Stronger with Less

A report by the Australian Bureau of Statistics revealed that in the 12 months ending 31st October 2014, freight vehicles travelled an approximate 203,000 million tonne-kilometres in Australia. Articulated vehicles accounted for 79% of the total tonne-kilometres travelled. According to The Australian Road Transport Suppliers Association (ARTSA), in the first quarter of the year (2016) there were approximately 280,000 heavy duty trucks ($\geq$ 12t) and approximately 240,000 heavy duty trailers registered. Reliability a key requirement and this is based on good engineering design practice.

The road conditions that freight vehicles must endure can often be extreme, and the battle with increased payloads, longer articulations and road vibrations is never ending. Creating long-lasting mechanical components and structures on freight vehicles is essential to keeping heavy vehicle fleet operations efficient and in business. However, dealing with heavy loads and roads vibrations is not a simple task. Good engineering design is needed to produce gradual changes in strength, avoid point loads and apply suitable factors of safety. Conservative designs that provide too much metal can sometimes also weaken the chassis!

Gradual changes in strength

Having a structure that is too rigid for an application will cause cracking at mounting locations or transition regions where there is an abrupt change of stiffness. Good engineering practice requires gradual changes in strength. Figure 1 shows an example of a poor sub-frame installation on a tip truck. There is a notable "zig-zag" transition directly after the hydraulic hoist cross member (Item 1). The sub-frame installation ends at the precise location where the start of a chassis transmission insert begins. This is highly undesirable because it creates a stress riser zone that may eventually crack.

Figure 1 Poor sub-frame installation.

Tip-trucks are particularly vulnerable to cracking due to point loads that occur at the pivots and at the lifting cross-member. Vehicle Standards Bulletin 6 (VSB 6) – *Section J: Body Mounting* takes this into account and recommends that sub-frame installations extend beyond the length of the body without any breaks or joins. Furthermore, the front end of the sub-frame requires a progressive load bearing transition to the chassis rails.

Chassis ladder torsional strength

The undulations in the road causes the chassis ladder of heavy vehicles to twist and bend. The constant twisting and bending will result in larger deflections at regions that are comparatively less stiff than others. Figure 2 below shows a typical chassis ladder with a strong sub-frame attached. The sub-frame ends abruptly well before the rear of the cabin region and almost in line with a chassis cross-member. There is sharp transition of strength between the chassis rail at the sub-frame and the cabin section of the chassis rail. A pure torsional strength analysis was conducted by fixing the front of the vehicle and twisting the rear cross-member clockwise.

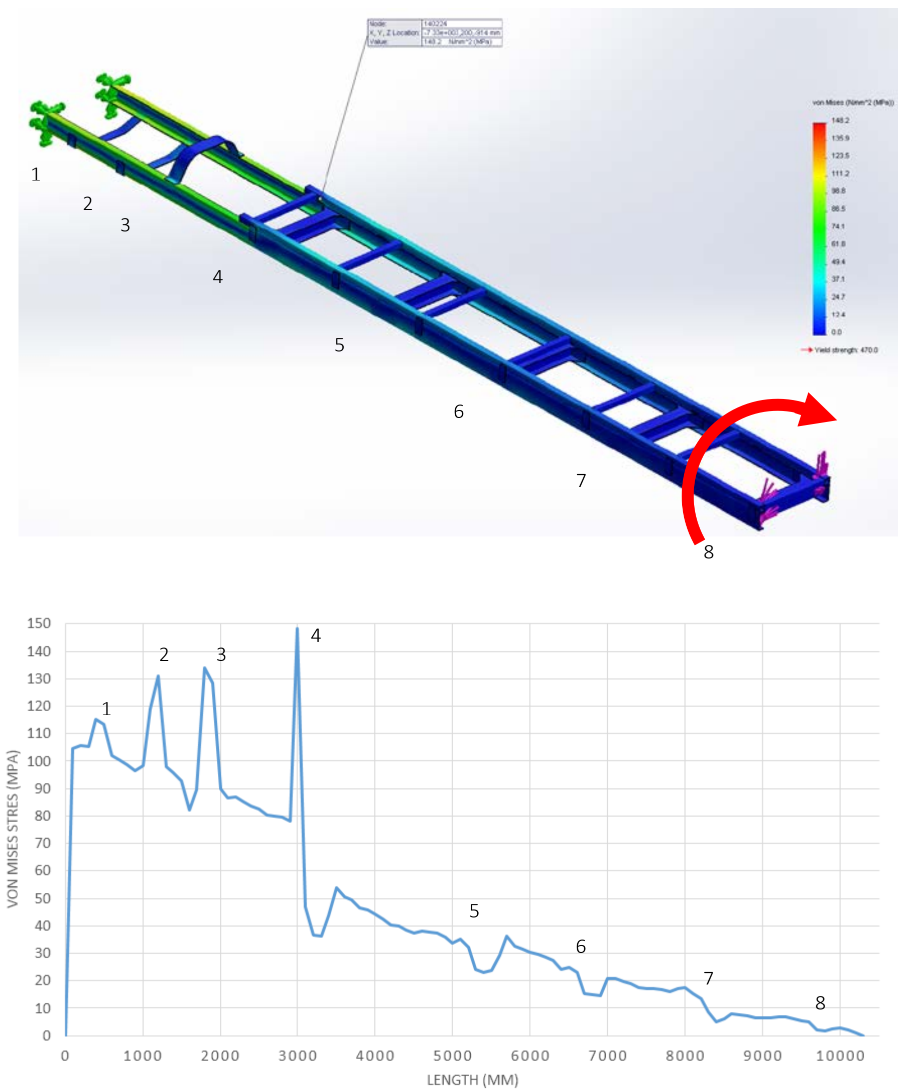

Figure 3 Torsional stress along chassis.

Figure 2 shows higher stress build up at the front of the chassis rails where there are fewer cross-members and no sub-frame attached. The torsional stresses experienced at approximately 100mm intervals along the length of the chassis are plotted in Figure 3. The graph shows the torsional stress along the chassis during twisting only. Areas of significantly higher stress are indicated by peaks and dips which correspond to transition regions between stiffer and more flexible structures. There are 8 such peaks and dips that are consistent with the cross members of the chassis ladder. The overall transition in strength between the chassis rail structure at the front of the truck compared to the rear, which is fitted with a sub-frame, is considerable. The chassis rail structure is therefore more susceptible to cracking at this location (peak and dip 4) throughout its service life. Gradual changes in stiffness reduce the chances of creating high stress riser locations (peaks and dips). This should be kept in mind not only by sub-frame designers but also for body installations, protective devices and other components. Making a sub-frame very strong in one place and not strong in another place eventually lead to failure.

Stress riser locations

Dealing with stress riser locations can be difficult. One way of dealing with them is by removing material from adjacent areas and allowing more flexibility in the structure. Can you really make something stronger by taking away material? The answer is yes! But only if it's done correctly. Baffle cracking has been a recent issue for one of Australia's large tanker fleet owners. Finite Element Analysis (FEA) investigations showed high stress locations of 273 MPa at the bottom welded sections of the rear baffles. The tank itself has a yield strength between 205 and 310 MPa.

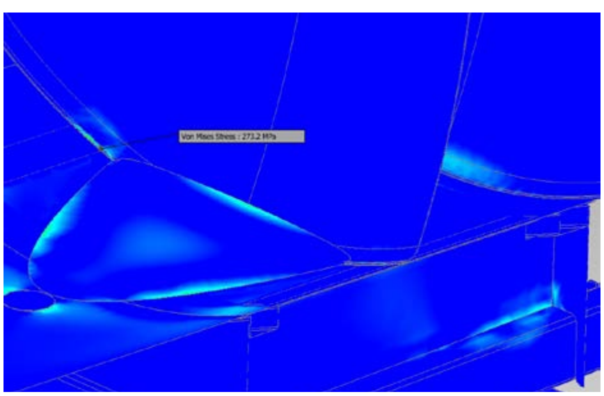

Figure 4 Stiff tanker design.

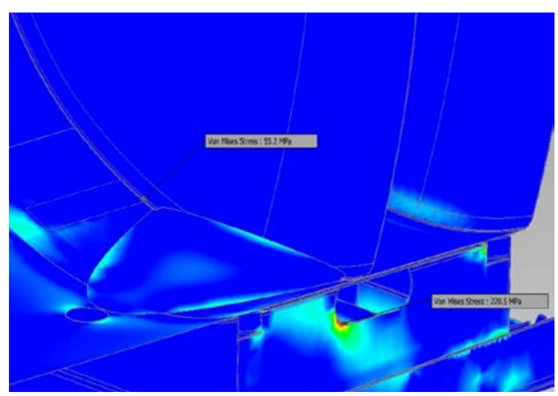

Figure 5 Flexible tanker

By cutting a slot out of an infill plate at the welded baffle location the structure gained additional flexibility. The stress at the welded baffles dropped to 55 MPa, well below yield. The stress at the infill plate cut out section increased to 220MPa. The infill plate is made from 350 grade mild steel. The maximum stress is approximately 60% of the yield strength of the material. This is acceptable considering the application and allows a suitable Factor of Safety (FoS).

Suitable Factor of Safety

The National Heavy Vehicle Modification Code of Practice (Vehicle Standards Bulletin 6 - VSB 6) recommends different FoS depending on the components and their application. The Code of Practice is only applicable where manufacturer guidelines have not been provided. VSB 6 Section H – Chassis Frame recommends that the minimum FoS for chassis rails of highway vehicles is 3.0. However, for vehicles working in more severe road conditions such as tip trucks and off-highway vehicles, the FoS required is 5.0. VSB 6 Section J – Body Mounting, states that a FoS of 3.0 for all body mounting components is required. Note that it is very rare for a full FEA chassis study to be conducted and inevitably engineering judgement is applied.

What is a suitable Factor of Safety for components not outlined by manufacturer's guidelines or a code of practice? For components or safety critical items that do not have any set requirement, sound engineering judgement is required. In addition it may be necessary to conduct a hazard and risk assessment that takes into account the application, exposure and consequences if the component were to fail. However, as a guide, the following extract from the *Fundamentals of Machine Component Design* by Juvinall and Marshek is a good place to start. The following dot points are some considerations that should be taken into account by designers in any field of practice.

1. $SF = 1.25$ to 1.5 for exceptionally reliable materials used under controllable conditions and subjected to loads and stresses that can be determined with certainty—used almost invariably where low weight is a particularly important consideration.
2. $SF = 1.5$ to 2 for well-known materials, under reasonably constant environmental conditions, subjected to loads and stresses that can be determined readily.
3. $SF = 2$ to 2.5 for average materials operated in ordinary environments and subjected to loads and stresses that can be determined.
4. $SF = 2.5$ to 3 for less tried materials or for brittle materials under average conditions of environment, load, and stress.
5. $SF = 3$ to 4 for untried materials used under average conditions of environment, load, and stress.
6. $SF = 3$ to 4 should also be used with better known materials that are to be used in uncertain environments or subjected to uncertain stresses.
7. Repeated loads: The factors established in items 1 to 6 are acceptable but must be applied to the *endurance limit* rather than to the yield strength of the material.
8. Impact forces: The factors given in items 3 to 6 are acceptable, but an *impact factor* should be included.
9. Brittle materials: Where the ultimate strength is used as the theoretical maximum, the factors presented in items 1 to 6 should be approximately doubled.
10. Where higher factors might appear desirable, a more thorough analysis of the problem should be undertaken before deciding on their use.

Figure 6 Factor of safety considerations (*Juvinall and Marshek 2011).*

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