PRESENTATION ON FAILURE OF BELLY DUMP TRAILERS

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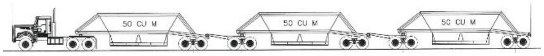
ABSTRACT:

There are some forensic investigations which cross the boundaries between Mechanical and Structural Engineering. The investigation of the failures within Belly Dump Assembly's used to transport 150cu.m of product in the assembly shown in the diagram presented was investigated. The loads and general proportions of the assembly are shown pictorially in the diagram presented on the screen.



KEYWORDS: Coupler Structures, Principal Stresses, Von Mises Stress, Finite Element Analysis, Dynamic Stresses.

1. INTRODUCTION

The load of the product in each of the Dump Trucks is of the order of 70,000kg with an all-up mass of 211,000kg. The Dump Trucks themselves weight 16,000kg each and the four wheeled assembly's called Dollies on which they seat weight 3,500kg each. It all looks very neat on the diagram and is probably easier to understand. An actual photograph of the three trailers and Dollies next to a loader are shown on the screen.

Photograph 1: *2 Trailers & Dollies Next to Loader*

The terrain upon which this equipment operate is biscuit flat and the only sloped area is where the train discharges.

Following multiple failures of elements of the Belly Dump Trailers and Dollies a series of investigations occurred. Ours was the last investigation of which I am aware. Previous investigations included inspection of the reported failures and metallurgical testing and analysis. The failures which were occurring, in every case, were in the coupler structure between wet haul trailers or of the hitch turret. An example failure was viewed by me when I inspected the facility and is shown on the photograph now on the screen.

Photograph 2: *coupler structure between wet haul trailers or of the hitch turret*

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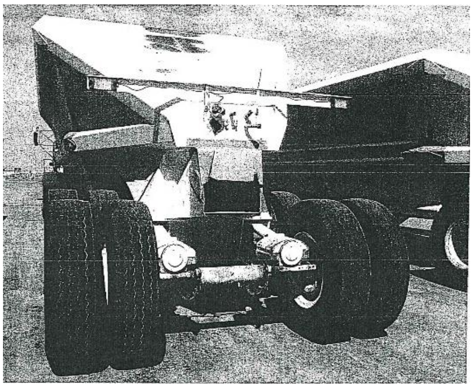
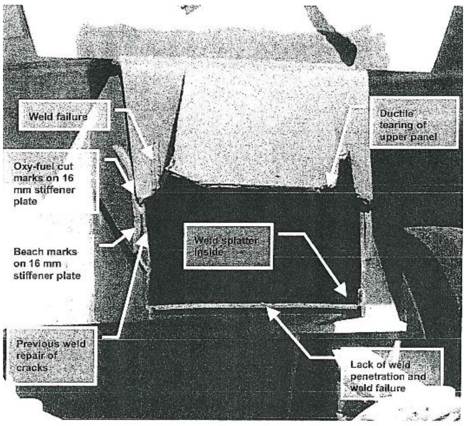


Photograph 3: *A previous failure in the linking structure*



Photograph 4*: A previous failure in the linking structure*

The interesting thing about the failures viewed is that they are through the metal and not the welds. The actual failure viewed by me was of the draw bar at the rear of the leading trailer on a Belly Dump Truck. The picture on the screen shows the failed (snapped) linking arrangement between the two trailers with a Dolly with turret over plus cantilevering arm which connected to the leading trailer by an articulated ball. A closer view of the failure is shown on the screen.

2. APPLICABLE FORCES

As Harry Messel was want to say, *"why is it so"*. The methodology of the investigation comprised an analysis of the coupling force between the trailers which was performed in accordance with AS/NZS 4968.1 2003 – Heavy Road Vehicles Mechanical Coupling Between Articulated Vehicle Combinations, Part 1: Design Criteria and Selection Requirements for Fifth Wheel, Kingpin and Associated Equipment and Australian Design Rule 62/00 Mechanical Connections Between Vehicles – Vehicle Standards (Australian Design Rule 62/00 – Mechanical Connections Between Vehicles). Having applied this we concluded the maximum horizontal design load at the ball joint connection was 320kN.

The 320kN load is transferred through the body of the trailer to the back wheels applying axial stresses to the trailers body and represents one source of the forces acting on the trailer structure.

In addition to this force, the trailer body is subject to the forces generated by the payload into the body of the trailer and the self mass of the container. The trailer is assessed as a two side by side Mass Flow. Squad Containers of geometry Type C2 as per the classification stated in AS 3774-1996 "Loads on Bulk Solid Containers".

3. RESULTING STRESSES

To analyse the stresses in the trailer body, a three dimensional analysis model was established based on the geometry and metal thickness documented in the shop drawings. The model for the trailer was developed using SAP2000 Static and Dynamic Finite Element Analysis. This structural analysis program has been intensively verified for its accuracy and was used as the analysis tool for a large number of iconic structures all over the world. The mathematical simulation of the trailer body is illustrated graphically in the figure on the screen.

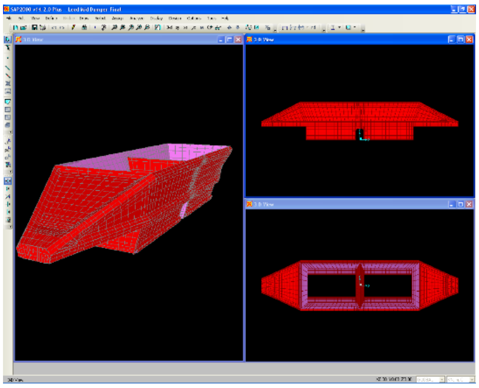


Figure 1: *Illustration of the mathematical simulation of the trailer body*

The analytical model did not include the bottom gates of the trailer but instead the weight of the gates and the portion of the product load that transfer onto the gates was introduced as joint loads at the hinging points at the gates to simulate the action of the gates.

The modelling was aimed to evaluate the working stresses in the body of the trailer with special focus on the welded connections of the arms at their interface with the containers and at the areas of abrupt change in the structure.

In an elastic body that is subject to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed. That is, at any point within the body there are stresses acting in different directions, and the direction and magnitude of stresses changes from point to point.

Using Finite Element Analysis "Principal Stresses" can be calculated at any point, acting in the x, y and z directions which are principal axes. Even though none of the principal stresses exceed the yield stress of the material, it is possible for yielding to result from the combination of stresses.

4. VON MISES STRESS

To combine the principal stresses into an equivalent stress, which is then compared to the yield stress of the material, the "Von Mises" criterion is normally used for elastic materials. The Von Mises criterion states that "failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial tension". Mathematically, in the cases of plane stress, like the case in hand, the Von Mises criterion is represented in equation (1) as:

$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 \le \sigma_y^2 \qquad (1)$$

The equivalent stress is often call the "Von Mises Stress" as a shorthand description. It is not really a stress, but a number that is used as an index. If the "Von Mises Stress" exceeds the yield stress, then the material is considered to be at the yield condition of failure mode.

Analysis revealed stress concentration at localised areas in the trailer body. The results of the principal stresses are shown in figures 2 & 3 respectively.

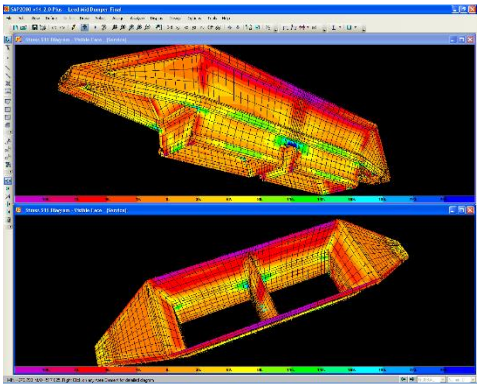


Figure 2: *Graphical representation of the Service Stress distribution in principal direction 1 (S11) in MPa*

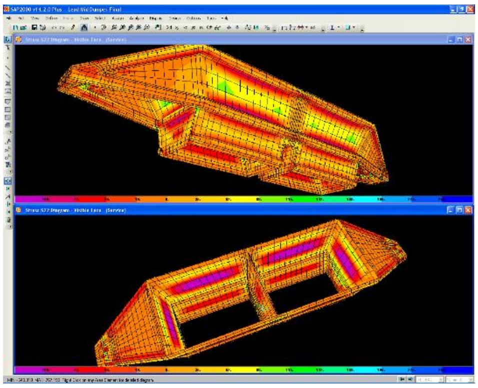


Figure 3: *Graphical representation of the Service Stress distribution in principal direction 2 (S22) in MPa*

Applying a 20% load factor to the self weight of the trailer and 50% load factor to the loaded material, the ultimate stresses were found to far exceed the 300MPa yield stress of the 5CR12 Ti Plates of which the trailer body was constructed. This is illustrated in the Von Mises Stress Distribution shown in figure 4.

Maximum Von Mesis Stress of 320MPa at arm connection and 460MPa at access hatch

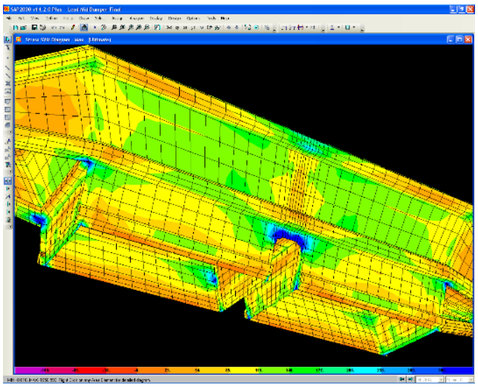


Figure 4: *Graphical representation of the Von Mesis Stresses at ultimate load (1.2 xSelf Weight + 1.5xSalt Load + 1.5xDrag Force)*

The high stress regions identify the areas where the stresses exceed the yield stress, which indicates areas of under-design.

5. WELDED CONNECTIONS

For the welded body of the trailer, due to the repetitive and fluctuating nature of the load, the allowable stresses need to be limited to prevent fatigue failure of the welded connections. One weld line of prime importance is the weld line at the container / arms connection. Such welding is categorised by AS 4100-1998 as falling within detail category 56, for which the limiting fatigue stress for 1,000,000 cycles is 90MPa. The analysis revealed a stress concentration of 240MPa under service load condition without the application of any dynamic load factors, as shown in figure 5.

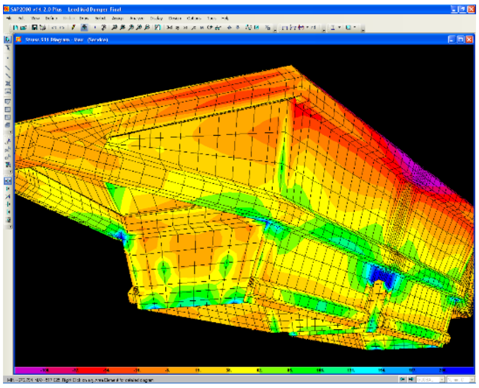


Figure 5: *Stresses concentration at the arm connection and the access hatch area*

I note that AS 4100-1996 gives the minimum requirements for the design, fabrication, erection and modification of steelwork in structures in accordance with the limit state design method. In my opinion, and that of my office, more stringent stress limitation should be applied on vehicles, trailers and the like due to the nature of the load applied to them.

The Finite Element Analysis performed identified a number of areas of stress concentration which exceeded the limiting fatigue stresses recommended by AS 4100-1996.

6. CONCLUSIONS

The review of the location of the reported areas of repetitive cracking identified by others revealed a high degree of correlation with high stress locations identified by analysis, which supports the conclusion that repeated failures of the trailer body were caused by under-design.

It was concluded that the multiple failures reported occurred at locations of high local stress, where, under ordinary in-service duty, stress levels greatly exceeded acceptable limits. This is a design generated problem. Manufacturing inadequacy was not found to be a cause of failure.

Such a clear-cut finding, ladies and gentlemen, is not always available. What this indicates to me is that, at the boundary, mechanical design needs to be augmented heavily by structural input from well-qualified Senior Structural Engineers. The penalty of failure to recognise this can be catastrophic.

ACKNOWLEDGEMENT

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Mr Bassam Matty BSc MSc FIEAust FAIM.
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[3] Principal Von-Mises Stress Equations and Calculator (2000-2018) Engineers Edge, LLC 510 N.Crosslane Road, Monroe, GA 30656, USA.