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Automotive Chassis Structures (ACHA5013)

Vehicle Structures: Past, Current and Future

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Introduction

I have conducted research into the history, future, and development of the different types of chassis structures that have been used in vehicles to date. I have provided information on the uses, advantages, disadvantages, and development of each of the main structure types. I have also performed SSS (simple structural surfaces) calculations on a van in torsion to find the shear loads on each panel and torsional load of the van, along with an analysis of the results.

Structure types: past current and future

There are four main types of chassis structures used in cars today. These include ladder frame, backbone, tubular and monocoque structures. Ladder frames are the most conventional type of structure used today, having been the most common structure used by all types of vehicle during the earlier days of motor vehicles in the early 20th century after having previously been used in horse-drawn carriages. They consist of two strong beams running the length of the structure connected by smaller beams on to which a body is then fitted on top of. These are used commonly today in commercial vehicles such as trucks, vans, and busses as they are very durable, easy/cheap to make/maintain and can withstand large payloads. The toughness of ladder frames also makes them a popular setup for off-road vehicles such as most pickup trucks and some SUVs. However, they are not used for most modern passenger cars as they are unrefined, heavy and have a low torsional stiffness often resulting in poorer vehicle handling compared to other chassis types.

Backbone structures are similar to a ladder chassis but are constructed using a strong tubular section (usually rectangular) connecting the front suspension connections to the rear, with a body then being mounted on top of the frame in a similar fashion to a ladder chassis. They have sometimes been used in low-volume sports cars, such as a variety of Lotus cars from the 1960s and 70s and some TVRs due to having a higher torsional rigidity than ladder frames, although they are less ideal for more high-end sports and performance vehicles. They can also be ideal for off-road vehicles due to having good contact with the ground when off-road and because the driveshaft is situated inside the structure, so it is less likely to be damaged on harsh off-road tracks. The problem with backbone structures however is the difficulty of maintenance with the driveshaft being positioned inside the structure, can be expensive to make and provide very little side impact protection.

Tubular structures (also known as spaceframes) are often present in low-volume performance and race cars due to having a high rigidity and providing excellent safety while being lightweight. These structures are made from a series of tubes welded together to make up the vehicle structure. This type of structure was first used in aviation due to its light weight and started to appear in performance and race cars in the mid-20th century. The disadvantage with tubular structures however is that their complex design makes them difficult and time consuming to build, making them unsuitable for mass production and therefore are not used in mass production passenger and commercial vehicles. The design of the structure also means that entering the vehicle is more difficult due to the amount of space taken up by the chassis tubes, resulting in a less practical vehicle to use every day.

Monocoque structures (also known as unibody structures) in various forms are the most widely used structures for modern cars and are also used for some sports, performance, and race cars. These consist of a frame making up both the lower structure of the car and the structure around the top of it, essentially making the monocoque frame a part of the body. Monocoques started to become mainstream in some cars in the 1930s and 40s and have been used for most passenger vehicles and some light commercial vehicles since the mid-20th century due to the benefits a monocoque has over 'body on frame' structures for lighter vehicles. These chassis structures have a high torsional rigidity compared to body on frame structures and provide a high level of safety while being cheap to mass produce. However, they are relatively heavy due to being a large part of the vehicle as a whole and are not ideal for small volume production vehicles. Monocoque structures are likely to continue to be widely used for passenger cars and light commercial vehicles for the foreseeable future, with continued development towards making the structures lighter to reduce emissions and increase fuel efficiency while making them stronger to further improve vehicle handling and safety.

Structure developments

Ladder frame structures have evolved little in basic concept since they were used in many of the first cars and trucks, however the materials have evolved from being made of wood in some early vehicles, to using steel of various grades and strength, with steel being used for the vast majority of ladder frame structures today. Steel is often the most popular choice as it is an affordable yet strong material that has been optimised for this use over time to make the frames stronger and lighter allowing for the vehicles that use these structures to be stronger and safer while being more fuel efficient. Other materials have been experimented with for use in ladder frames as with other chassis types, however with steel frames being the cheapest and easiest to maintain while still having a high durability, it is still the material of choice despite being heavier than most alternatives. One way to improve a steel ladder frame would be to use a combination of steel and other materials such as CFRP (carbon fibre reinforced plastic) to create a stronger, lighter, and safer chassis. Additional cross beams can also be added to some frames as a way to further strengthen ladder frames and increase their rigidity, whether this be by simply adding more cross beams or using 'X bracing' cross members where possible.

As backbone chassis structures are not used as often as the other main structures, development of this type of chassis has been relatively limited. Although having been used for some lightweight sports cars (and some trucks) in the past, it is uncommon to see them being used today as various forms of tubular structures and also sometimes monocoque structures (in some cases part-tubular and part-monocoque structures) are more commonly used for sports cars today. Some developments have been made to improve the design however, for instance the backbone chassis previously used by TVR used a 'lattice backbone made of tubular space frames' (What are the Types of Automobile Chassis?, 2020) instead of a rigid backbone. This made the chassis both lighter and stronger than a more conventional backbone structure. The use of more advanced materials could result in a stronger, lighter, and safer structure, however there is very little that can be done to improve side impact protection due to the layout of the backbone. As a result of this, the side impact protection must be mounted entirely within the bodywork of the vehicle, which is a less effective method than allowing the chassis to take some of the impact. Backbone structures could potentially be useful in future with electric vehicles, as it is possible to fill the structure with batteries and other equipment used to power the vehicle, instead of a conventional drive shaft as seen in ICE (internal combustion engine) vehicles. This would allow for a usefully low centre of gravity but with the lack of side impact protection offered with these structures a lot of work would be needed to strengthen the bodywork if this setup were to be used in future.

Tubular structures have seen various refinements since first being used for road cars. For instance, steel has often been used to make the tubes in spaceframe structures in various grades, however in some cases space frames have been made partially or entirely of aluminium as it is a lighter material than steel. Aluminium's advantages however are limited as 'the ratio of stiffness to weight is almost identical to steel' (Formula 1-dictionary.net, 2021), meaning that an all-aluminium chassis would have to weigh the same as an equivalent steel chassis if it were to provide the same level of stiffness. What many manufacturers have also done is combine a spaceframe structure with a monocoque. This normally consists of a monocoque frame being used in the centre of the vehicle (i.e., around the cabin) with the front and rear sections being made from a tubular frame. These structures are heavier and less rigid than full spaceframe designs, however they offer various advantages, from being cheaper and easier to produce than fully tubular structures to being more user friendly as the central monocoque allows for the doors to be larger and lower than on a full spaceframe vehicle making it easier to get in and out of.

Monocoque chassis structures have developed extensively to improve the rigidity, safety, and fuel economy of the many vehicles they have been a part of. In passenger cars, ULSAB (ultra-light steel auto body) technology has been used since the 1990s as an alternative to regular steel in monocoques. This allowed for the structure to be both lighter and stiffer than a more conventional steel monocoque, resulting in vehicles that are both safer and more economical due to having a lower weight and higher strength. Aluminium has also been used but due to the limited benefits and increased price over steel, few cars have used an all-aluminium structure to date, with aluminium more commonly being used in other areas such as bodywork to reduce weight. Monocoques have also been used in motorsports such as Formula 1 where the structures are made of carbon fibre, which is a very light yet strong material regularly reserved for high performance and race cars due to the high cost and complexity of design. As previously mentioned also, monocoques have been combined with tubular structures in many sports and performance cars which saves weight compared to a regular monocoque and cost compared to a full spaceframe.

In future with the movement towards electric and autonomous vehicles, chassis technology is evolving to include 'sensors to support Advanced Driver Assistance Systems (ADAS)' (The global market for Automotive Chassis is projected to reach US\$66.7 billion by 2025, 2021) which would allow for autonomous vehicles to perform more effectively and safely. Many chassis designs are having to be adapted to support battery packs, most often in the form of 'skateboard' layouts which allow for the batteries to provide a lower centre of gravity (therefore improving vehicle handling)

while maximising space within the cabin of the vehicle. It is also possible that more complex materials such as aluminium and carbon fibre may become more commonplace in attempt to decrease vehicle mass and in some areas provide more strength and rigidity to improve handling and safety.

Van torsion calculations

In this section I have used the simple structural surface (SSS) method to calculate the shear loads on each panel and torsional load of a van in torsion. Most of the values required for the SSS calculations were provided, however I needed to calculate all the P and Q values before I could find the shear loads. Firstly, I had to calculate the P values of the front and rear cross beams which I was able to do by multiplying their respective R and t values and dividing them by the w value multiplied by two. This gave me a result of 1875N for both the front and rear cross beams. These values allowed me to find the shear loads of these areas, which both resulted as 0 after being put into the equation.

Once I had both of the P values, I was able to put them into an equation which allowed me to calculate the value of Q6. I needed this value to work out the other five Q values which I would need to find the shear loads of all the other panels. I used an equation combining the P, h, and l values (most of which were provided) as well as the w value. After performing the calculation, I found the value of Q6 to be 414N. For most of the other Q values, I used an equation that would multiply the lengths/heights (l/h values) of the panels by Q6 and then divide by w. Due to the angle of Q5 (part of the windscreen), I had to divide the top value by $w \sin 45$ where 45 degrees is the angle at which the windscreen is placed. I also calculated the total load on the vehicle after having found each of the other Q values.

The results for each Q value and the SSS for each panel can be found in the figures below:

$$\frac{W[P_2(1+h_1) - P_2 h_1]}{h_1(1+h_1+h_2+h_3)+15(h_1-h_2)+h_2(1+h_2+h_3+h_4)} = 0.6$$

$$\frac{2[P_2(2+3) - P_2 2.4]}{2(2+3+1)+3(2-1)+1(2+3+1)} = 0.6$$

$$\frac{2[P_2 5 - P_2 2.4]}{14.46+3+6} = 0.6$$

$$\frac{2[(1875 \times 5) - (1875 \times 2.4)]}{48.46+23.46} = 0.6$$

$$\frac{2[9375 - 4518.75]}{23.46} = 0.6$$

$$\frac{9712.5}{23.46} = 0.6$$

$$414.1 = 0.6$$

$$H = \frac{h_1 - h_2}{S = N \alpha}$$

$$H(S = N \alpha) = h_1 - h_2$$

$$2 \times (5 = N \alpha) = h_1 - h_2$$

$$10 = h_1 - h_2$$

$$1.41 = h_1 - h_2$$

$$1.41 + h_2 = h_1$$

$$1.41 + 1 = h_1 - 2.41 = h_1$$

$$P_2 = \frac{R_e E_r}{2W} = \frac{5000 \times 1.5}{2 \times 2}$$

$$P_2 = 1875 N$$

$$P_3 = \frac{R_e E_r}{2W} = \frac{5000 \times 1.5}{2 \times 2} = 1875 N$$

$$SSS \text{ shear}$$

$$SSS 2 \text{ and } 3 \text{ to } 1875 N$$

$$(Front and Rear (max beams))$$

$$= 1875 \times 2 - \frac{(5000 \times 1.5)}{2}$$

$$= 0$$

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Figure 1: van torsion equations and answers page 1

• Q1
 $\frac{Q_b h_2}{w} = Q_1$
 $\frac{414 \times 1}{2} = 207N = Q_1$ SSS 8 (Front panel) = 207N

• Q2
 $\frac{Q_b (1 + l_2 + l_3 + l_4)}{w} = Q_2$ SSS 8 (Floor panel) = 1242N
 $\frac{414 \times (2 + 3 + 1)}{2} = 1242N = Q_2$

• Q3
 $\frac{Q_b h_1}{w} = Q_3$ SSS 6 and 7 (Side panels) = 0
 $\frac{414 \times 2}{2} = 414N = Q_3$ SSS 5 (Rear door frame) = 414N
 $\frac{414 \times 2}{2} = 414N = Q_3$ SSS 10 (Roof) = 621N

• Q4
 $\frac{Q_b h_1}{w} = Q_4$
 $\frac{414 \times 3}{2} = 621N = Q_4$

• Q5
 ~~$\frac{Q_b h_1}{w} = Q_5$~~
 $\frac{Q_b (h_1 - h_2)}{w \sin \alpha} = Q_5$
 $\frac{414 \times (2.41 - 1)}{2 \times \sin(45)} = 412.77N = Q_5$
SSS 9 (Windscreen) = 412.77N

~~$T = P \cdot W$~~
 ~~$T = 1855 \times 2 = 3750N$~~
Total load acting on vehicle = 2692.47N

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Figure 2: van torsion equations and answers page 2

Van torsion analysis

Of each of the panels on the van, the Floor panel (surface 8) has the highest load at 1242N, which is significantly greater than all the other surfaces. The panel with the second highest load (621N) was the roof panel (surface 10). The rear door frame (surface 5) and the windscreen (surface 9) both had very similar loads, with those being 414N and 412.77N respectively. For the front panel (surface 4), I found the load to be just 207N. Both the front and rear cross beams (surfaces 2 and 3 respectively) had a load value of 0, a result that I also had for the side panels (surfaces 6 and 7).

It is possible to improve rear access to the van, which would increase the practicality and ease of getting items in and out of the back. This however should not be done to the point where the door frame (surface 5) would no longer act as a shear panel. This would likely increase the load on other panels, on some significantly, which could cause problems as the other surfaces may struggle to handle the increased load which would otherwise be distributed to the door frame. With the other panels having to deal with higher loads, it could potentially decrease the maximum payload the van can carry and/or result in poorer handling.

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