

BARGE STABILITY ***GUIDELINES***



INTRODUCTION

The purpose of these Guidelines is to provide insight into the basic stability concepts relevant to loading and to loaded pontoon barges.

Pontoon barges are used for a wide variety of cargoes from bulk loads such as coal, rock, and logs – with low to medium centres of gravity – through to vehicles, and unique ‘one-off’ loads such as industrial equipment and storage tanks, which can have very high centres of gravity, and windage areas. Pontoon barges are also used as work platforms for many types of equipment including cranes and pile drivers.

Stability considerations are critical when conducting transportation and other marine operations safely.

The guidance that follows only deals with stability. It is assumed that other aspects of best marine practice – such as having sufficient handling power (bollard pull), and manoeuvring capability, watertightness arrangements (including securing of hatches etc), and ensuring adequacy of tow rigging, emergency, and safety gear – have also all been addressed.

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10 BASIC STABILITY RULES

FOR SAFE PONTOON BARGE OPERATIONS

Understanding and managing the stability of your barge is critical to the safety of you and your crew, and to the safe delivery of your cargo.

The following basic rules offer step by step guidance aimed at ensuring safety and success. In case of any doubt appropriate advice must be obtained prior to agreeing to undertake a marine operation. Differences in cargoes, environment, routing, equipment and crewing make each situation unique.

Proper planning is common sense – safety is no accident.

- 1 Know the lightship *displacement* of the barge before loading.
 - 2 Know the lightship *centre of gravity* (KG) for the barge.
 - 3 Know the weight and centre of gravity of the cargo.
 - 4 Be aware of the *block coefficient* of the barge.
 - 5 Be aware of *initial metacentric height* (GM) and know how to calculate it for the loaded barge using the *rectangular block formula*.
 - 6 Know how to calculate the *combined KG* for the barge loaded with its cargo.
 - 7 Be aware of the *limiting KG* curve, and have one available for guidance in loading your barge.
 - 8 Talk to a Maritime NZ recognised Ship Surveyor about conducting an *inclining experiment* and make contact with a Maritime NZ recognised Naval Architect to obtain a *limiting KG* curve for your barge.
 - 9 Always check the loading and discharge conditions as well as the loaded cargo condition for the barge.
 - 10 Take special care that cargo is properly secured, and that *free surface effects* are minimised, when using cranes or other equipment that may affect the stability of the barge.
- Consult a Maritime NZ recognised Ship Surveyor, or Naval Architect in any cases of doubt.

STABLE / UNSTABLE VESSEL

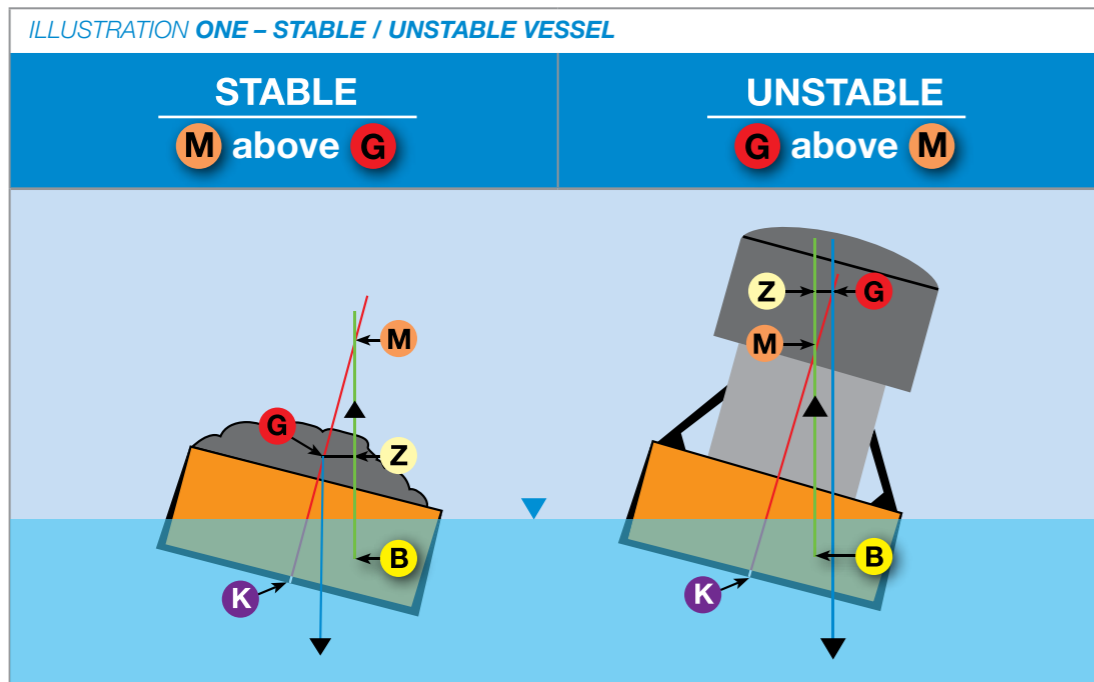


ILLUSTRATION ONE GLOSSARY

K	Keel
G	Centre of gravity
B	Centre of buoyancy (centre of the underwater displaced volume)
M	Metacentre
GM	Metacentric height
GZ	Righting or Overturning lever

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Illustration Definitions

- Centre of gravity (G)**
 is an imaginary point in the exact middle of a weight where the entire weight may be considered to act. (The force of) weight always acts vertically downwards.
- Centre of buoyancy (B)**
 is an imaginary point in the exact middle of the volume of *displaced* water where the entire buoyancy may be considered to act. (The force of) buoyancy always acts vertically upwards.
- Metacentre (M)**
 is a point in space where the vertical line upwards through the centre of buoyancy (B) of the *'inclined'* vessel cuts through the vertical line upwards through the centre of buoyancy (B) of the *'upright'* vessel.
- Metacentric height (GM)**
 is the vertical distance between the Centre of Gravity (G) and the Metacentre (M). If M is above G the vessel will want to stay upright and if G is above M the vessel will want to capsize. i.e. GM positive is Stable, GM negative is Unstable.
- Righting lever (+GZ) or Overturning lever (-GZ)**
 is the (horizontal) distance between the two (vertical) 'lines of action' of the buoyancy force (upwards), and the gravity force (downwards). The size of GZ is the measure of how stable or unstable the vessel is at any particular angle of heel. For small angles of heel (less than 15°), the 'righting' or 'overturning lever' $GZ = GM \times \sin \theta$ (where θ is the angle of heel, in degrees).

STABILITY

Initial Stability

To be adequately stable, the metacentric height (**GM**) of the loaded vessel, floating upright in still water, is required to be above a minimum value.

$GM_{min} = 0.35$ metres is a recommended minimum guidance value.¹

Metacentric height can be calculated using the formula:

$$GM = KB + BM - KG$$

(where the distances between **K**, **B**, **G**, and **M** are all in metres, **KB** is the vertical distance from the keel to the centre of buoyancy, **BM** is the vertical distance from the centre of buoyancy to the metacentre, and **KG** is the vertical distance from the keel to the centre of gravity).

The vertical distance between the centre of buoyancy (**B**) and the metacentre (**M**), that is $BM = I / V$ (where **I** is the *inertia of the water plane area*^{*}, and **V** is the volume of displacement.)

For a rectangular water plane area, such as that displaced by a pontoon barge, the 'roll inertia' is $I = (l \times b^3) / 12$, and (for a box shaped barge) the 'displaced volume' is $V = (l \times b \times t)$ (where **l** is the length, **b** is the beam, **t** is the draught).

EXAMPLE ONE - HOW TO CALCULATE BM IN PRACTICE

A box shaped barge 16 metres long, and 6 metres wide floats at a draft of 0.5 metres.

Find her BM.

$BM = I / V$	
$I = (l \times b^3) / 12:$	$(16 \times 6^3) / 12 = 288$
$V = l \times b \times t:$	$16 \times 6 \times 0.5 = 48$
$BM = 288 / 48 = 6$ metres	

^{*} *Inertia of the water plane area* is the measure of the resistance offered by the water to movement in one of the six possible directions (roll, pitch, yaw, sway, surge, or heave). The most significant direction – the only movement generally considered in a standard stability analysis – is that of roll (about the longitudinal axis). For roll, *the beam of the barge is the main contributor to roll inertia or roll resistance*.

section continued ▶▶

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¹ The value $GM_{min} = 0.35$ metres is from Maritime Rule 40C Appendix 1; 2 (f) (v).

ILLUSTRATION TWO – DETERMINING GM

$$GM = KB + BM - KG = \frac{t}{2} + \frac{b^2}{12t} - h$$

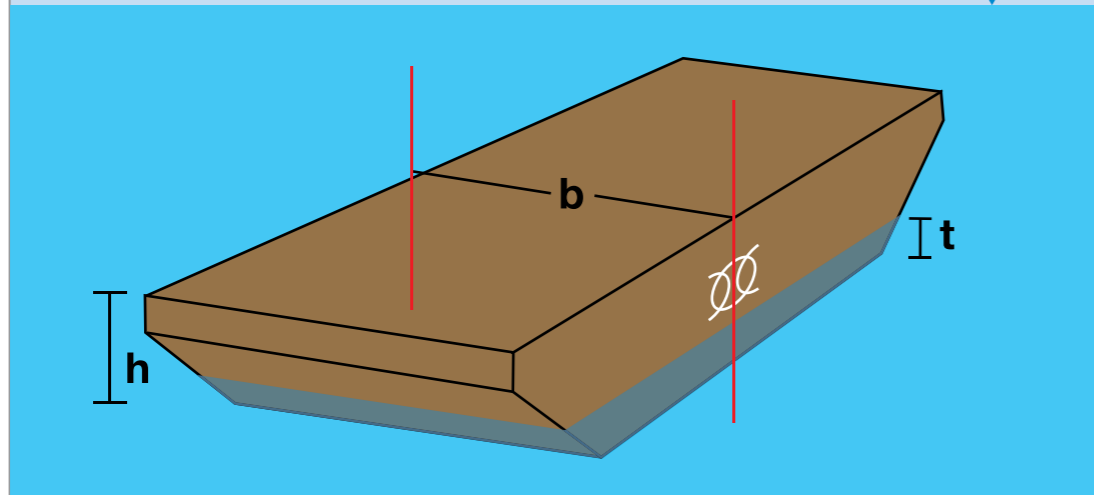


ILLUSTRATION TWO GLOSSARY

t	Draught
g	Length
b	Beam
h	Height

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For a pontoon shaped barge an approximation for the metacentric height (**GM**) can be obtained from the *rectangular block formula* which says:

$$GM = (t/2) + (b^2/12t) - h$$

(where **t** is the draught, **b** is the beam, and **h** is the height of the barge, as shown in illustration two).

This formula assumes the barge is a rectangular block with the lightship centre of gravity at *deck level*. Careful examination of this formula shows the stabilising effect of a *beamy* barge, referred to above, when considering inertia.

The initial metacentric height (**GM**) obtained using the *rectangular block formula* is a fair approximation for a vessel with a *block coefficient* of about 0.9 and above. The *block coefficient* is a measure of how close, a particular vessel is to a rectangular block of:– **length x beam x height**.

In order to more exactly determine the position of the centre of gravity (**G**) and the metacentric height (**GM**) for a particular barge, an inclining experiment needs to be conducted and the results used for a *stability analysis*. In an inclining experiment weights are moved to the outer edge of the deck of the barge and the heel that results is measured with a pendulum.

An inclining experiment should be undertaken by a Ship Surveyor recognised by Maritime NZ to do so, and the results of the inclining experiment should be analysed by a similarly recognised Naval Architect.

► Static Stability

For stability to be adequate, the *righting lever* (**GZ**) resulting from the heeling of a loaded barge is required to be greater than zero (positive) for all angles of heel up to a certain minimum heel angle. 35° is a recommended minimum heel value.²

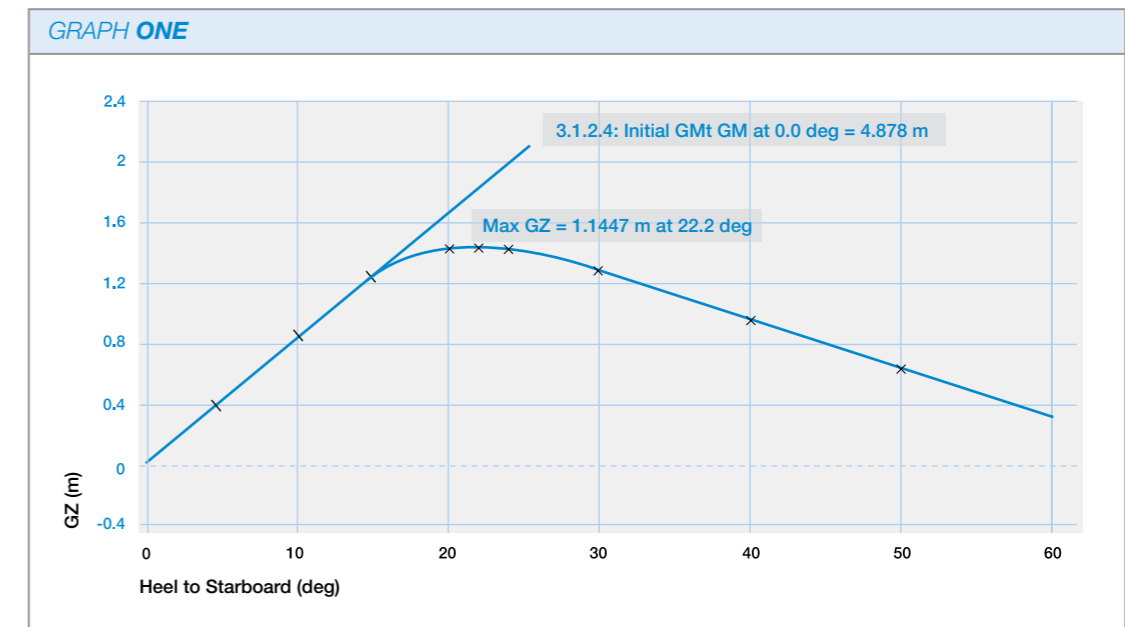
The *righting levers* arising from different angles of heel are best understood when plotted on a curve. A typical *righting lever curve* (GZ curve) is shown below in graph one. This particular curve is for a 24m by 8m barge with a loaded displacement of 148 tonnes. It can be seen that the **GZ** value (measured in metres) is greater than zero for all heel angles up to more than about 60°.

GZ curves, such as the one shown, are generated from the stability analysis undertaken by a Naval Architect who will most often use the results from an inclining experiment. Each vessel will have a unique curve depending on displacement, weight distribution and hull shape.

► Dynamic Stability

The *area under the GZ curve* (and above the horizontal (0) axis), is a product of metres and degrees, and is also an important measure of the stability of a vessel. The larger this area the greater the capacity of the vessel to right itself as it rolls from side to side. This is known as **righting energy**.

A recommended minimum value for the area under the GZ curve is **5.73 metre x degrees**.³



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The size of this area is determined by the *initial GM* (which gives the starting slope of the curve), the *heel angle at which maximum GZ occurs* (which gives the height of the curve) and the *range of heel angles for which GZ is positive* (which gives the length of the curve).■

² This value is a simplified summary of Maritime Rules 40C Appendix 1 (2)(f)(iii) and (i), and consistent with Class Society requirements for barging operations.

³ This is a conservative simplification of the requirements of Maritime Rule 2(f)(i).

► Combined KG

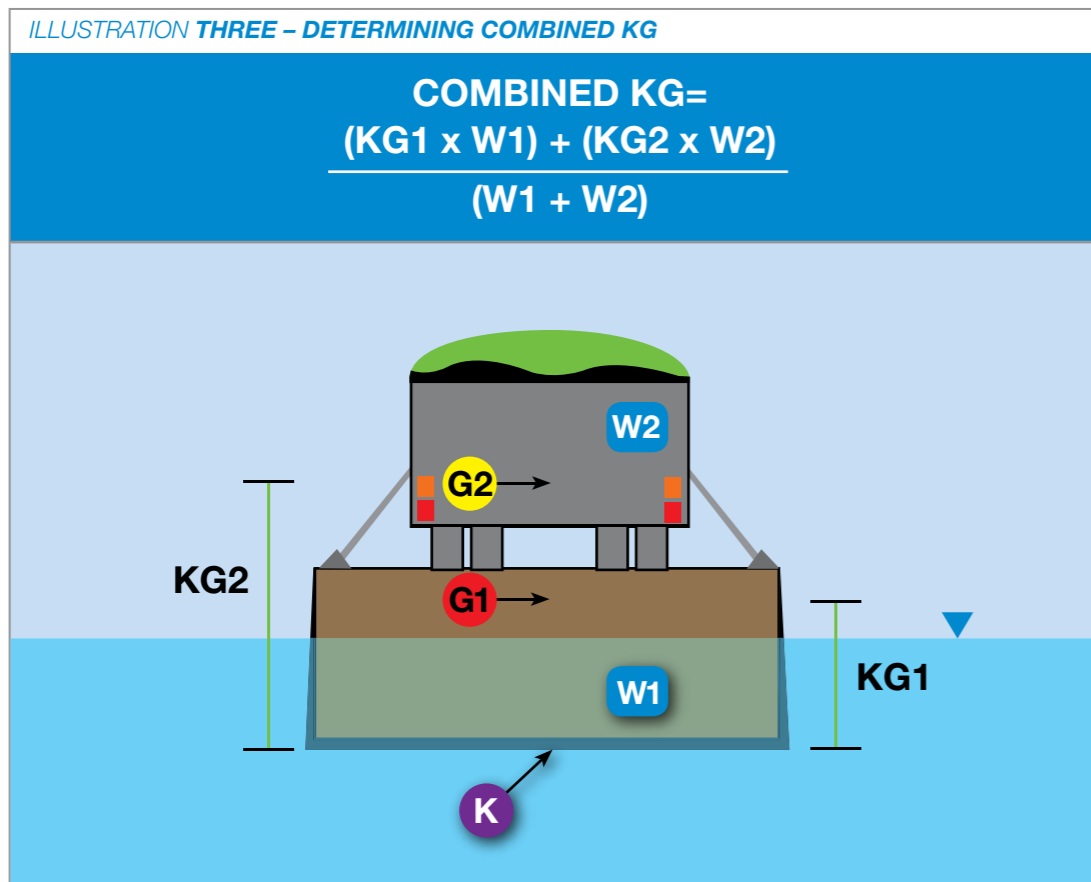


ILLUSTRATION THREE GLOSSARY

KG1	Vertical distance from keel to G1
KG2	Vertical distance from keel to G2
W1	Weight 1
W2	Weight 2

A straightforward check of initial stability involves determining the **combined KG** value for a barge and its cargo. Illustration three shows a pontoon barge loaded with secured deck cargo. The centre of gravity of the lightship barge is marked as **G1** and the centre of gravity of the cargo is marked as **G2**. The distance from the keel to these positions are the distances **KG1** and **KG2**. The lightship weight of the barge is **W1** tonnes, and the cargo weight is **W2** tonnes. The combined **KG** is then obtained using the formula in example two on the facing page.

EXAMPLE TWO – HOW TO CALCULATE KG IN PRACTICE

The use of the formula in practice.

$$KG = \text{total moment } ((KG1 \times W1) + (KG2 \times W2)) / \text{total weight } (W1 + W2)$$

This formula can be tabulated for ease of calculation

Barge's weight		Barge's KG		Weight x KG =		Barge's moment	
Load weight		Load KG		Weight x KG =		Load's moment	
Total weight						Total moment	

A box shaped barge has a *lightship displacement* of 85 tonnes and a KG of 1.8 metres. A weight of 65 tonnes with a KG of 3.8 metres is loaded on to the barge deck.

Calculate the combined KG

Barge's weight	85t	Barge's KG	1.8m	Weight x KG =		Barge's moment	153tm
Load weight	65t	Load KG	3.8	Weight x KG =		Load's moment	247tm
Total weight	150t					Total moment	400tm

Combined KG = total moment/total weight, which is 400/150 = 2.67 metres.

Answer: combined KG = 2.67 metres

The *combined KG* and *loaded displacement* values can then be used for a check on the initial stability of the loaded barge, as described in the next section.

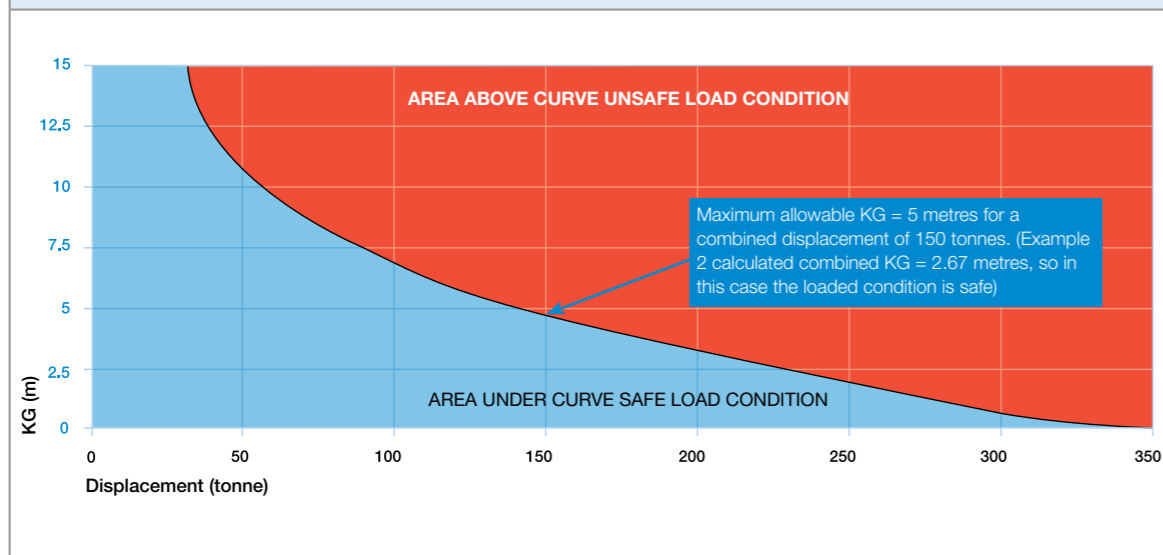
LIMITING KG CURVES

A Naval Architect, as part of a stability analysis for a barge, can draw a limiting KG curve. The limiting KG curve is used, in conjunction with the combined KG and loaded displacement to establish whether the loaded condition is safe. The limiting KG curve has safety margins built in. These margins are achieved by using **recommended minimum values** (such as, *initial GM* greater than 0.35 metres⁴; *vanishing stability (positive GZ)* to greater than 35°; and *area under the GZ curve* not less than 5.73 metre x degrees).

The limiting KG curve such as the one shown opposite enable you to establish how much combined weight (lightship and cargo) can safely be carried, for a known combined KG.

- The area **under** the curve is a **safe** load condition.
- The area **above** the curve is an **unsafe** load condition.

GRAPH TWO – LIMITING KG CURVE FOR A BARGE 24 METRES IN LENGTH & 8 METRES IN BEAM



EXAMPLE THREE – HOW TO USE LIMITING KG CURVES IN PRACTICE

Using graph two and the calculated values in example two – ie. combined KG = 2.67 metres, loaded displacement = 150 tonnes – establish if the load condition is safe or unsafe?

It can be seen from graph two that for a loaded displacement of 150 tonnes and a combined KG of 2.67 metres the load is safe provided the combined KG of the lightship barge and cargo is less than 5 metres.

Answer: 2.67m is less than 5m, therefore the loaded condition is safe.

EXAMPLE FOUR – HOW TO USE LIMITING KG CURVES IN PRACTICE

Graph three shows a limiting KG curve for a barge of 24 metres in length and a beam of 6 metres.

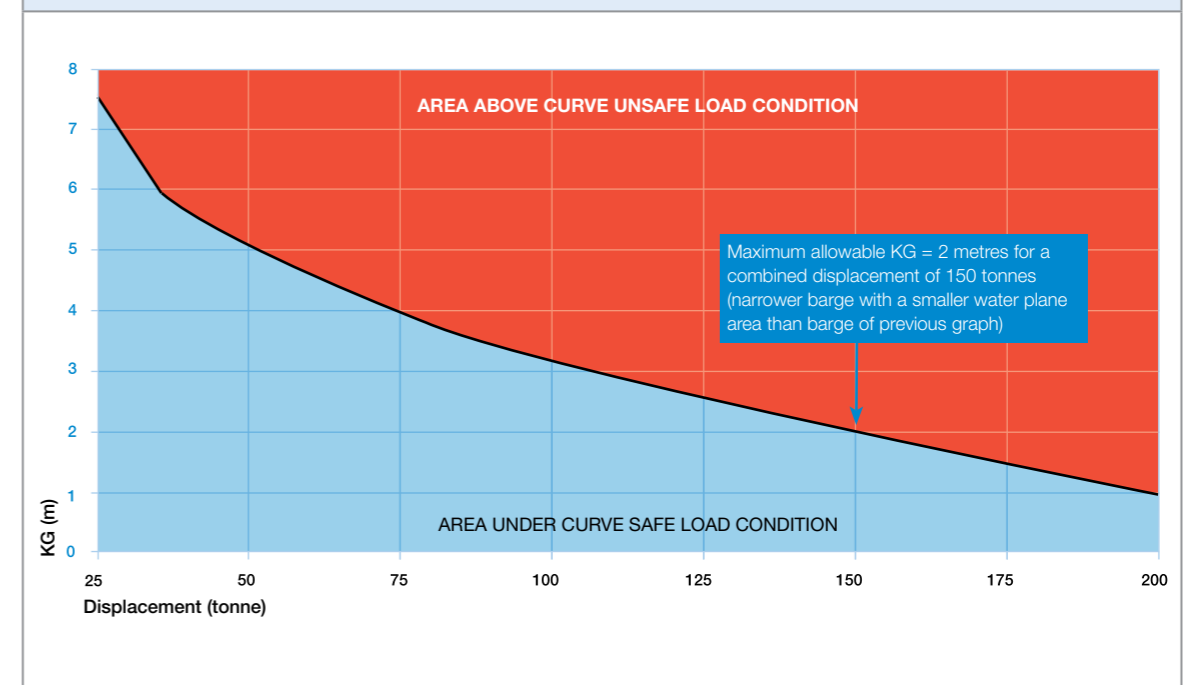
Using the same values in example two – ie combined KG 2.67 metres, loaded displacement of 150 tonnes – establish if the load condition is safe or unsafe.

It can be seen from graph three that for a loaded displacement of 150 tonnes and combined KG of 2.67 metres the load condition is **unsafe**.

From graph three it can be seen that a load displacement of 150 tonnes is only acceptable provided that the combined KG is less than 2 metres above the keel.

By comparing graph two with graph three it can be seen that all the Measures of Stability ie the initial (**GM**) the righting levers (**G2**) and the righting energy will be much less for a barge with a narrower beam.

GRAPH THREE – LIMITING KG CURVE FOR A BARGE 24 METRES IN LENGTH & 6 METRES IN BEAM



⁴ This value is from Maritime Rule 40C Appendix 1 (2)(f)(v).

OTHER STABILITY CONSIDERATIONS

► Crane Outreach

When using cranes and other lifting gear such as A frames that are barge mounted, it must be noted that the weight of the lifted load acts at the *point of suspension* – not at the base of the crane. The *overturning moment* on the barge, tending to cause it to capsize, is the *product* of the weight of the lifted load, and the (horizontal) distance (**d1**) of the *point of suspension* (**p**) from the *centre of buoyancy* (**B**).

ILLUSTRATION FOUR – CRANE OUTREACH

CRANE OVERTURNING MOMENT = $d_1 \times W$
MAXIMUM UPLIFT FORCE = $d_2 \times W$

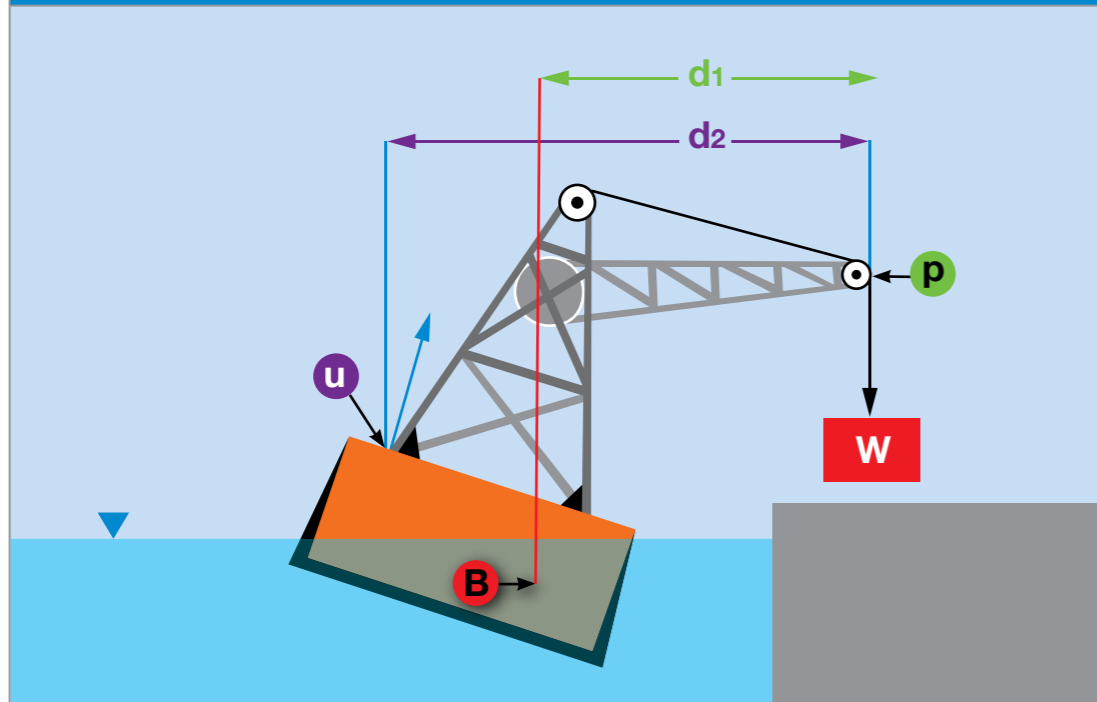


ILLUSTRATION FOUR GLOSSARY

u	Point of maximum uplift
p	Point of suspension
B	Centre of buoyancy
d1	Horizontal distance of p from B
d2	Horizontal distance of p from u

The greatest uplift or detachment force, acts at the *point of attachment* (of the crane to the barge) *furthest from the point of suspension*. This is the force tending to turn the crane over and the moment of this force is the product of the weight of the lifted load, and the (horizontal) distance (**d2**) of the point of suspension (**p**) from the point of uplift (**u**).

► Free surface effect

Fluids such as fuel and water can adversely affect the stability of a moving vessel. As shown in illustration five, the weight of a tank of fluid – acting at the centre of gravity – moves further off the centreline the further the vessel rolls.

Even a shallow covering of water over a large enclosed deck can cause a significant problem. 150 mm of fresh water covering a 24 m by 6 m deck weighs 21.6 tonne, and as the vessel rolls this weight will be transferred outboard to the down side of the roll.

Sloshing is another phenomenon, which can greatly amplify the destabilising effect of a large free surface of fluid. The effect of sloshing is worst if the movement of fluid coincides with the movement of the vessel.

Baffles are used to break up the free surface within a tank and to prevent sloshing. A Naval Architect will be able to offer guidance on the best baffle spacing, and the requirements on baffle strength needed to minimise the adverse effects of free surfaces.

ILLUSTRATION FIVE – FREE SURFACE EFFECT

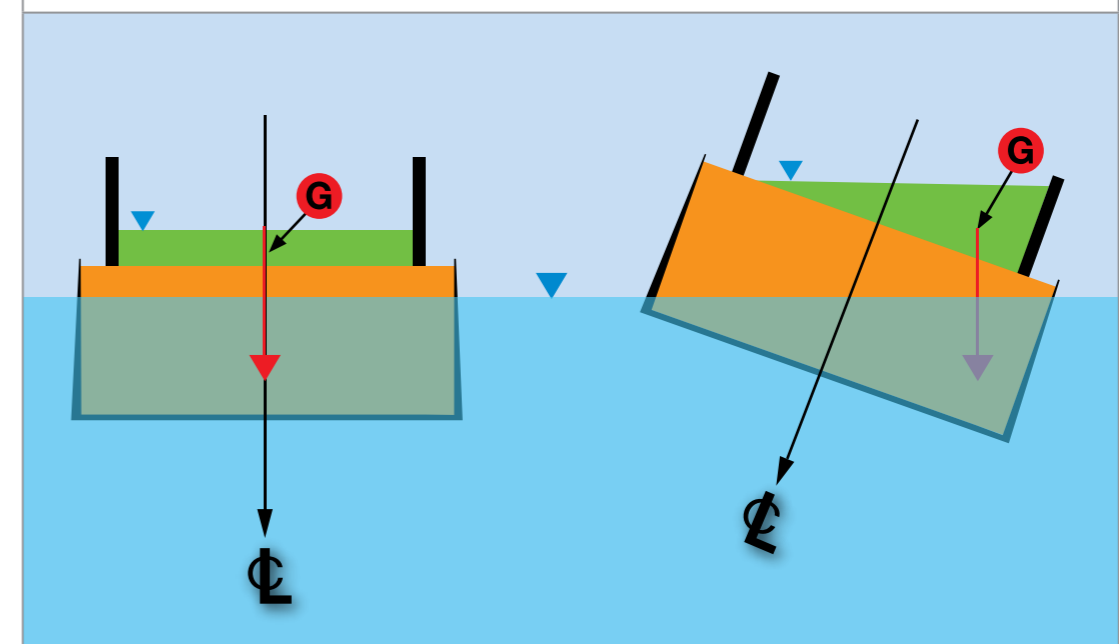


ILLUSTRATION FIVE GLOSSARY

CL	Centreline
G	Fluid centre of gravity

► Shifting Cargo

Securing arrangements should be of such design that they are strong enough to prevent any cargo movement during transit.

Maritime Rule part 24B gives prescribed requirements for stowage and securing of all cargoes.

It is recommended that Maritime Rule part 24B be read in conjunction with these guidelines.

► Loading and Discharge

It is vital that stability is considered during all phases of barge operations, including loading and discharge. The stability conditions during loading and discharge are often quite different from those when fully loaded. Guidance should be sought from a Surveyor or Naval Architect in any cases of doubt.

High loads, moving loads, and off-centreline loading plans all need special consideration.

A low **initial GM** value, a **combined KG** that is close to or below the required minimum and **small righting areas** all mean that the loaded barge will have poor recovery characteristics when rolling in a seaway.

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