Machine Stability Calculations

Gemma Broccardo[1]
[1]Aspec Engineering Pty Ltd, Brisbane, Australia; gemma.broccardo@aspec.com.au
12 February 2025

Abstract

Determining the stability of a machine is a critical design consideration. Material handling machines often work in close proximity to each other as well as other infrastructure, especially shiploaders which work within the confines of a berth layout and within the space allowance of docked ships. Additionally, ensuring machine stability also ensures the safety of crew and personnel in the vicinity of these machines. Therefore, it is critical to understand how the process of calculating machine stability can be dependent on the machine type.

1. Introduction

Machine stability is dependent on two factors: the stabilising moment and the destabilising – overturning – moment, which together give the stability ratio. Depending on the type of machine these moments are influenced by specific factors and loads and other conditions. Stability moments can be calculated if the following is known:

- Machine arrangement and dimensions.
- Structure and component mass and location.
- AS4321.1-2017 (Standards Australia) loads.

2. Determining Machine Stability

There are eight distinct requirements to determining the stability of a machine.

1. Portal Geometry
2. Luffing Geometry (N/A for non-luffing machines)
3. As-Built Dead Load List
4. Machine weighing report and luff cylinder forces for calibration of dead load distribution
5. Permanent Dead Load Changes
6. Machine Operating Parameters
7. AS4324.1-2017 (Standards Australia) Loads Document
8. AS4324.1-2017 (Standards Australia) Load Combinations

With this information, the stabilising and destabilising moments and stability ratio for each load case, compared to each potential tipping axis can be calculated and the minimum ratio for each load case across all tipping axes is determined.

If the stability ratio is less than 1.0 then there is a risk of the machine tipping. If the stability ratio is between 1.0 and the minimum requirements of AS4324.1-2017 (Standards Australia), stability is not satisfactory and the machine may tip under operating conditions. If the stability factor is greater than the minimum requirements of AS4324.1-2017 (Standards Australia) then the machine is considered to have adequate working stability.

3. Three vs Four Point Machines

Rail mounted machines are typically either a four-point (Figure 1) or three-point machine (Figure 2). This means that the load of the machine is either distributed between three or four sets of wheels. A three-point machine will generally have a greater wheel load at each point than that of a similarly sized four-point machine. Some three-point machines can resemble a four-point machine but are still treated as a three-point machine as two of the wheel groups are connected to one corner of the triangle via a pivoting cross head. It is reasonably common that stackers and reclaimers have four-wheel groups and a crosshead, while shiploaders are often true four-point machines.

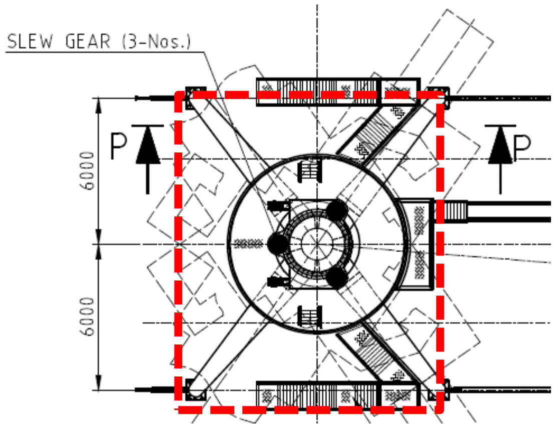

Figure 1 - Typical four-point stacker machine arrangement (plan view).

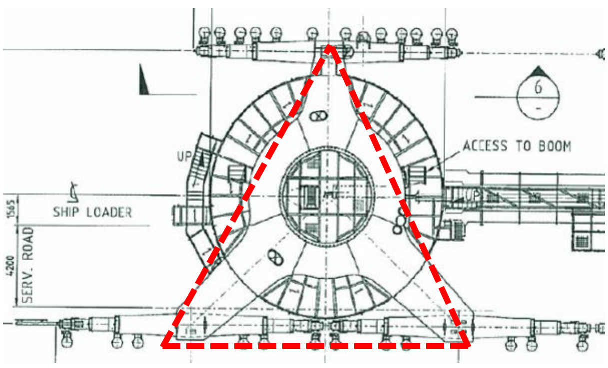

Figure 2 - Typical three-point shiploader machine arrangement (plan view).

4. Tipping axes

The type of wheel arrangement – either three-point or four-point – will define a machine's tipping axes and this must be considered in the design process. It should be noted that number of "points" does not correspond to the number of wheels that a machine has. For each machine type there are numerous possible configurations of wheel and drive arrangements but only the centre-points of each group are considered.

The number of tipping axes on a machine corresponds to its wheel arrangement, therefore for a three-point machine there will be three corresponding tipping axes, and for a four-point machine there will be four corresponding tipping axes.

Both configurations have their advantages and disadvantages for a given design implementation in terms of tipping axis. Three-point machines typically have identical or at least similar minimum stabilising moments about each tipping axis meanwhile four-point machines can have varying stabilising moments between each tipping axis, depending on the machines slew position.

The major drawback for implementing a four-point machine is the potential for a changing stability envelope as the requirements for the machine change and grow during its life cycle. Three-point machines naturally redistribute evenly a certain amount of weight change and additional loads placed on the machine as its duties change. However, this is untrue for four-point machines.

5. Stabilising and Destabilising Loads

According to AS4324.1-2017 (Standards Australia), the only stabilising moment allowed is dead load as dead load is the only "permanent" load acting on the machine. Other loads are considered to be "non-permanent" and may be stabilising or destabilising depending on their position on the machine. A stabilising load is a load that acts within the area defined by the tipping axes. A destabilising load is a load that falls out of the defined tipping axis area. Any "non-permanent" load that is stabilising must be excluded from the calculations or have its direction of action changed to make it destabilising. Dynamics and wind loads are examples of non-permanent loads that can be stabilising or destabilising depending on their direction. Distributed loads like live load can have stabilising components and destabilising components at the same time. Such loads need to have their destabilising part removed from calculations as well. As per AS4324.1-2017 (Standards Australia) all destabilising loads are checked for assuming worst case direction.

6. The Next Step

So, what is the point? Where do we go from here? Contrary to belief most engineering calculations do get applied.

In the case of stability calculations these results are fed into further analysis required for machine design. Key information is gathered including the minimum stability ratio, the maximum wheel load and the minimum wheel load for numerous AS4324.1-2017 (Standards Australia) load combinations. Commonly, these calculations form the basis for FEA model calibration; centre of gravity calculations for maintenance activities (Figures 3 & 4); calculation of wheel loads and slew bearing moments; fatigue calculations and further machine analysis.

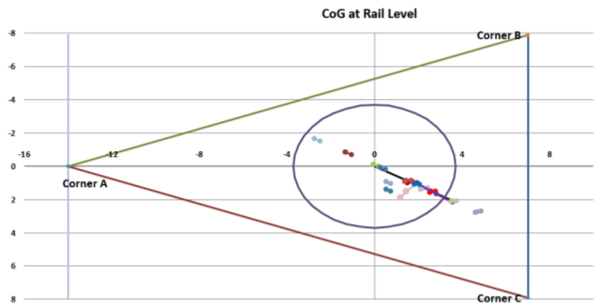

Figure 3 - Centre of gravity distribution – 3 point machine (plan view).

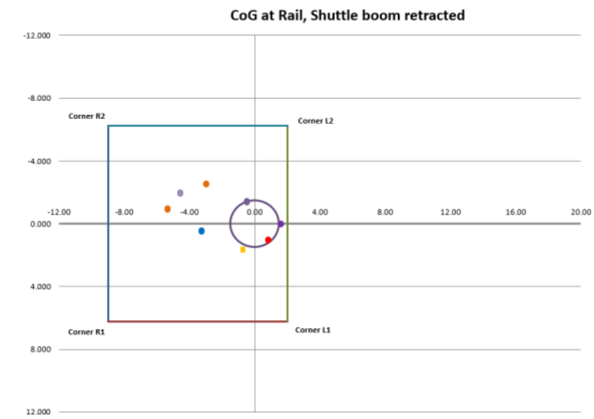

Figure 4 - Centre of gravity distribution – 4 point machine (plan view).

7. Case Study: Example Settlement of Support and Stability Re-Distribution

So why does all this matter and what does it mean in the real world? An example is where settlement of a support caused an uplift of one leg of a four-point machine (Figure 5). Effectively the uplift of this leg turned this four-point supported machine into a three-point supported machine. This increased the wheel loads at two of the three remaining legs as the mass of the machine re-distributed. This shift in mass increased stresses on the loaded legs of the machine (Figure 6).

Figure 5 - Machine leg uplift at wheel level.

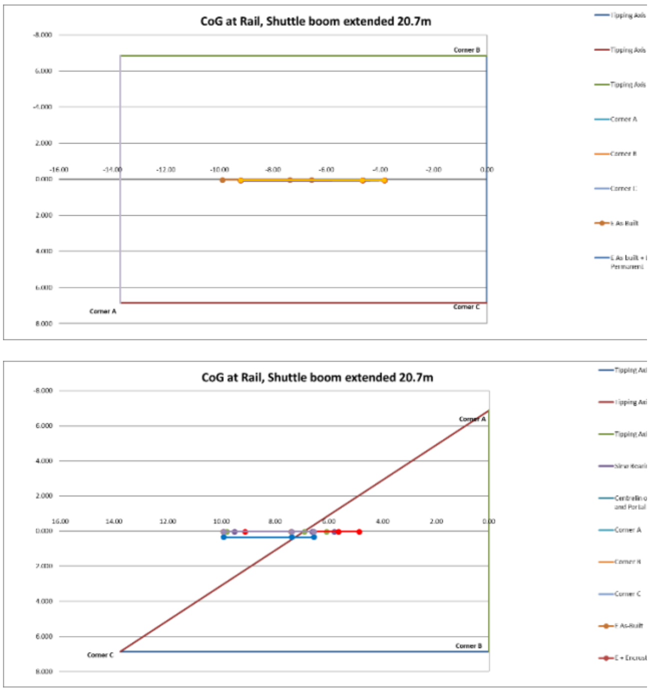

Figure 6 - Tipping axes before (top) and after (below) uplift.

With the help of calibrated machine stability calculations, an accurate dead weight distribution could be entered into FEA models. It was found that the machine could remain stable on three supports in the short term while settlement of the support was addressed.

8. Conclusion

To conclude, machine stability calculations are critical to a fundamental understanding of the condition of a machine. The procedural steps to obtaining the machine stability have been explored and the common loads associated with different machine types have been identified. From these inputs a final machine stability result is achieved, and the knowledge gained from this process can then be used in tandem with other data, as exemplified in the case study, to produce a strong basis on which to provide reliable engineering advice.

9. References

Standards Australia. (n.d.). 4324.1-2017 Mobile Equipment for Continuous Handling of Bulk Materials Part 1: General Requirements for the Design of Steel Structures.

For any enquires regarding this document, please email: admin@aspec.com.au.