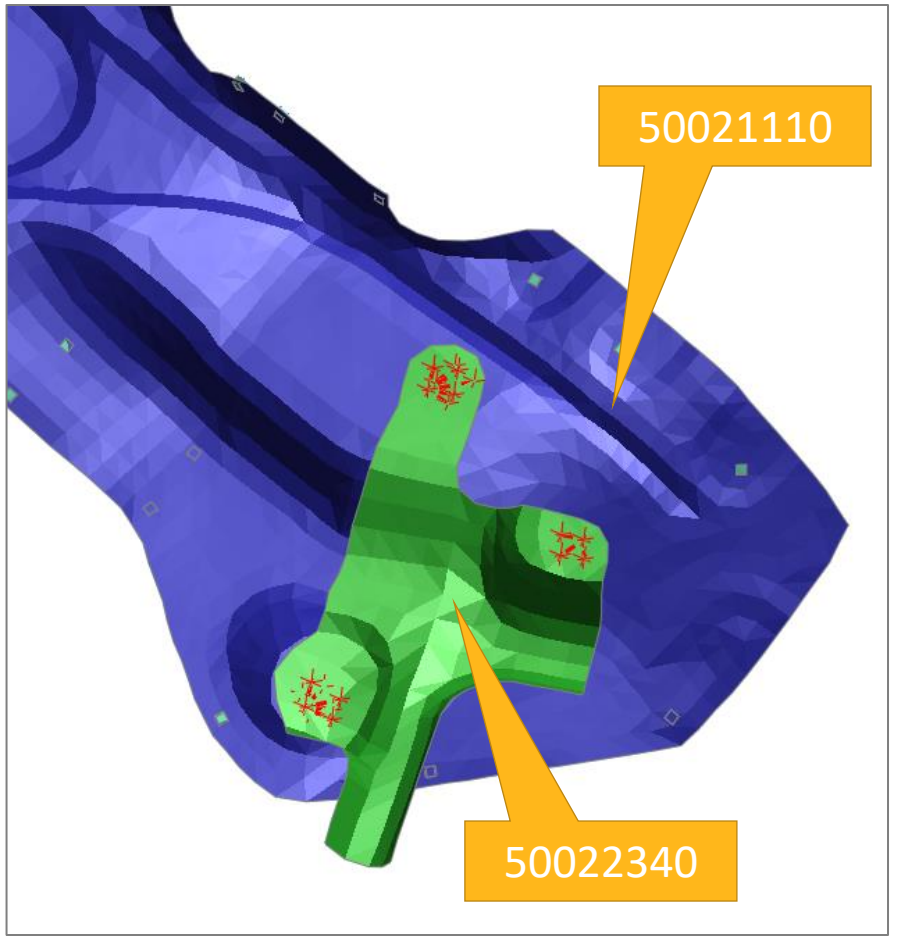
The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- When switching two deformable bodies to rigid bodies and if they shared some same *CONSTRAINED_NODAL_RIGID_BODY, this would lead an error.

```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
          1          0        0.0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf      dtmax       d2r        r2d     offset
          0          0          0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50022340          0       PART
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1                 time3      entno      relsw     paired
          2          0        0.0                 0.0          0          0          0
$:     nrbf       ncsf       rwf                  d2r        r2d     offset
          0          0          0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50021110          0       PART
```

- Solution: Assign a same lead rigid body.

```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
          1          0        0.0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf      dtmax       d2r        r2d     offset
          0          0          0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50022340   50000001       PART
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
          2          0        0.0                 0.0          0          0          0
$:     nrbf       ncsf       rwf                  d2r        r2d     offset
          0          0          0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50021110   50000001       PART
$
```



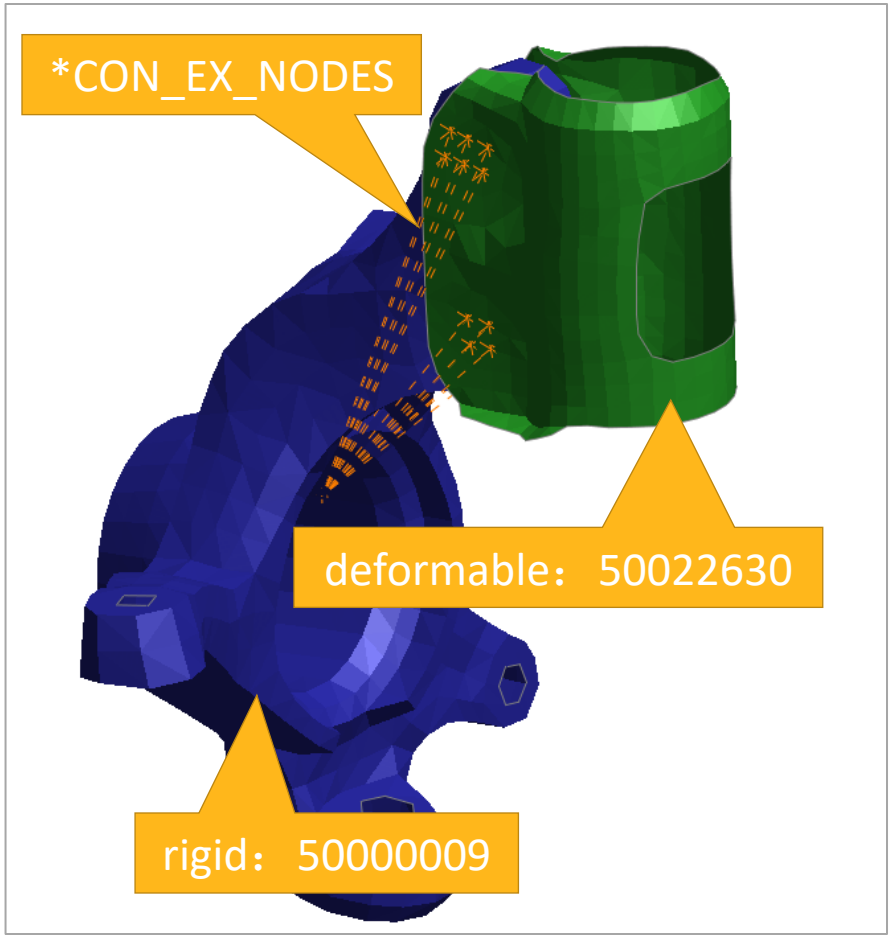
The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- When the nodes of the deformable body are called by *CONSTRAINED_EXTRA_NODES this would lead an error.

```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time3      entno      relsw     paired
         1          0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf       d2r        r2d     offset
         0          0          0         1          0        0.0
$:      pid        lrb      ptype
  50022630          0       PART
```

- Solution: Assign a same lead rigid body.

```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
         1          0        0.0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf      dtmax       d2r        r2d     offset
         0          0          0        0.0         1          0        0.0
$:      pid        lrb      ptype
  50022630   50000001       PART
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time3      entno      relsw     paired
         2          0        0.0        0.0          0          0          0
$:     nrbf       ncsf       rwf       d2r        r2d     offset
         0          0          0         1          0        0.0
$:      pid        lrb      ptype
  50000009   50000001       PART
```



The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- When a deformable is connected to multiple rigid bodies, the rigid bodies sharing the same node with the deformable will be automatically merged. There is just warning and no error.

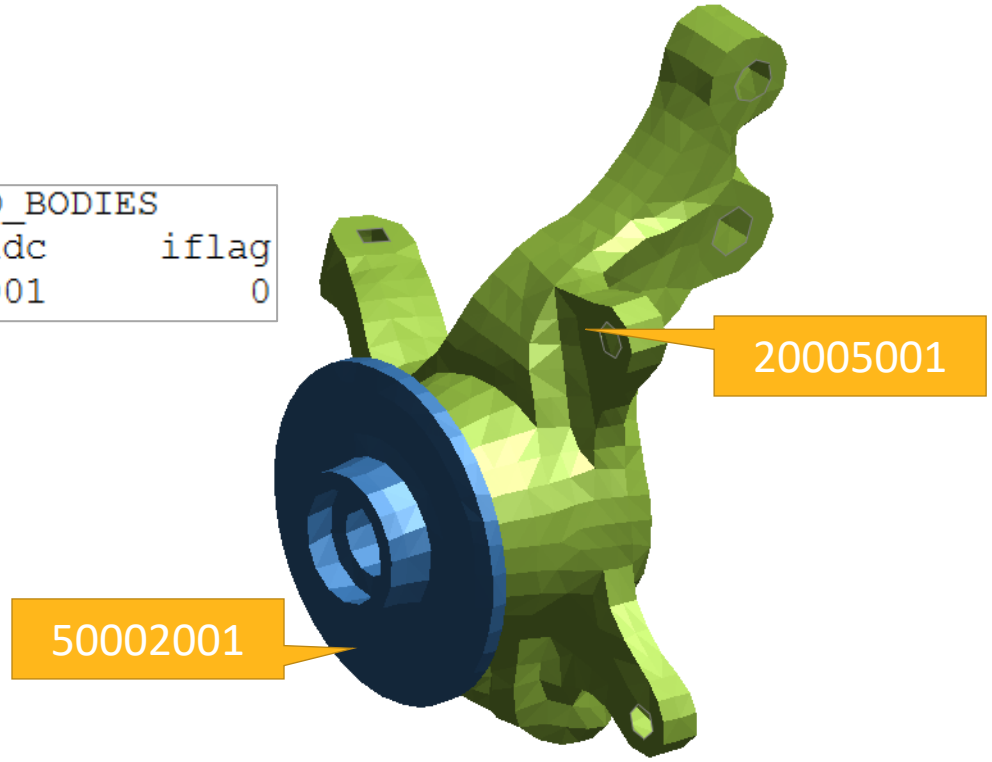
```
*DEFORMABLE_TO_RIGID_AUTOMATIC
$:    swset       code      time1      time2      time3      entno      relsw     paired
          1          0        0.0        0.0        0.0          0          0          0
$:     nrbf       ncsf        rwf      dtmax       d2r        r2d     offset
          0          0          0        0.0          1          0        0.0
$:      pid        lrb      ptype
   50020110          0       PART
```

```
*** Automatic material switch at time      7.65000E-07
    Switch case 1

*** Warning 30308 (INI+308)
    Due to common shared node(s) it is necessary to merge
    rigid part ID: 50000013 with part ID: 50020110

*** Warning 30308 (INI+308)
    Due to common shared node(s) it is necessary to merge
    rigid part ID: 50000011 with part ID: 50020110

*** Warning 30308 (INI+308)
    Due to common shared node(s) it is necessary to merge
    rigid part ID: 50000012 with part ID: 50020110

*** Warning 30308 (INI+308)
    Due to common shared node(s) it is necessary to merge
    rigid part ID: 50000010 with part ID: 50020110
```

The Methods of achieving vehicles equilibrium---Switching deformable to rigid

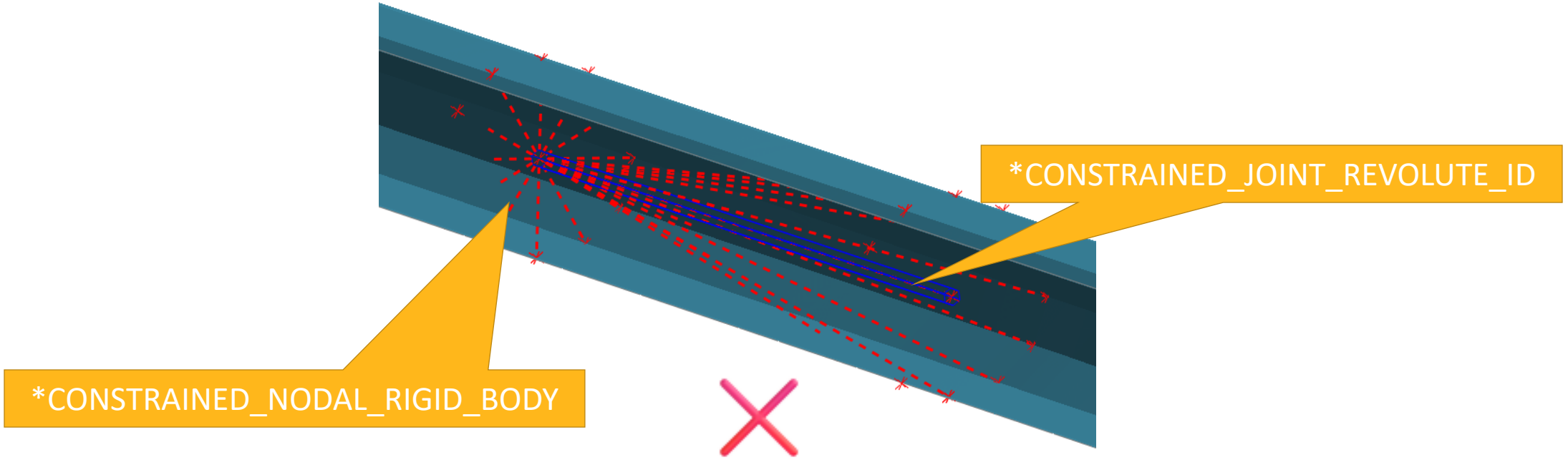
- *CONSTRAINED_RIGID_BODYS. There is no error.

```
*CONSTRAINED_RIGID_BODIES
$:     pidl       pidc      iflag
  50002001   20005001          0
```



The Methods of achieving vehicles equilibrium---Switching deformable to rigid

- The nodes of Joint are part of *CONSTRAINED_NODAL_RIGID_BODY. After the deformable body switch to a rigid body, the nodes disappear. It will cause an error.
- The Part connected by Joint should be used with caution for the switching between deformable and rigid bodies. If all the rigid body connected by Joint is merged into the same Part. It will cause an error.



The Methods of achieving vehicles equilibrium---Switching deformable to rigid

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  - 4. *CONSTRAINED_RIGID_BODYS
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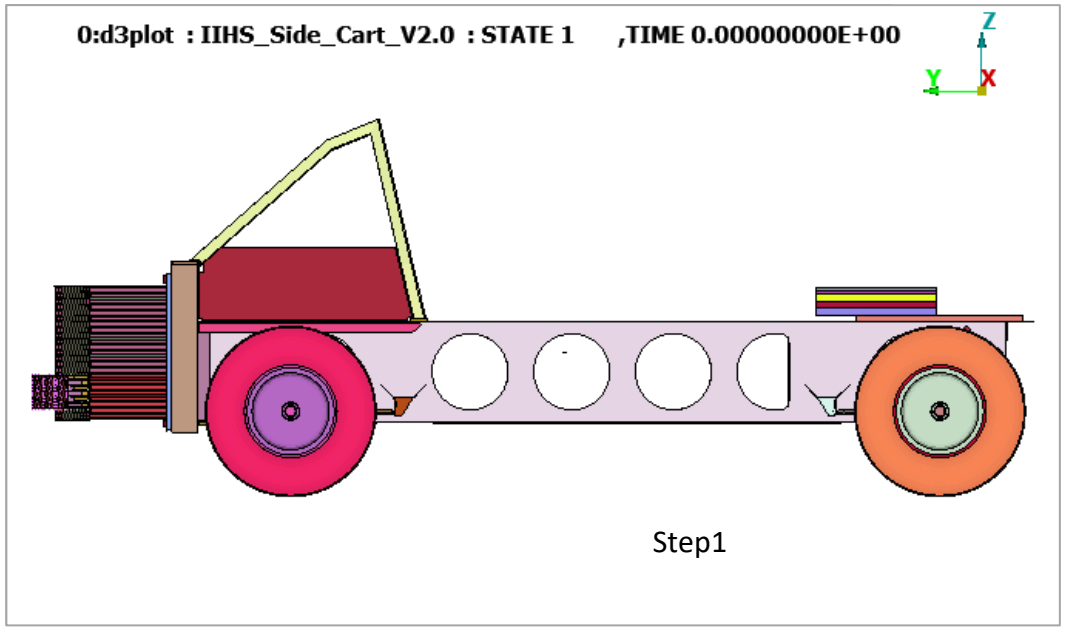
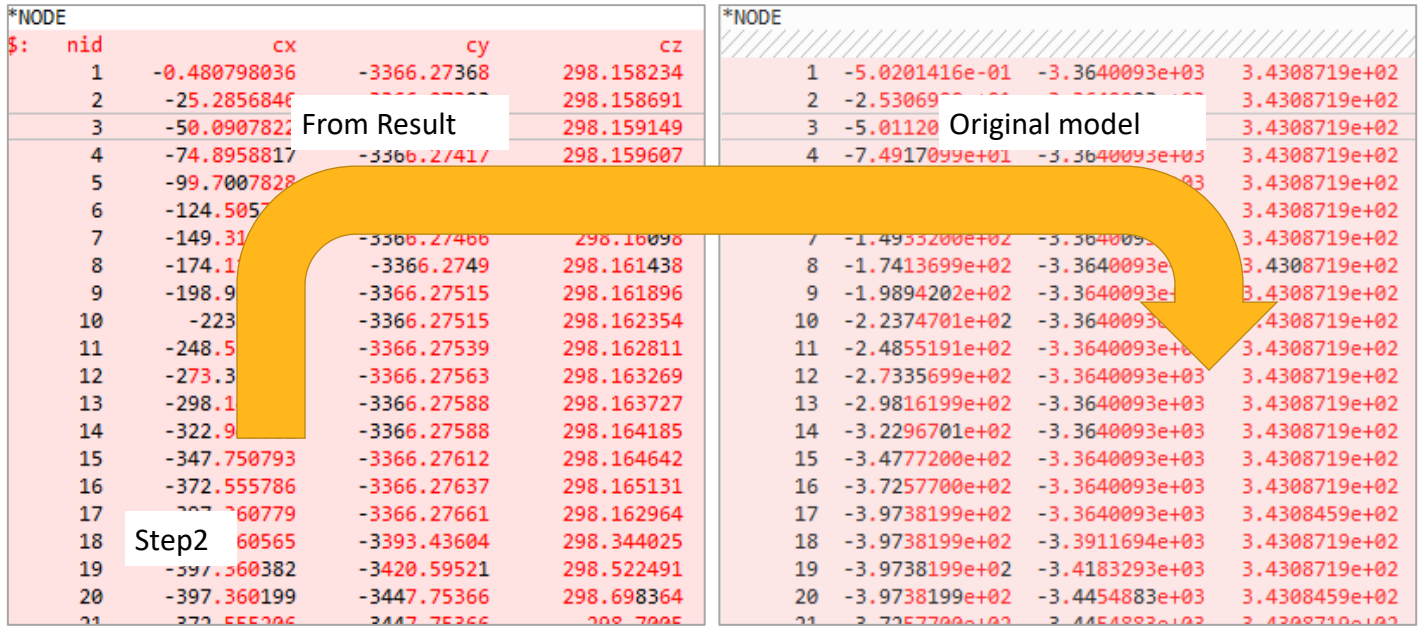
The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

- Step 1, Let the whole vehicle model reaches equilibrium after simulation more than 1s;
  Step 2. Exporting the *NODE from the last time step in the result. Replacing the *NODE of the original model with the one just exported from the result;
  Step 3. Measuring the suspension compression and writing it to ‘offset’ in the *ELEMENT_DISCRETE;
  Step 4, There are some Joint those nodes do not fully coincide. Using OASYS Primer to auto fix it.

- Now we have a new model that is very close to static equilibrium. This model can be used for analysis such as scraping the bottom.





The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

- Step 1, Let the whole vehicle model reaches equilibrium after simulation more than 1s;
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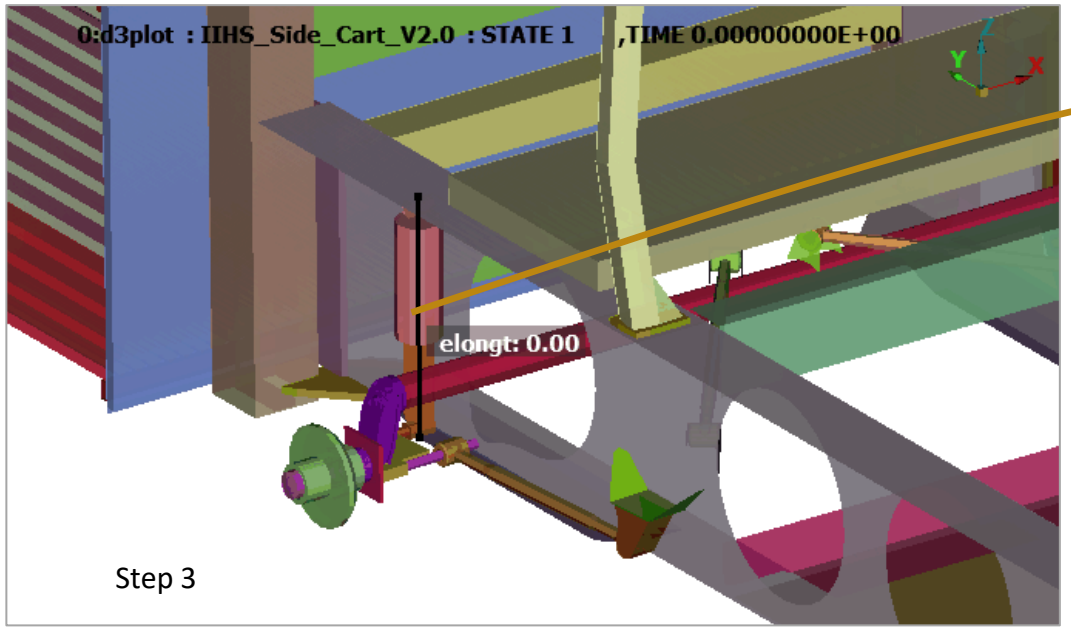


Step 3

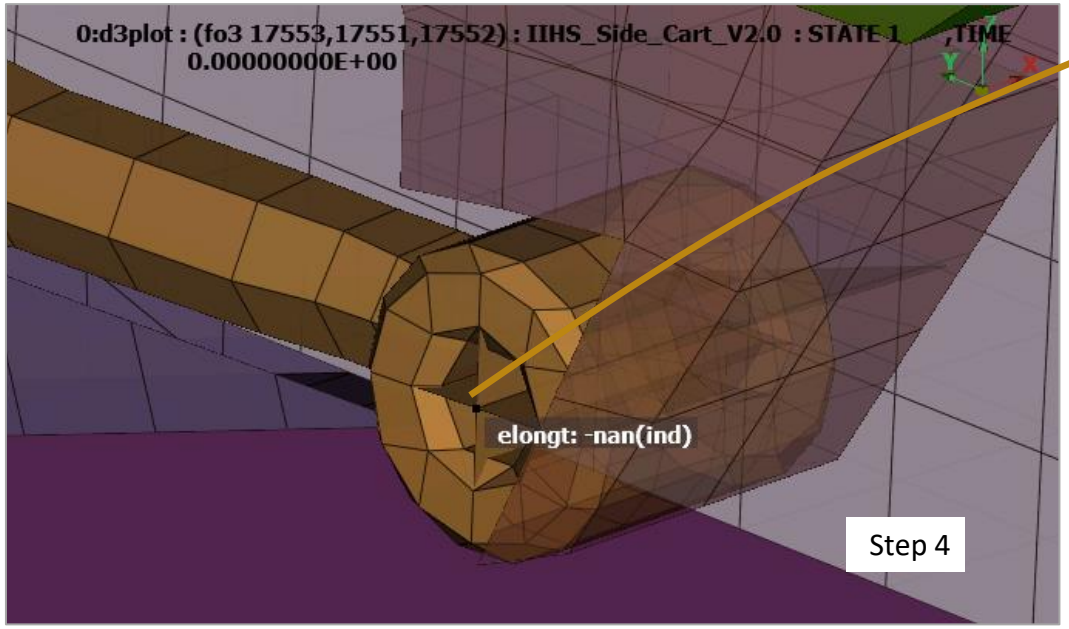
*ELEMENT_DISCRETE

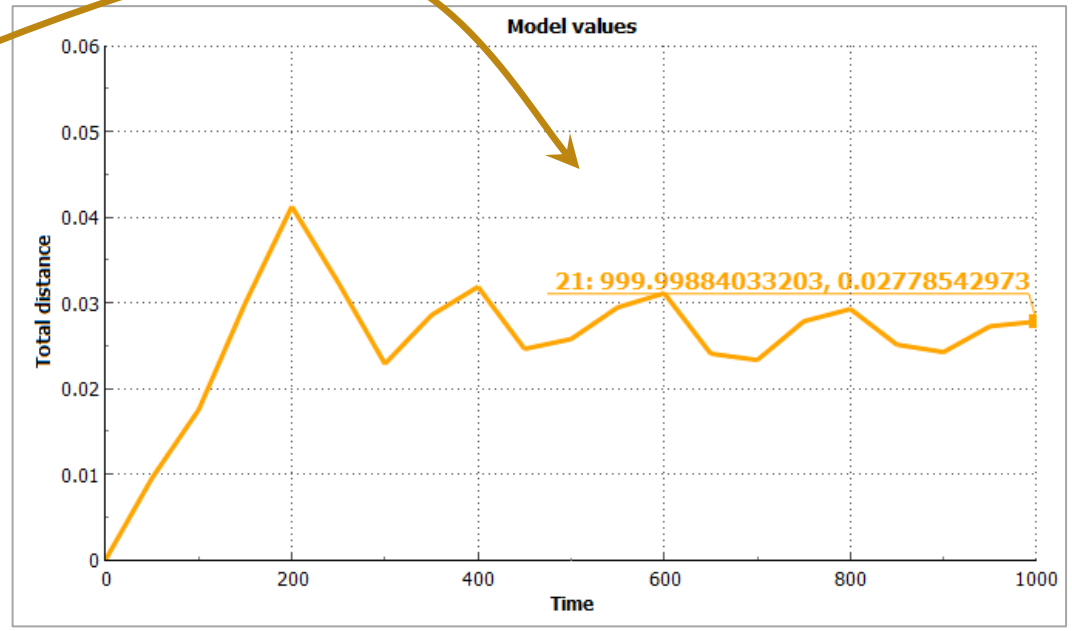
$: label	pid	n1	n2	vid	s	pf	offset
80862	73	36011	36050	0	0.0	0	0.0
80863	77	36218	36257	0	0.0	0	0.0
80864	82	36218	36257	0	0.0	0	-54.55
80865	81	36011	36050	0	0.0	0	-39.06
80866	120	73238	73277	0	0.0	0	0.0
80867	124	73445	73484	0	0.0	0	0.0
80868	128	73445	73484	0	0.0	0	-54.55
80869	127	73238	73277	0	0.0	0	-39.06

The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

- Step 1, Let the whole vehicle model reaches equilibrium after simulation more than 1s;
  Step 2. Exporting the *NODE from the last time step in the result. Replacing the *NODE of the original model with the one just exported from the result;
  Step 3. Measuring the suspension compression and writing it to ‘offset’ in the *ELEMENT_DISCRETE;
  Step 4, There are some Joint those nodes do not fully coincide. Using OASYS Primer to auto fix it.

- Now we have a new model that is very close to static equilibrium. This model can be used for analysis such as scraping the bottom.

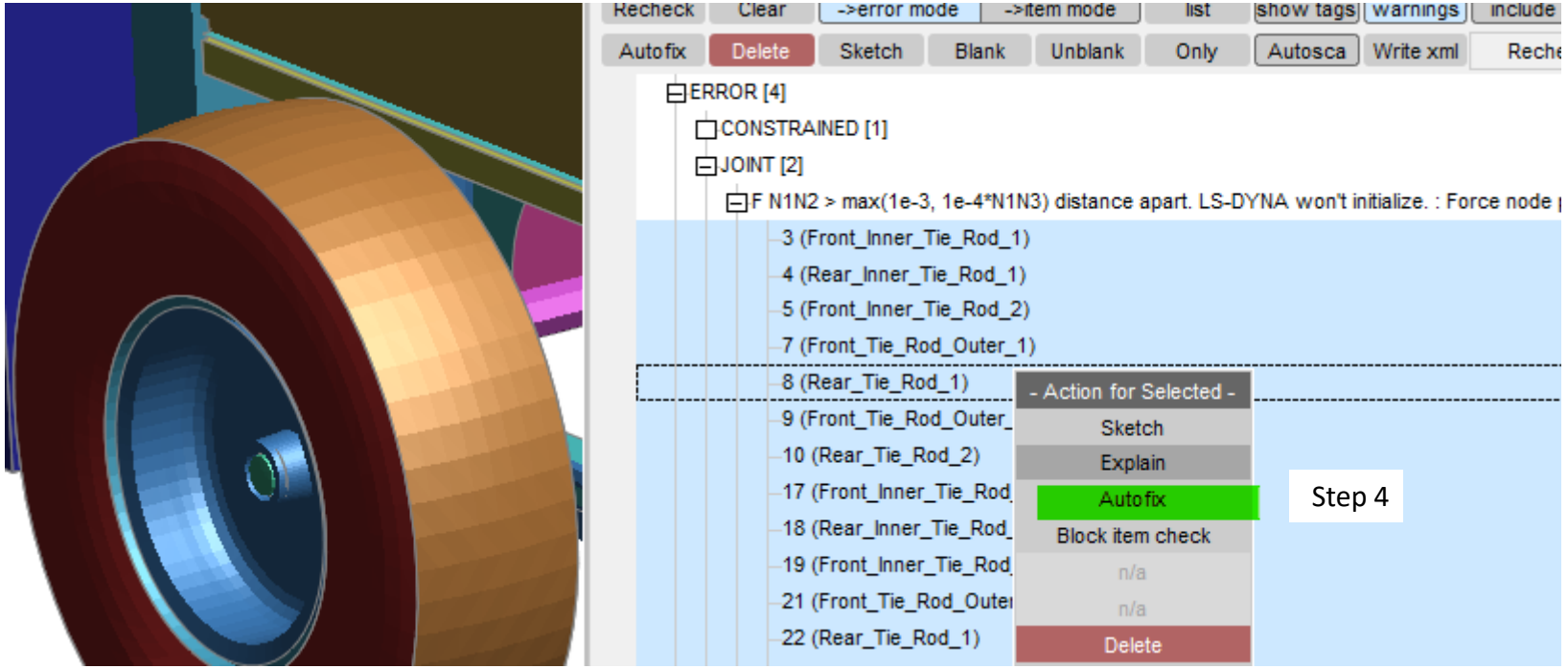




The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

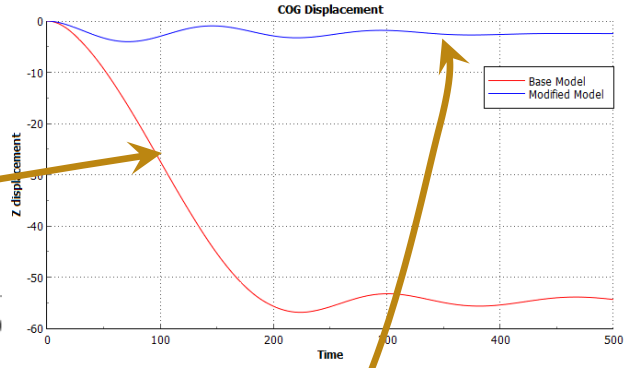
- Step 1, Let the whole vehicle model reaches equilibrium after simulation more than 1s;
  Step 2. Exporting the *NODE from the last time step in the result. Replacing the *NODE of the original model with the one just exported from the result;
  Step 3. Measuring the suspension compression and writing it to ‘offset’ in the *ELEMENT_DISCRETE;
  Step 4, There are some Joint those nodes do not fully coincide. Using OASYS Primer to auto fix it.

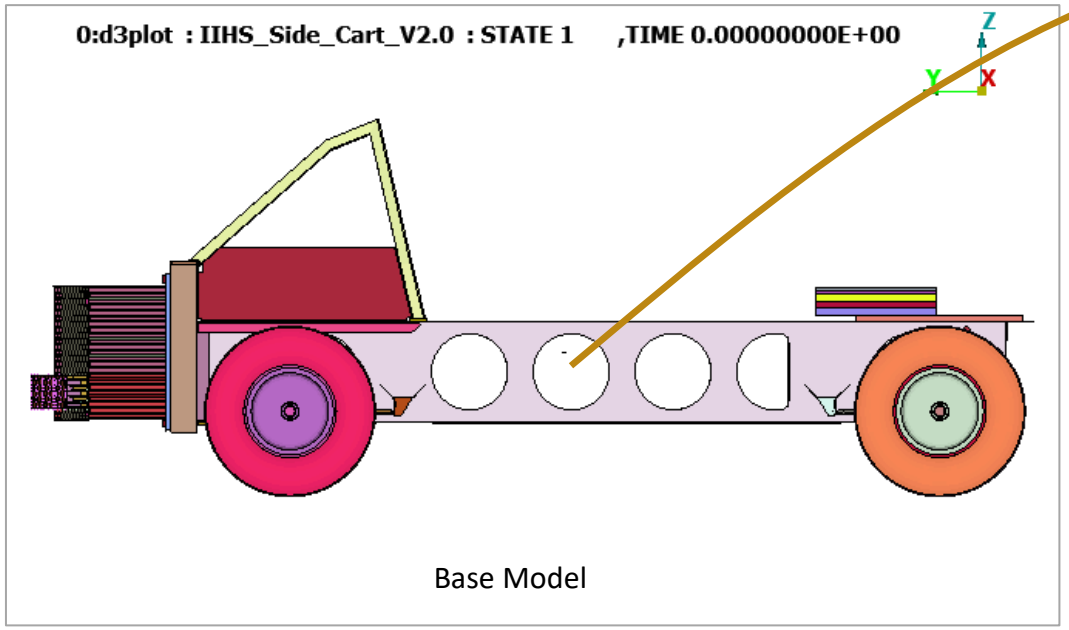
- Now we have a new model that is very close to static equilibrium. This model can be used for analysis such as scraping the bottom.



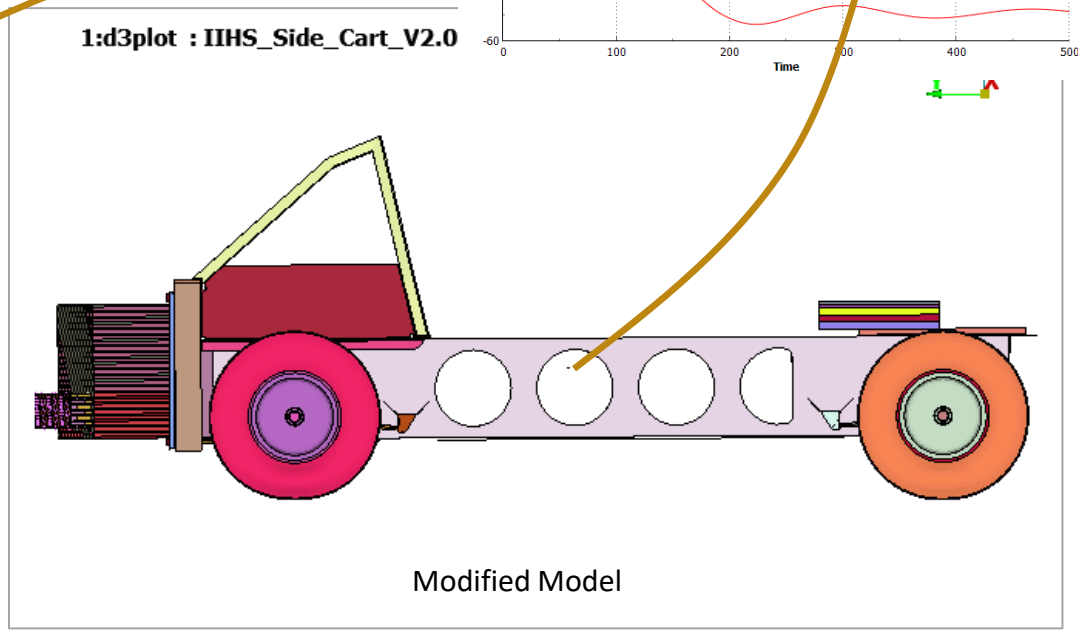
The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

- Now we have a modified model that is very close to static equilibrium. This model can be used for analysis such as scraping the bottom.
- Under the gravity, the COG of the base model decreases continuously and reaches equilibrium.
- At the same time, the COG of the modified model does not decrease.





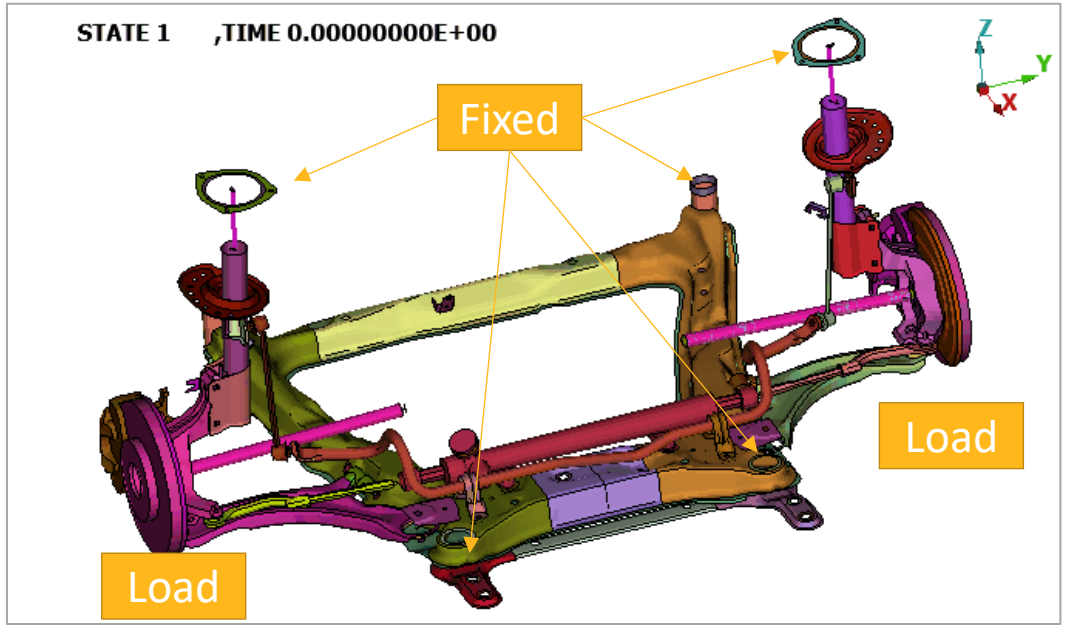
Base Model

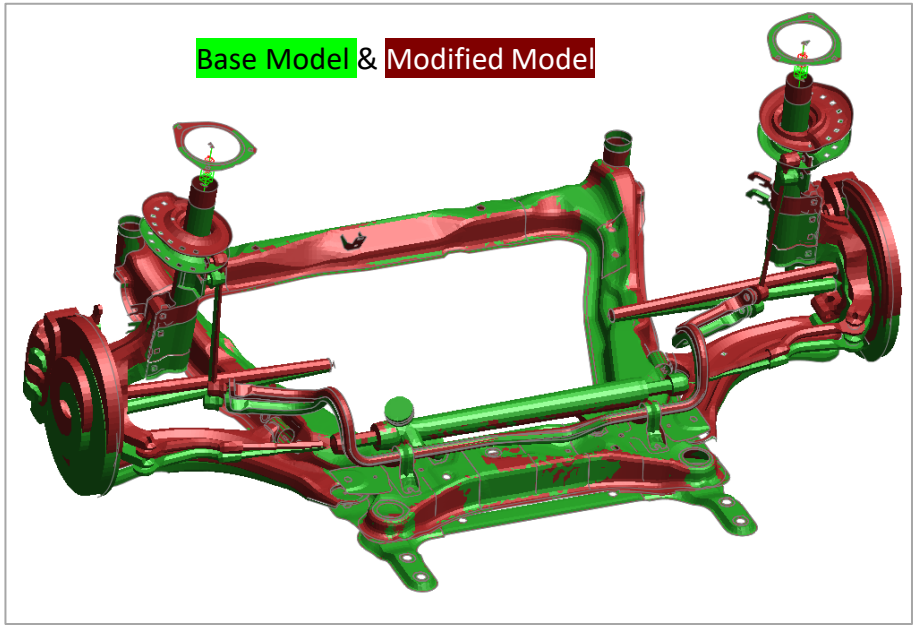


Modified Model

The Methods of achieving vehicles equilibrium---Replacing nodes after equilibrium once

- There are many include files of the whole vehicle, and replacing all nodes is very complicated. A simpler way: Only replace the front and rear suspension include files, and the tires need to be transformed. No other files need to be changed.
- How to do: Applying the displacement at the position of knuckle, along the direction of the spring. The packaging Engineer is required to give the ground line under the scraping test condition. We can calculate how much displacement to apply based on the ground line. The rest of the step is the same as before.





Model based on the public model nissan-rogue downloaded from https://www.ccsa.gmu.edu/models/2020-nissan-rogue/

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  3. Replacing nodes after simulating vehicle equilibrium once
- Summary
  - The method of replacing node of chassis include file is recommended considering simultaneously computing resources and workload of engineer.