A Study on the Suspension System of Spartan Superway

1. Purpose

In case of general car suspension system, it plays a role to support the body of a car, and improve ride comfort by reducing vertical vibration. In addition, suspension system prevents a car from getting damaged by easing excessive loads on each part. Also, it acts to connect the body of the car and wheel.

We invented a suspension system to play a role like car suspension in Spartan Superway. It has purposes to improve ride comfort by reducing cabin's vibration and connect cabin and boggie. Also, it is for preventing excessive loads and damaging caused from big impact transmitted to the cabin.

In particular, as Spartan Superway is a structure of pendulous form, we researched to ease every direction of vibration such as bounce, pitching, swinging.

2. Research

(1) Structure

The first suspension began with a simple structure that connects the 4 shock absorber directly to boggie. However it was unreasonable to use this structure, as the width between steel columns of boggie was too narrow, which cause hardship in reducing bounce, pitching, and swinging vibration. Because it will be more effective to reduce vibration at the edge of the cabin's body.

Second idea based on this reason is the method to connect shock absorbers by inserting rods in steal columns of boggie. Doing this will be advantageous to decrease vibration, as vertical and horizontal distances between 4 shock absorbers will become wider. However, it has unstableness, since it has a possibility to get out from spring's elastic range. This is because these shock absorbers are on the form of tension by the weight of cabin.

We thought about the compression mechanism of shock absorber. A condition required to make shock absorber as a form of compression is that the bottom of the spring should be fixed. To satisfy this condition, we located shock absorbers above the rods connected to the boggie. Then, we could suggest the suspension structure having a form of supporting the ceiling of the cabin inside. However, this suspension structure needs to be connected to the ceiling of the cabin, which can lead the whole suspension system and cabin to become one rigid body.

For these reasons, we tried to make suspension system get out from cabin. As a result, steel columns of boggie are attached to the steel plate that is connected to the bottom of the shock absorbers. Also, shock absorber is on the form of compression, having the weight of the cabin applied to the top of the shock absorbers such as figure 2.1.

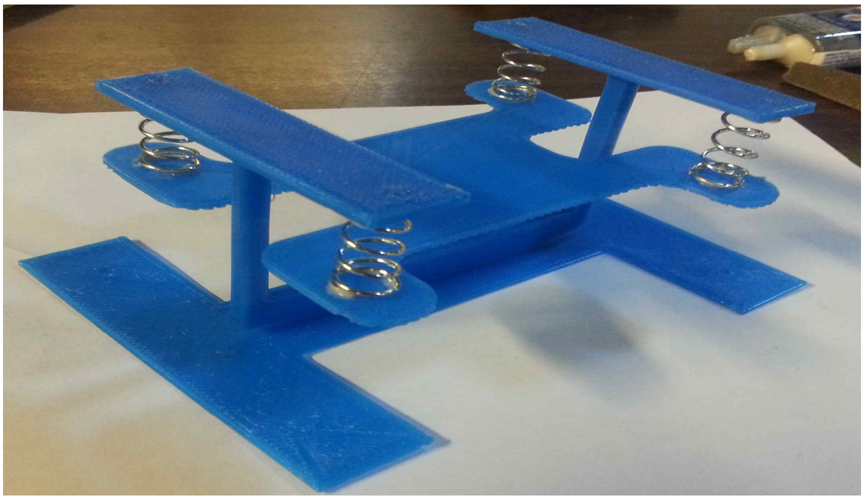

figure 2.1

This suspension structure will be connected to the cabin as shown in figure 2.2.

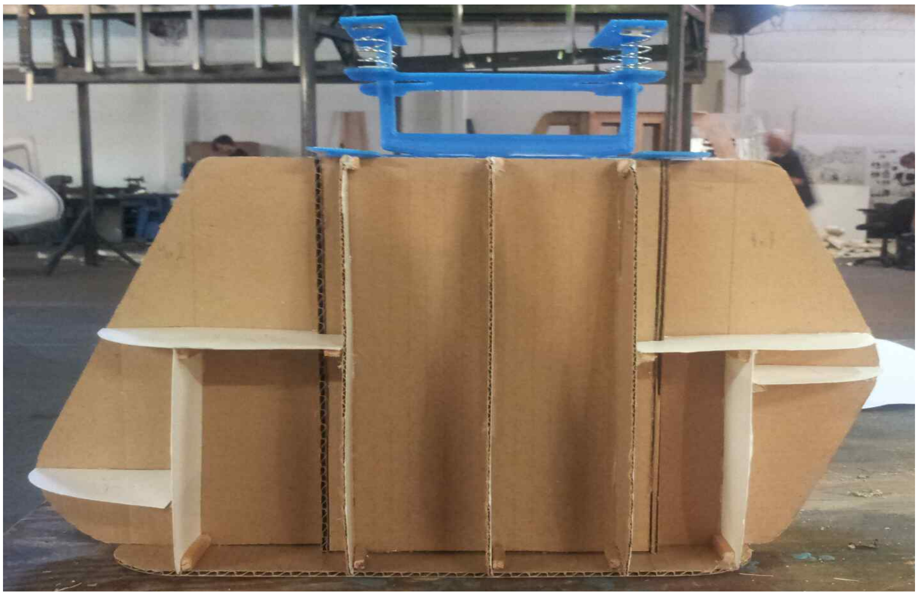

figure 2.2

(2) Determining the stiffness of shock absorber

We received an order of restricting conditions on manufacturing from Bengt. That was ① Bounce vibration≤2cm, ② Pitching vibration≤5˚, ③ Swinging vibration≤5˚. We conducted the disturbance analysis to determine the stiffness of shock absorber (k) in order to satisfy those conditions.

i) Bounce

figure 2.3

First, we had to decide the stiffness of our spring by considering the height of suspension. Please remember that the limit deflection ε is about 1~2cm(①), and maximum cabin weight including passengers is 1790kg(17500N). With these information,

$$k = \frac{F}{\varepsilon} = 400kN/m$$

By this formula, the stiffness of shock absorbers should be 400kN/m.

ii) Pitching

figure 2.4

Maximum acceleration of the cabin is $2m/s^2$. Therefore, the acceleration force of the cabin is

$$F = m_{cabin} a_{\max} = 35000N$$

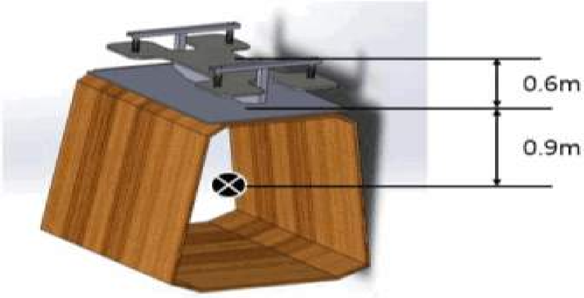

figure 2.5

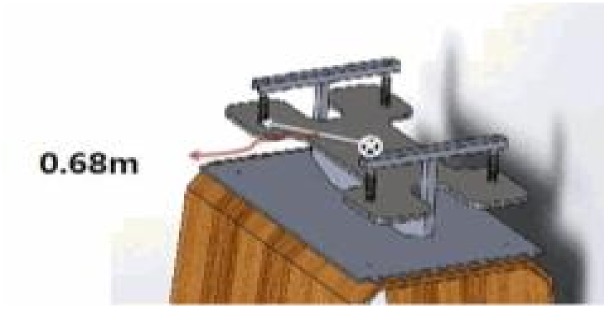

figure 2.6

Also, the distance of center of rotation is 1.5m as shown in the figure 2.5. Based on the distance of center of rotation and the acceleration force, maximum torque applied to the cabin will be

$$T_{\max} = Fd = (35000N)(1.5m) = 52500Nm = 52.5kNm$$

Force per one spring will be

$$F_{one\,spring} = \frac{52.5kNm}{(4)(0.68m)} = 19301.5N$$

Maximum deflection of one spring will be

$$\varepsilon = \frac{F}{k} = \frac{19301N}{400kN/m} \approx 0.048m \approx 4.9cm$$

By this formula, maximum deflection of one spring if the cabin obtains maximum acceleration is about 4.9cm.

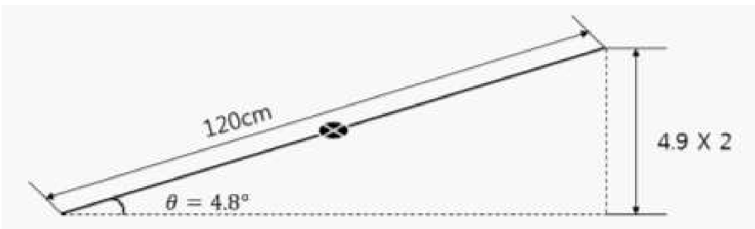

figure 2.7

Max slope(direction of pitching) will be derived from figure 2.7. Maximum slope angle θ will be

$$\theta = \sin^{-1}\left(\frac{(2)(4.9cm)}{120cm}\right) = 4.8^{\circ}$$

120cm is the height of the cabin. With this numerical value, we can assure that the pitching vibration is under 5˚, which is ② condition.

iii) Swinging

figure 2.8

When the cabin switches from rail to station, it will experience a centrifugal force.

$$F = \frac{mv^2}{r} = \frac{(17500N)(15m/s)^2}{80m} = 49219N$$

Specifically, r is radius of curvature, and we decided to use average train rail curvature 80m here. Also, v is derived from the paper on ATN manufacturing. In addition, the distance of center of rotation will be 1.5m as shown in the figure 2.5.

Therefore, maximum torque of the cabin (swinging direction) will be

$$T = Fd = (49219N)(1.5m) = 73800Nm = 73.8kNm$$

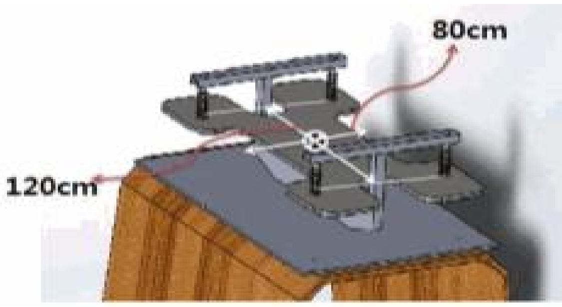

figure 2.9

Swinging force per one spring will be

$$F_{one\,spring} = \frac{73.8kNm}{(4)(0.68m)} = 27143N$$

Maximum deflection of spring (direction of swinging) will be

$$\varepsilon = \frac{F}{k} = \frac{27143N}{400kN/m} \approx 0.0678 \approx 6.8cm$$

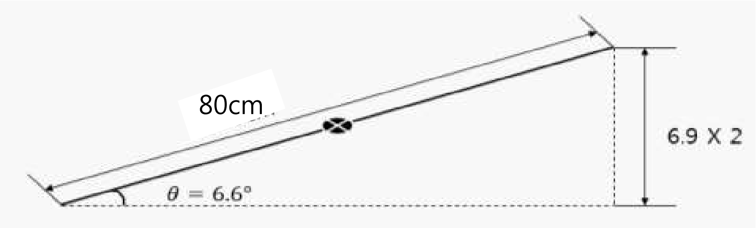

figure 2.10

Maximum slope angle as shown in the figure 2.10 will be

$$\theta = \sin^{-1}\left(\frac{(2)(6.8cm)}{80cm}\right) = 9.8\,^{\circ}$$

To reduce maximum slope angle and deflection until 5˚, cabin velocity should be under 10.75m/s.

In short, determining the stiffness of shock absorber as 400kN/m will satisfy all of the restricting conditions with adjusting the maximum velocity under 10.75m/s during swinging motion.

(3) Analysis

After determining the stiffness, we conducted the analysis of 3 elements of suspension structure using Ansys program.

i) mid plane

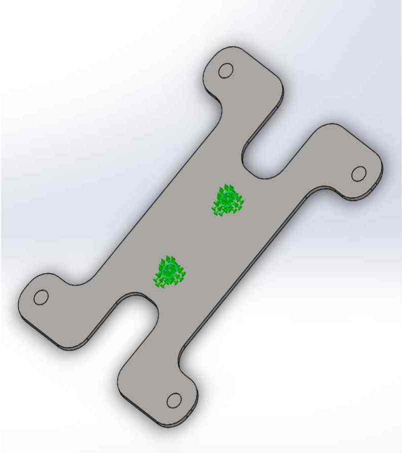

figure 2.11

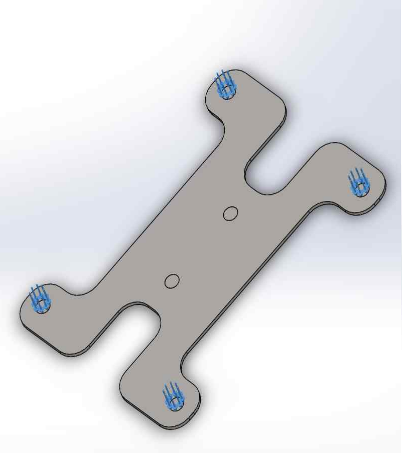

figure 2.12

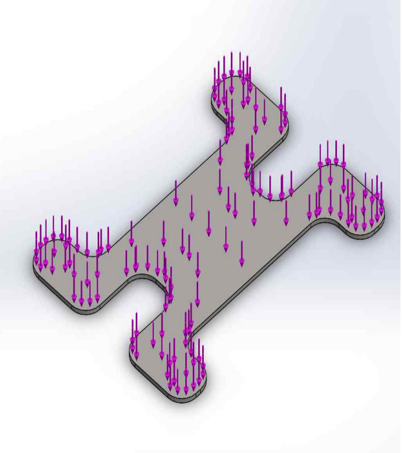

figure 2.13

Figure 2.11 shows the constraint, as those parts will be connected to the boggie. Figure 2.12 shows the applying loads caused by spring force, and figure 2.13 indicates the weight of mid plane itself.

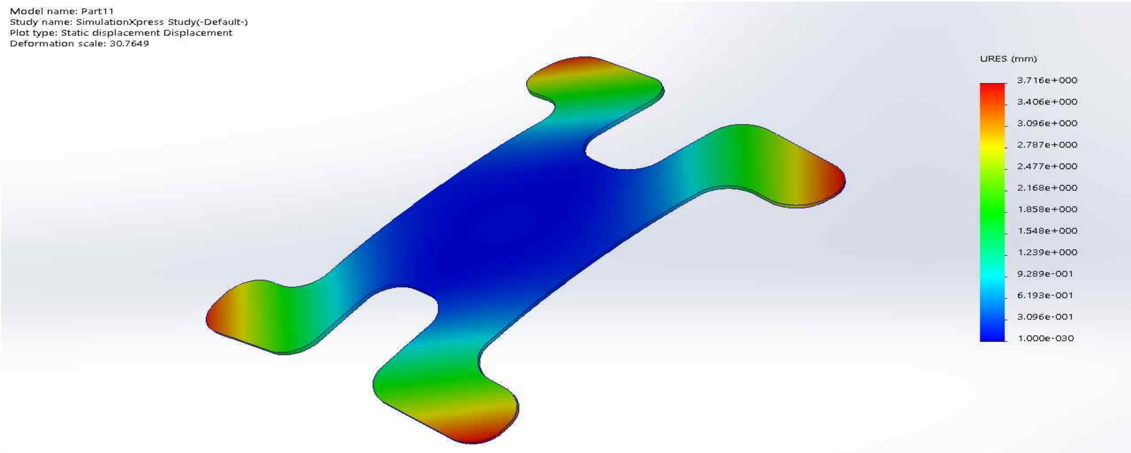

figure 2.14

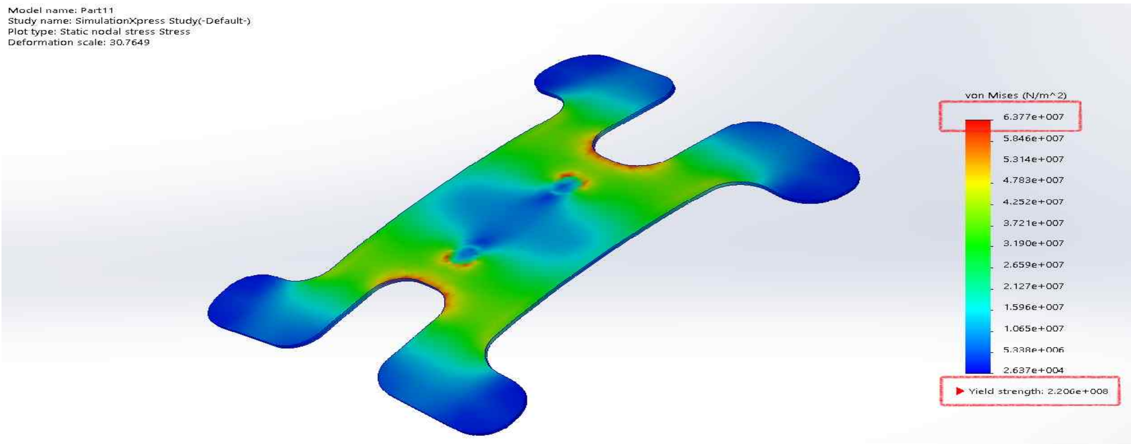

figure 2.15

Figure 2.14 and 2.15 shows the result. Figure 2.14 is about deflection, and figure 2.15 is about stress. Maximum stress shows the amount about 1/3 of yield strength, which means that this part has a safety factor of 3. Also, the maximum deflection is not greater than 5mm, which is the upper limit.

ⅱ) upper plane

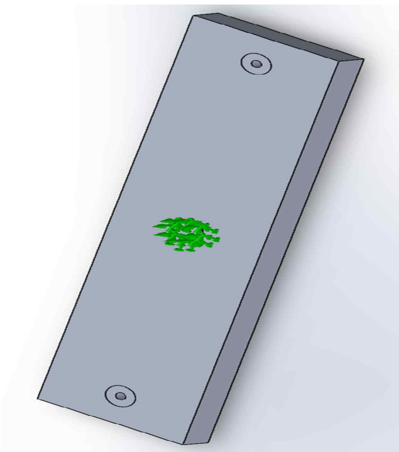

figure 2.16

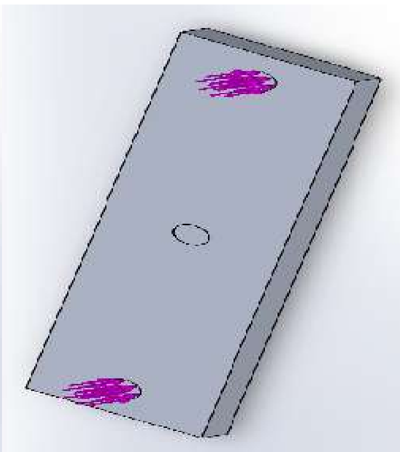

figure 2.17

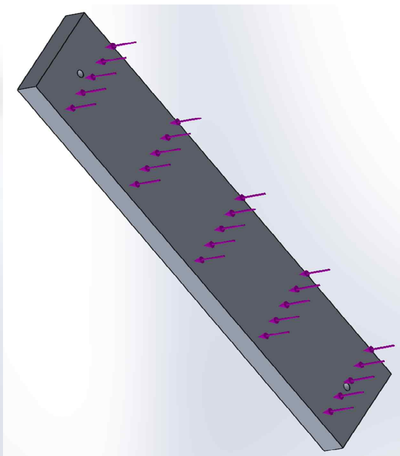

figure 2.18

Figure 2.16 shows the constraint, as that part will be connected to the shock absorber.

Figure 2.17 shows the applying loads caused by spring force, and figure 2.13 indicates the weight of upper plane itself.

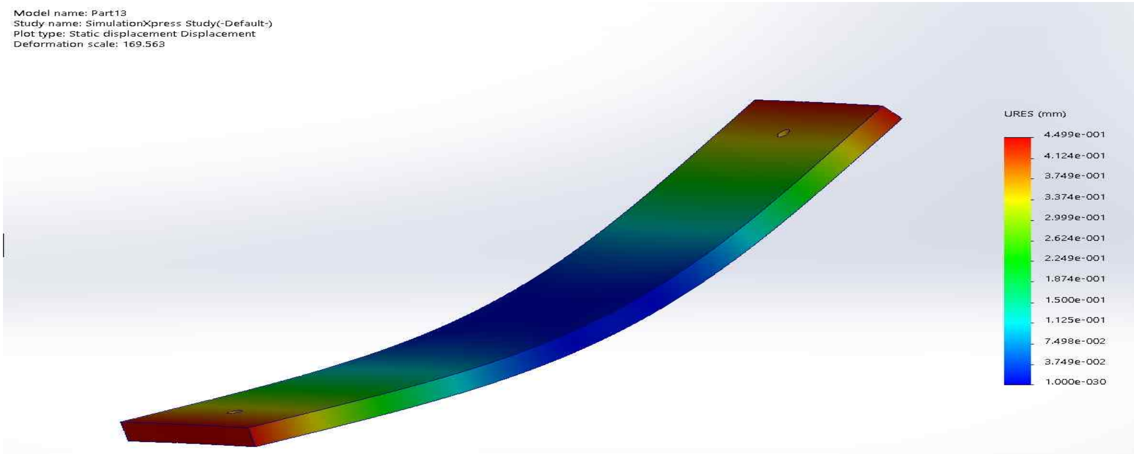

figure 2.19

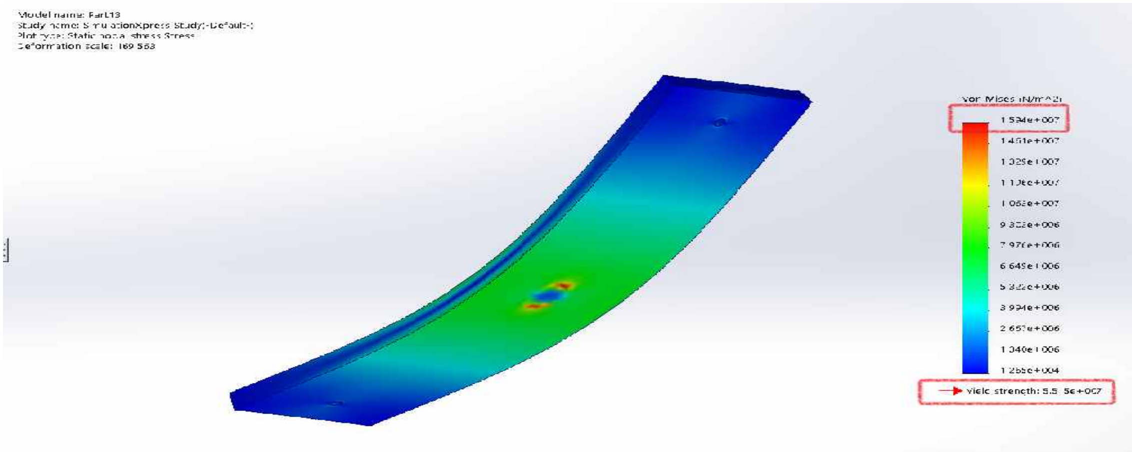

figure 2.20

Figure 2.19 and 2.20 shows the result. Figure 2.19 is about deflection, and figure 2.20 is about stress. Maximum stress shows the amount about 1/4 of yield strength, which means that this part has a safety factor of 4. Also, the maximum deflection is not greater than 5mm, which is the upper limit.

iii) main beam

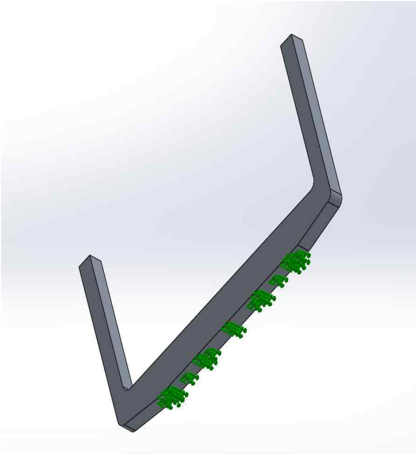

figure 2.21

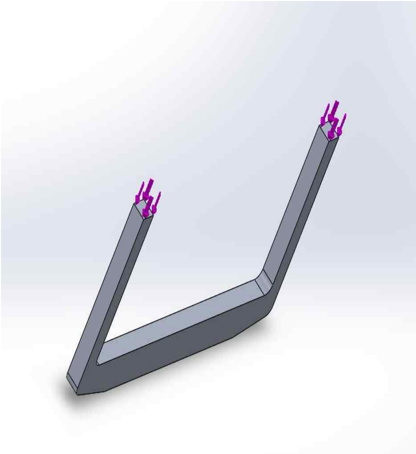

figure 2.22

Figure 2.21 shows the constraint, as that part will be attached to the cabin ceiling. Figure 2.22 shows the loads caused by cabin weight applied on the upper plane.

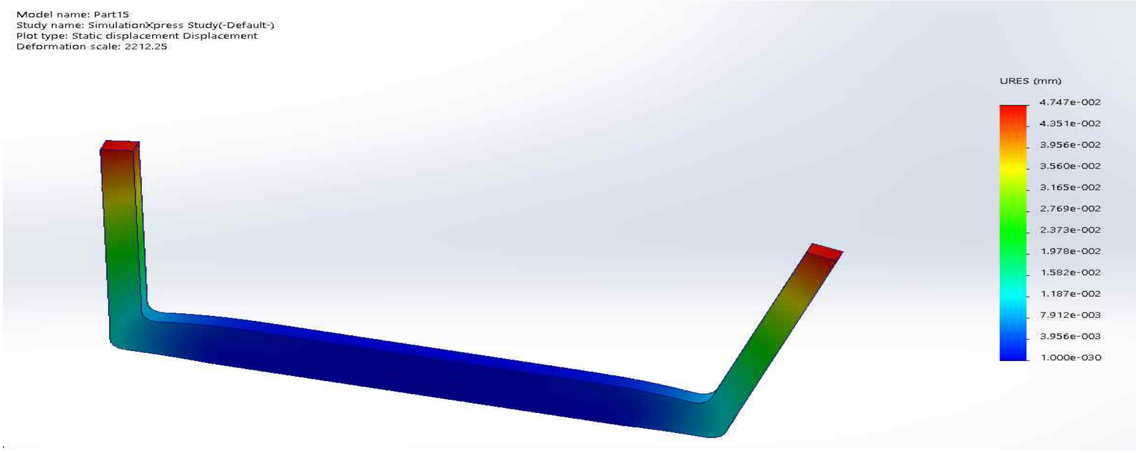

figure 2.23

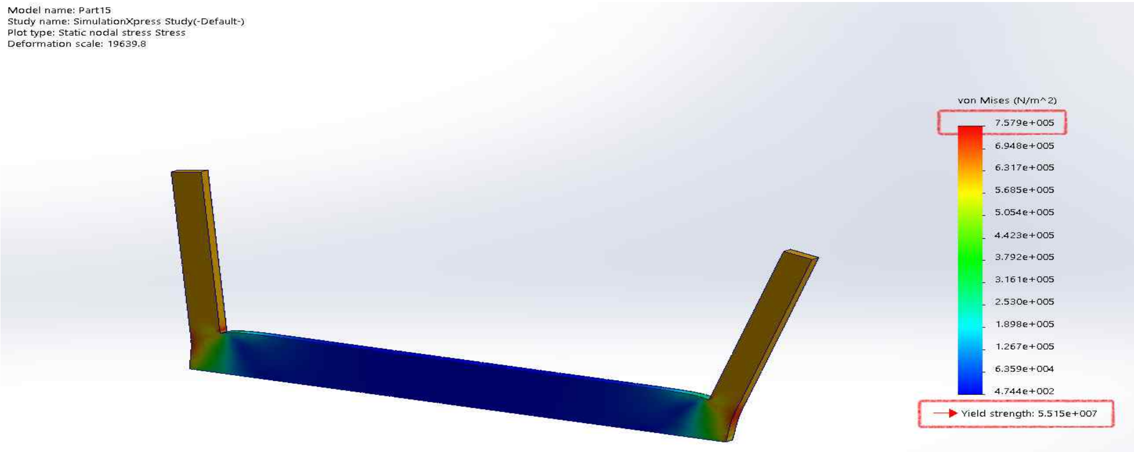

figure 2.24

Figure 2.23 and 2.24 shows the result. Figure 2.23 is about deflection, and figure 2.24 is about stress. Maximum stress shows the amount about 1/70 of yield strength, which means that this part has a safety factor of 70. Also, the maximum deflection is not

greater than 5mm, which is the upper limit.
In short, every part of the structure satisfy the safety limit.

3. Manufacturing

Unfortunately We couldn't make suspension system what we expected. Because the quote we got was too much. So we bought RECT A513, A500 and hired welder. Before making suspension we considered connection point of cabin. Also we had to think again how to suspension can be attached to boggie.

Figure 3.1

Figure 3.2

Figure 3.1 is the part what we used to connection cabin and suspension.
Figure 3.2 shows steel that we used to make suspension.

Figure 3.3

Figure 3.4

Figure 3.3 and 3.4 show the moment of manufacturing suspension. Two things are very important for manufacturing. First steels are should be grinded. Grinding can help you to weld much easier. Second Try to keep a balance between left and right. If not Tolerance will be much bigger and it will be hard to connect with cabin.

Figure 3.5

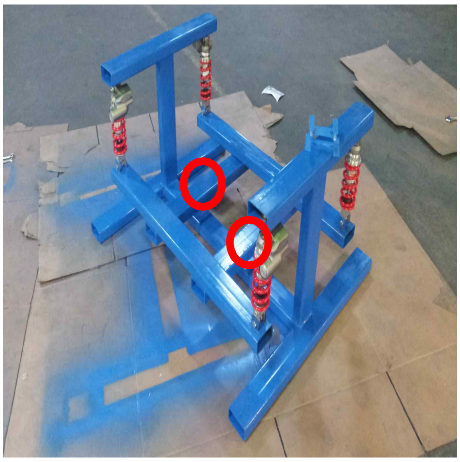

Figure 3.6

After making structure we attached suspension like Figure 3.6 There are two red circles on Figure 3.6. Those are position where boggie will be attached.
Before lifting up the suspension on the cabin we made a hole to use bolt.

Figure 3.7

Figure 3.8

We used forklift in the store so we could lift up the suspension and then we tried to connect with cabin but it was very hard work. The holes that swedish team made was not fit to suspension. So we drilled new holes which were fit to cabin.

4. Improvement points

(1) Finding reasonable damping coefficient

If you want to operate the suspension in the real situation, you have to adjust damping coefficient of spring/damper system. You can get the information of vibration by attaching an acceleration sensor on the cabin or using software to solve vibration equation.

We found the reasonable stiffness of spring (k=400kN/m) by solving equations. However, finding damping coefficient was limited because we didn't have any device to obtain vibration data.

(2) The connected point of suspension (just one bolting)

The connected point of suspension is not perfect because they are connected just by one bolting. If the cabin moves, the bolting can be loosen and then the spring/damper system can rotate like a hinge when the cabin get a moment or acceleration.

We can recommend two solutions for resolving the problem. First, as shown in the below picture (figure 4.1), add one more bolting point in order to avoid rotating.

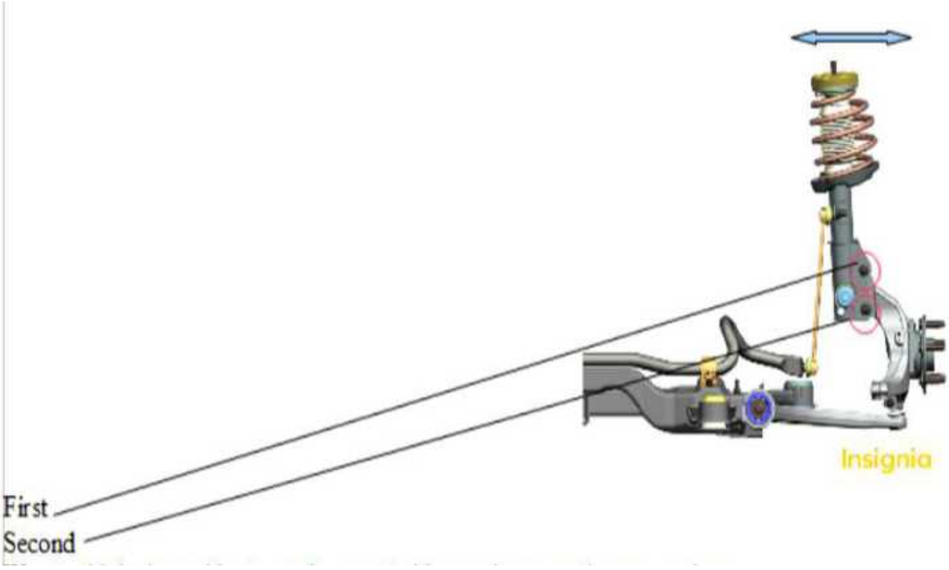

figure 4.1

Second, change the spring/damper system which doesn't need bolting to connect each other or choose different ways of connecting such as welding between the suspension and the spring/damper system directly. If you do like this, the spring/damper system will not rotate.

(3) Reduce the weight of suspension.

We don't exactly know the weight of our suspension but it can be reduced. The weight is very important for fuel efficiency of ATN. We chose only steel to make our suspension because of limited time, but some parts can be replaced to other materials like Al(aluminum). If you have an interest in reducing the weight of suspension, you can try to change the material.