# Breaking Point: Understanding the Dynamics of Parted Mooring Lines and Protection Barriers

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**Summary**
The parting of mooring lines presents a serious threat to personnel on wharfs and can often be fatal. Very little literature exists on how to quantify the magnitude of energy imparted on impact in these events; even less so in international standards. WGA have undertaken a number of projects recently in which the kinematics of parted lines were accurately predicted using novel theoretical methods adapted and developed by WGA. Similarly, the effects of these events were modelled in transient time domain analyses to understand the impact on mooring line protection barriers. The results indicated that traditional force-deflection methods for quantifying the energy absorption of these barriers were inadequate and failed to capture the local effects and transfer of momentum that occurs over extremely short timeframes in the structure. This abstract and presentation should be considered in conjunction with the sister abstract submitted by WGA on the quantification of risk around these events.

*Keywords: Mooring Line Safety, Structural Analysis, Engineering Dynamics*

## Introduction

Parting mooring line events are among the most dangerous occurrences on wharves around the world. Unfortunately, they are also extremely common. Approximately one in seven parted mooring line events that include line-human interactions results in a fatality, with approximately one fatality every five years in Australia [1].

To further increase the risk, very little literature exists that adequately describes methods for quantifying the energy in a parted line, the energy imparted on a structure, the resultant force in that structure, or the probability of specific design events happening.

To the former, namely the kinematics of parted lines and structural interactions, WGA have undertaken recent works in which new and novel methods for the analysis of parted lines have been shown to accurately match observed real-world testing.

To the latter, probability and risk of design events, please refer to the sister abstract submitted by Nicholas Deussen of WGA in which the probabilistic methods presented within the National Construction Code (NCC) Structural Reliability Handbook and ISO2394: General Principles on Reliability for Structures are used to quantify design percentile events for parted mooring lines.

## Foreword on Analysis

Due to limitations of an extended abstract in lieu of a complete paper, the methodology presented herein is simplified and summative in nature, providing the reader with the key points to understand the kinematics of a parted mooring line at a high level.

## Design Energy in a Parted Mooring Line

Due to the conservation of energy, it is required that the design engineer must first determine the potential energy stored within a mooring line should they wish to ultimately quantify the energy imparted on a structure. Whilst mooring lines do not perfectly obey Hooke's Law (as they have non-linear spring behaviour) the potential energy stored within a line can generally be described a function of the spring stiffness and imposed elongation in the line under tension, or as a function of the strain and length of the line under tension.

$$E_P = \frac{1}{2}k \times \Delta^2 = \frac{1}{2} \times P_{\%MBL} \times \varepsilon_{\%MBL} \times L_O \tag{1}$$

Where $E_P$ is the potential energy in the line, $P_{\%MBL}$ is the imposed tension for some percentage of the minimum breaking load, and $\varepsilon_{\%MBL}$ is the strain on the initial line length under zero tension ($L_O$).

As a line breaks, force transfers through the line based on the stiffness and density of that line; effectively, at the speed of sound in that material.

Because this transfer of force takes time there is a non-uniform acceleration on the mass along the length of the line, with the end closest to the breaking point being accelerated for the longest amount of time. This results in an uneven distribution of kinetic energy within the free body, with the highest velocities occurring at the tip of the line. Due to the conservation of linear and angular momenta, depending on the geometry of the line in its initial state prior to parting, it is possible for the free tip of the line to draw the line back into tension due to its higher velocity. This results in a transfer of momentum up the line, akin to the cracking of a whip. In this state of motion, the energy concentrations at the tip of the parted line can approach significant percentages of the total potential energy of the line. The velocity of the tip can approach Mach 1, and even exceed it for long, high energy lines.

## Design Force on Mooring Barrier Structure

Traditional engineering approaches would suggest that the force imparted on a structure is proportionate to twice the energy acting upon it divided by the deflection it undergoes – for linear elastic behaviour.

In the case of mooring line failures, velocities of the free tip of the line can be so extreme that failure of the structure occurs locally before the force is able to transmit through the structure and to the supports. Because of this, the linear elastic deflected shape of the structure is irrelevant to the absorption of energy.

WGA have undertaken time domain FEA analyses of lumped masses with design velocities approximating the behaviour of real parted lines to understand the performance of existing barriers for design events.

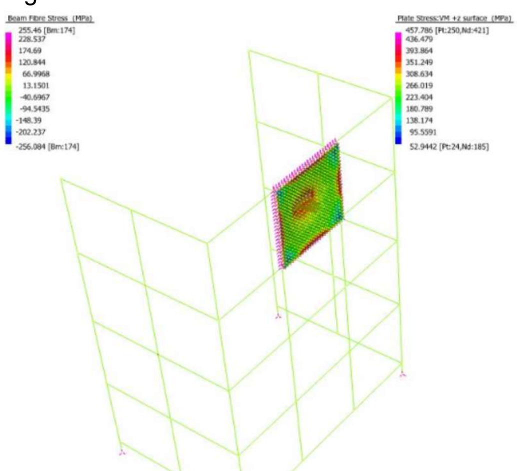


Figure 1 FEA Analysis of a mooring barrier structure undertaken by WGA demonstrating local failure of the grating before mobilisation of the structure.

It was observed from the modelling that structural failure typically occurred in the single digits or tens of milliseconds; well ahead of complete mobilisation of the structure. This ultimately severely limited the efficacy of the structure in arresting a parted line.

## Comparison to Real World Testing

As part of WGA's recent works, real world full scale testing of a parted line was undertaken by our clients to better understand the velocities, energy, and effects on structures that needed to be considered for design.

The WGA theoretical model accurately predicted an initial period of acceleration of the line, followed by a relatively constant velocity in motion, followed by a parabolic increase in tip velocity as the line whipped out in an arc and momentum transferred through to the tip. This can be seen below in Figure 2 and Figure 3.

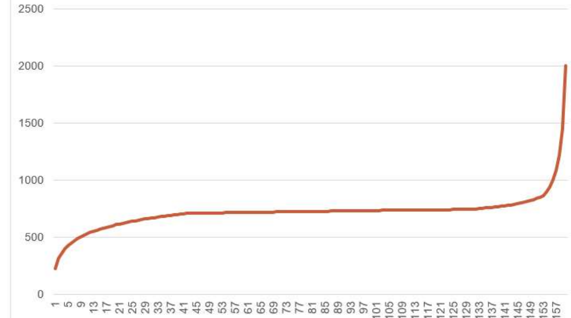


Figure 2 Velocity curve for the tip of a parted line in a vacuum (x axis = milliseconds, y axis = meters/second)


Figure 3 Real world velocity curve for tested line. Note that the decrease in velocity from the peak is due to impact with a structure. Source [2].

It was observed during the testing that failure of the structure occurred locally with the immediate impact location, undergoing yielding and shearing hundreds of milliseconds before the force reached the supports. At this time, the line had already passed through the structure and would have resulted in a casualty to the personnel behind it. This was the predicted result of the WGA FEA model and agreed closely with the expected mode of failure.

## Conclusions

The analysis of parted lines must consider the non-uniform distribution of energy within the line and the conservation of linear and angular momentum. The conservation of momentum is equally important for understanding the response of barrier structures for which traditional force deflection methods do not adequately describe.

## References

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[2] Smith, A.S, BHP Mitsubishi Alliance Snapback Barrier System – Validation Testing Mobile And Fixed Barrier Fences, 2021.