Chassis fatigue and factors of safety

I recently considered the causes of metal fatigue in a chassis. Metal fatigue is the most common type of metal failure on trucks and trailers. The chassis components are subject to fluctuating loads arising from road vibrations and the movements of loads. Fatigue cracking of chassis rails and sub-frames are relatively common. I considered how the design, in this case of a tipping dog trailer, could have been changed to avoid fatigue cracking.

Metal fatigue begins by the formation of a small crack almost always on the external surface. Usually the crack was created during manufacture of the part, and it is often minute. The crack grows slowly into the material, approximately perpendicular to the tensile axis. As the crack grows the uncracked material must take more of the load force and eventually the remaining material fails due to brittle fracture.

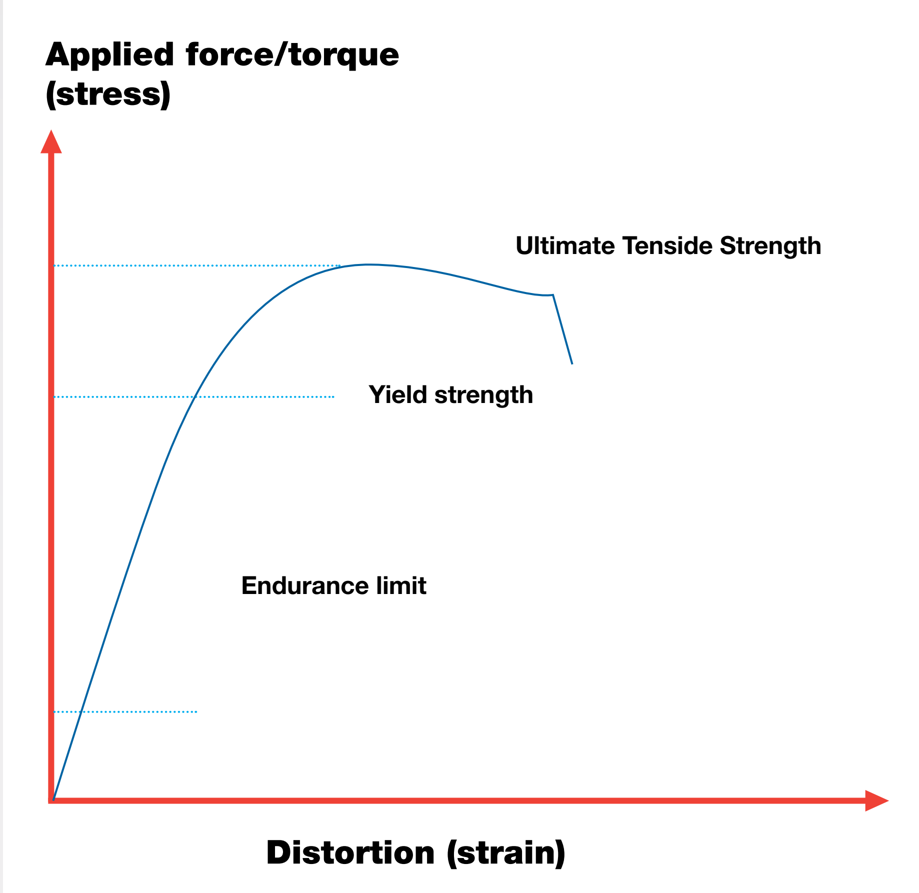
Every cycle of high stress causes the crack front to advance a small distance. The metal at the base of the crack experiences plastic deformation during compression which is not reciprocated when the force reverses, so the crack advances very slightly with every substantial force cycle.

The material deformation and breakage produces a small undulation or ripple at the base of the crack. The ripples are roughly circular, concentric arcs that are focused on the origin of the crack. Under practical conditions some of the ripples are bigger than others and they are obvious to the untrained eye. A collection of ripples is called a 'beach mark'. Eventually the uncracked remaining material will reach its tensile limit and a brittle fracture occurs. So, the beach marks give way to a jagged crystalline failure surface. This can be seen in the photo.

So how can fatigue in chassis rails or subframes be avoided? Here are eight design and repair tips:

1. Surfaces should be smooth and contoured without strain concentrators such as notches and sharp steps.
2. Avoid putting holes in highly stressed locations. In particular, avoid holes in the flanges of the rails.
3. Avoid putting holes or section changes where the rails or cross members experience significant flex or twisting. For example, when a rigid body is installed on a truck the two front mounts should be flexible.
4. Use medium grade steel (grade 350 or higher) rather than mild steel. This will help achieve an adequate Factor of Safety.
5. Use steel that has a surface hardness. Because cracks start on the surface, hardness here will hinder crack development. Nitriding or Carburising, for which the metal is exposed to a Nitrogen-rich or Carbon-rich environment at high temperature will produce a surface layer that is hardened.
6. Use gradual changes to the section properties. Sharp changes will cause stress risers and this will promote crack propagation at these locations.
7. Tensile stresses open cracks whilst compressive stresses close them. The most vulnerable regions are in tension.
8. The fatigue life of a welded part is independent of the material properties. The quality of the weld is the important factor. Undercutting and discontinuities in the weld are risk factors. Preheating and tempering of the weld can be important.

The question of what is an adequate Factor of Safety (FoS) in mechanical design of a truck is a key consideration for the designer. The diagram shows the distinction between UTS, Yield Strength and Endurance Limit for a metal part. The UTS and Yield values are determined by the material properties whereas the Endurance Limit also depends upon design factors. Yield Strength is the force above which the new part does not return to the original shape. UTS is the point at which the new part breaks. The Endurance Limit is the force below which the part is unlikely to break after a long time in service.



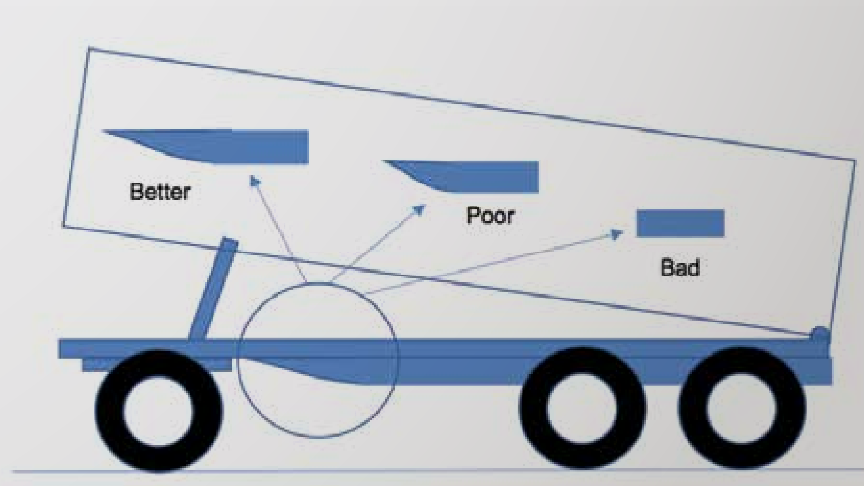
Only for simple part shapes, such as towing kingpins, can a guideline Factor of Safety be applied that is relevant to endurance. Australian Standard AS4968:2011 Part 3 requires that the maximum calculated stress be no more than 40 per cent of the UTS when subjected to a force corresponding to 63 per cent of the D-value rating. This determines the Factor of Safety for a particular part with specified dimensions and material. For most structural parts on a truck an adequate FoS is needed and the design tips should be followed.

Vehicle Standards Bulletin No 6 (VSB 6) specifies that a Design Factor of Safety of 3 be applied to body mounting components (Code J, p4). For tippers and off-highway vehicles, VSB 6 specifies a minimum Factor of Safety of 5 (Code H, p11). These Factors are intended to include fatigue considerations. Note that VSB6 applies the above Factors of Safety with respect to the yield strength of the material (Code H, p11).

As a guide the Factor of Safety for truck and trailer parts should exceed 3. That is the maximum static working force should be less than Yield Strength / 3. Higher stresses may occur on the road and they are assumed to be well within the Factor of Safety. There are however, no guarantees that this rule will avoid all fatigue failures, because design is also an important factor in fatigue cracking.

The failure shown in the photo of the truck chassis rail illustrates the risk of fatigue failure that arises from placing holes in highly stressed regions; in this case the rail flange at a front spring hanger. The crack started at the bottom flange hole and has propagated upwards across the web. Some trucks are designed with rivets in the bottom flange of the chassis rails. This significantly weakens the rails and makes them vulnerable to fatigue cracking if they carry heavy loads. Another risk factor is welding the bottom flange to form a trailer chassis rail. The fatigue strength is dependent on the quality of the weld and absence of weld cracks, irrespective of the Factor of Safety that exists.

The diagram of the dog trailer shows that tapering of the chassis rails that is used to transition between the turntable region and the rear-axle group region is very important. By using a gradual taper the load is spread and this reduces the likelihood that fatigue cracks will develop.



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