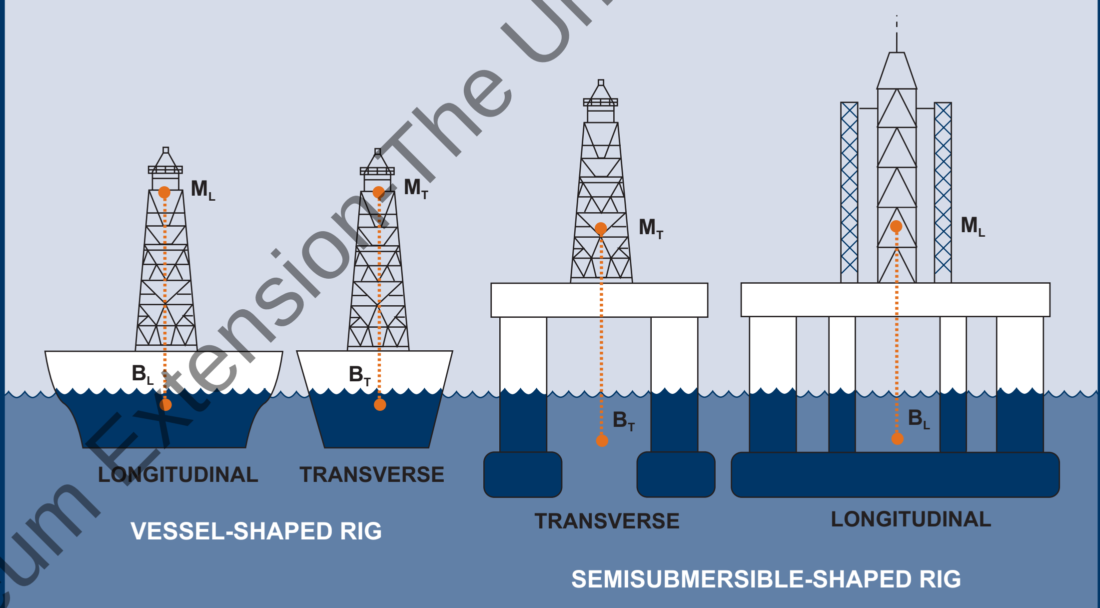
Comprehensive Stability

First Edition



THE UNIVERSITY OF TEXAS
CONTINUING EDUCATION
PETROLEUM EXTENSION SERVICE
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OBJECTIVES AND CONTENTS

1.1 DESCRIPTION

STCW95—Resolution A.891(21) specifies the knowledge, understanding, and proficiency for stability on offshore drilling units required for the function of offshore installation manager (OIM), barge supervisor (BS), and ballast control operator (BCO) on board mobile offshore units (MOUs).

The aim is to cover the entire theory of stability up to and above the standard as required by the Resolution A.891(21).

1.2 CONTENT

Comprehensive Stability covers the fundamental stability theory in eleven chapters with individual exercises for each chapter. The instruction, evaluation, and exercises covers the following subjects:

- Basic units, quantities, and measurements for the Imperial and metric system
- Definitions used for stability in the Imperial and metric systems
- The center of gravity (G), center of buoyancy (B), and metacenter (M)
- The principles of change of draft, heel and trim
- Calculations for G, B, and M
- Explanation of the hydrostatic property tables
- The free surface effect
- The inclining experiment
- Stability at large angles and related international regulations
- Stability curves
- Stability calculations on board
- Damage stability
- Design and construction

1.3 OBJECTIVES

The reader should be able to:

- Calculate with formulas as set out in the section with definitions on how to use the Imperial and metric systems for forces, moments, and weight changes.
- Understand and explain the various categories of stability.
- Understand and explain the interrelation between the points G, B, and M.
- Understand and calculate the change of draft, trim and heel caused by weight changes.
- Understand and calculate the position of G, B, and M for various types of drilling units in vertical, transverse, and horizontal configuration.
- Be able to use the Hydrostatic Property tables for multiple weight changes to find the positions of G, new draft readings, and corresponding maximum allowed VCG value.
- Understand the importance of free surface effect and perform calculations to show the reduced effect on the stability.

- Understand the purpose of the inclining test. Demonstrate with exercises how the inclining test is performed and calculated.
- Demonstrate with examples and calculation the information obtained from the stability curves.
- Understand and explain the difference between stability for small and large angles.
- Understand the basics of damage stability and the primary counteraction to be followed.
- Understand and explain the international regulations concerning stability for normal operations, survival, and damaged stability conditions.
- Understand and explain the difference of static and dynamic stability.
- Understand and use of the maximum allowable VCG curve in conjunction with the GM value.
- Understand and explain the daily stability calculations including the effect of the anchor mooring system.
- As an all over result, the student should be able to demonstrate with exercises how to perform a stability calculation with multiple load changes in the vertical, transverse, and horizontal configuration with the use of all the information explained in the course.
- Understand and explain the causes and consequences of damage stability.
- Demonstrate with calculations the effect and countermeasures for damage stability conditions.
- Understand and explain the principles of the ballast system.
- Understand and explain the basic principles of design and structure of the offshore drilling rigs.

INTRODUCTION

The International Maritime Organization (IMO) adopted the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) in 1978, with Amendments in 1995 and 1997, to set qualification standards for masters, officers, and watch personnel on seagoing merchant marine vessels.

Because the STCW was developed for seagoing merchant marine vessels, the IMO adopted on 25 November 1999 Resolution A.891(21) to cover the training of personnel on mobile offshore units (MOUs). Resolution A.891(21) specifies the minimum standards of competence for the functions of the offshore installation manager (OIM), the barge supervisor (BS), ballast control operator (BCO), and the maintenance supervisor. These minimum standards of competence include knowledge, understanding, and proficiency of stability.

Table 1.0 is a summary of the stability knowledge, understanding, and proficiency required in accordance with the Resolution A.891(21) for the offshore installation manager, the barge supervisor, and the ballast control operator on mobile offshore units versus the contents of the *Comprehensive Stability.*

TABLE 1.0—STCW REQUIREMENTS
Table with Indication of Training in Accordance with A.891(21)
Covered in *Comprehensive Stability* for offshore installation manager (OIM),
barge supervisor (BS), and ballast control operator (BCO)

<table>
<tr><th colspan="2">Knowledge, Understanding, and Proficiency as Required by A.891(21)</th><th>OIM</th><th>BS</th><th>BCO</th><th>Covered in Comprehensive Stability Chapter–Section</th></tr>
<tr><td colspan="2">Knowledge of and ability to apply relevant international and national standards.</td><td>×</td><td>×</td><td>×</td><td>Chapter 1, 1.1–1.3,
Chapter 8, 8.1–8.11</td></tr>
<tr><td colspan="2">Use of loading stability information from stability and trim diagrams, Marine Operatons Manual, and/or computerized loading/stability programs.</td><td>×</td><td>×</td><td>×</td><td>Chapter 1, 1.3,
Chapter 5, 5.1–5.12,
Chapter 6, 6.1–6.6,
Chapter 9, 9.1–9.5</td></tr>
<tr><td colspan="2">Understanding of fundamental principles-theories-factors affecting trim and stability to preserve trim and stability and measures to preserve trim and stability.</td><td>×</td><td>×</td><td></td><td>Chapter 1, 1.1–1.3,
Chapter 2, 2.1–2.16,
Chapter 3, 3.1–3.4,
Chapter 5, 5.1–5.12,
Chapter 6, 6.1–6.6</td></tr>
<tr><td colspan="2">Static and dynamic stability criteria for MOUs, environmental limits, and criteria for survival conditions.</td><td>×</td><td>×</td><td>×</td><td>Chapter 4, 4.1–4.8,
Chapter 8, 8.1–8.11</td></tr>
<tr><td colspan="2">Understanding of inclining experiment, deadweight, and their use.</td><td>×</td><td>×</td><td>×</td><td>Chapter 1, 1.3,
Chapter 7, 7.1–7.5</td></tr>
<tr><td colspan="2">Use of daily loading calculations.
×</td><td>×</td><td>×</td><td></td><td>Chapter 5, 5.1–5.12,
Chapter 8, 8.1–8.11</td></tr>
<tr><td rowspan="5">Knowledge of the effect</td><td>1) Trim and stability of MOUs in event of damage and consequent flooding and countermeasures.</td><td>×</td><td></td><td></td><td>Chapter 8, 8.2, 8.9–8.11</td></tr>
<tr><td>2) Off-loading supplies and ballasting in order to keep the unit's stress within the acceptable limits.</td><td>×</td><td></td><td></td><td>Chapter 9, 9.4
Chapter 11, 11.1–11.15</td></tr>
<tr><td>3) Mooring system and mooring line failures.</td><td>×</td><td></td><td></td><td>Chapter 9, anchor system correction only in 9.3</td></tr>
<tr><td>4) Preloading and leg stresses on JUs.</td><td>×</td><td></td><td></td><td>Chapter 11, 11.1–11.15</td></tr>
<tr><td>5) Loss of buoyancy.</td><td>×</td><td></td><td></td><td>Chapter 10, 10.1–10.13</td></tr>
<tr><td rowspan="3">Knowledge of</td><td>1) The emergency response for flooding due to damage, fire fighting, loss of buoyancy, and the effect on trim and stability.</td><td>×</td><td>×</td><td>×</td><td>Basics only in Chapter 8, 8.9–8.10</td></tr>
<tr><td>2) Countermeasures for damage stability.</td><td>×</td><td>×</td><td>×</td><td>Basics only in Chapter 8, 8.9–8.10</td></tr>
<tr><td>3) Effectively communicate stability-related information.</td><td>×</td><td>×</td><td>×</td><td>Chapter 9, 9.1–
9.5</td></tr>
<tr><td colspan="2">The effect of trim and stability of cargo and cargo operations.</td><td>×</td><td>×</td><td></td><td>Chapter 1, 1.3,
Chapter 3, 3.1–3.4,
Chapter 5, 5.8–5.12,
Chapter 9, 9.1–9.5</td></tr>
</table>

CHAPTER 1
Basic Units and Definitions

THE METRIC AND CONVENTIONAL SYSTEM

1.1 UNITS

A unit is a standard measure of quantity such as length, mass, energy, etc. Compared to the SI (Système International d'Unités), or metric system, the conventional system (also called Imperial or U.S. system) is more complicated because several units are used for each quantity. For example, measurements of length can be expressed in miles, yards, feet, and inches. In the SI or metric system only one unit is used for each basic quantity, like the metre is the basic unit of length and the kilogram is the basic unit of weight. For stability calculations both systems are used in the offshore drilling industry

The basic units and derived quantities for each system are shown in Table 1.1.

TABLE 1.1

Fundamental Quantities and Derived Quantities	Conventional System		Metric (SI) System	
	Unit	Symbol	Unit	Symbol
Acceleration	feet per sec per sec	ft/sec^2	metre per sec per sec	m/sec^2
Area	square feet	ft^2	square metre	m^2
Density	pound per cubic ft	lb/ft^3	kilogram per cubic m	kg/m^3
Force	pound force	lb_f	Newton	N
Frequency	hertz	Hz	hertz	Hz
Length	foot	ft	metre	m
Mass	pound	lb	kilogram	kg
Power	foot-pound per sec horsepower watt	ft-lb/sec hp W	joule per second kilogram-metre per sec watt	J/s kg.m/sec W
Pressure	pound per square inch	psi	pascal (N/m^2) kilogram/square cm	Pa kg/cm^2
Temperature	degree Fahrenheit	ºF	degree Celsius	ºC
Tons	short tons (2,000 lb)	st	tonne (1,000 kg)	t
Velocity	foot per second	ft/sec	metre per second	m/s
Volume	cubic foot gallon barrel	cu.ft or ft^3 gal bbl	cubic metre	m^3
Work	foot-pound	ft-lb	joule Newton-metre	J N-m

CHAPTER 2
The Center of Gravity, the Center of Buoyancy, and the Metacenter

2.1 INTRODUCTION

Four important points to understand the basic principles of stability will be discussed in this chapter. These points are:

1. The center of gravity (G)
2. The center of buoyancy (B)
3. The metacenter (M)
4. The center of flotation (COF)

2.2 THE CENTER OF GRAVITY

The *center of gravity* (*G*) or *vertical center of gravity* (*VCG*) of a rig or vessel is the point through which the total *weight of the rig* (*W*) is considered to act in a vertically downwards direction (fig. 2.1). Because the rig is not a homogeneous body, the position of the center of gravity depends on the shape of the hull and the position of the weights stored on the rig.

As explained in Chapter 1, mass is the quantity of matter in a body and weight is the vertical force experienced by a mass as a result of the gravity force.

The total weight of a vessel or rig is the resultant weight of the lightship weight plus all variable loads stored on the rig.

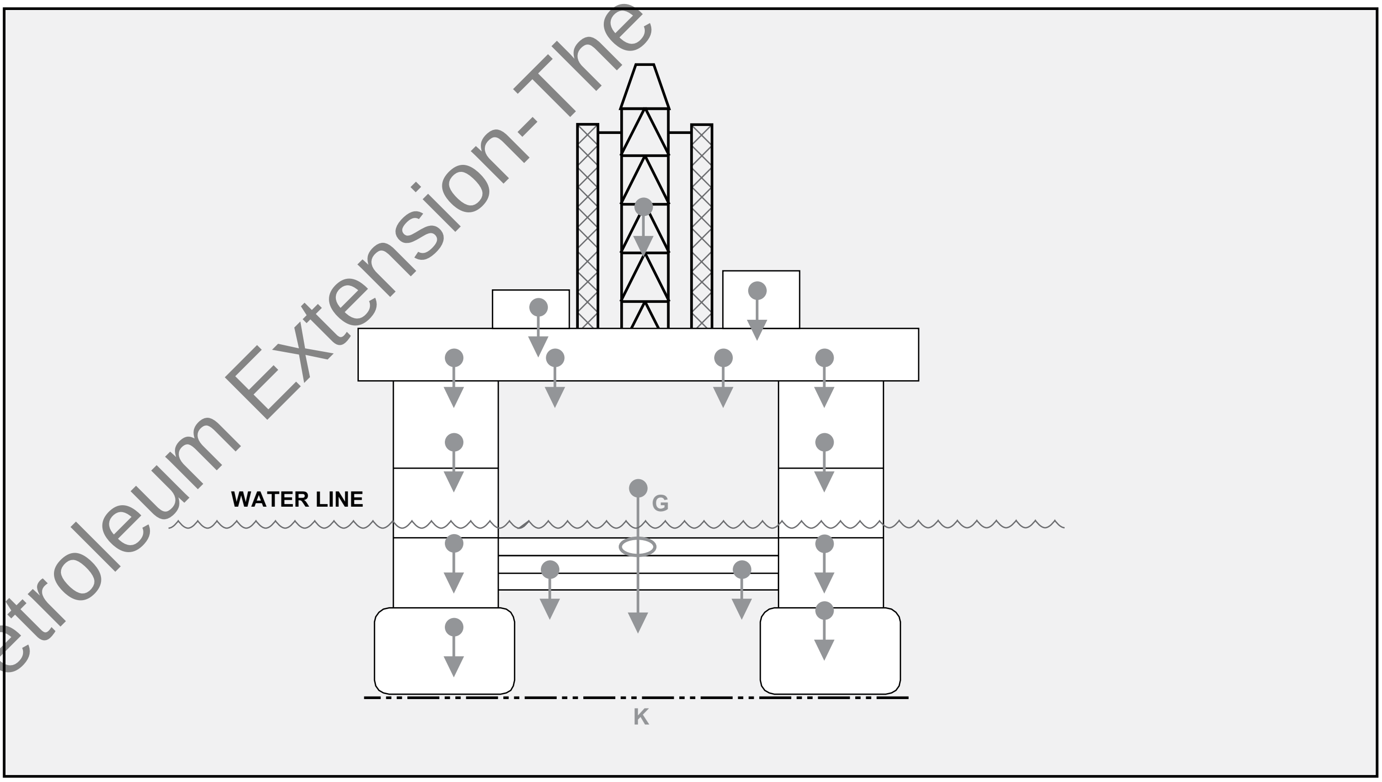

Figure 2.1 The position of *G*

CHAPTER 3
Change of Draft, Heel, and Trim

3.1 MEAN DRAFT (MD)

Mean draft (*MD*) is the draft amidships at the intersection of the transverse and longitudinal centerlines.

$$\text{Mean Draft Drilling Vessel} = \frac{\text{Draft Reading Forward} + \text{Draft Reading Aft}}{2}$$

$$\text{Mean Draft Semisubmersible} = \frac{\text{The Sum of the Draft Reading of Four Columns}}{4}$$

3.2 TRUE MEAN DRAFT (TMD)

The *true mean draft* (*TMD*) is the draft at the center of flotation (*F*). The position of *F* depends on the waterplane area. If the position F is not amidships, the *TMD* and *MD* are different.

The position of *F* in Figure 3.1 shows the situation where longitudinal center of flotation (*LCF*) does not coincide with amidships because of an asymmetric waterplane area. The *TMD* in this case is less than the *MD*. The correction is the distance *C-C′*. There are two ways to find the *TMD*.

NOTE: The vertical line through the draft marks is called the *aft perpendicular* (*AP*) and for *forward perpendicular* (*FP*).

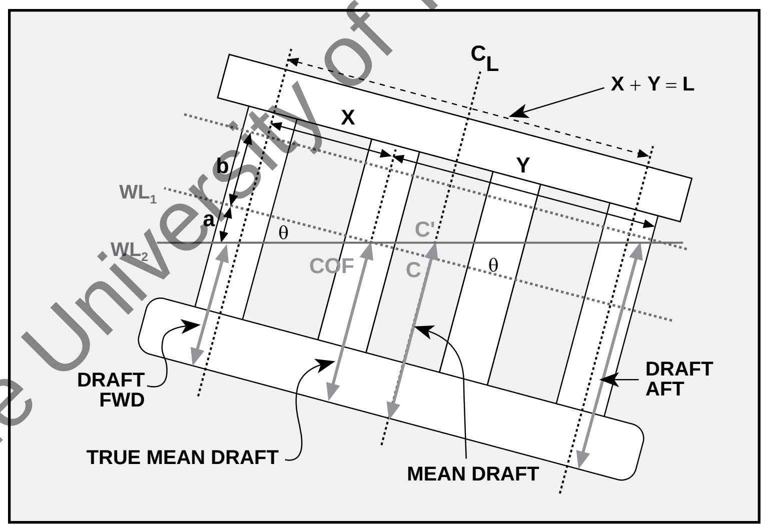

Figure 3.1 Mean draft and true mean draft

$$\text{Total trim (T)} = a + b$$

$$L = X + Y \text{ (L is the distance between forward and aft draft marks)}$$

$$\theta = \text{inclination}$$

$$\tan\theta = \frac{T}{L} \text{ but also}$$

$$\tan\theta = \frac{a}{X} \text{ so}$$

$$\frac{a}{X} = \frac{T}{L}$$

$$a = T\frac{X}{L}$$

$$\text{TMD} = \text{Draft Forward} + T \times \frac{\text{Distance between forward draft marks and center of flotation}}{L}$$

For trim by the head the sign will be minus (–). Another way is with the formula—

$$\text{Correction for TMD} = \pm T \times \frac{\text{Distance between COF and } ⊄}{L}$$

CHAPTER 4
The Calculations for G, B, and M

4.1 INTRODUCTION

From the explanation of the stability theory in previous chapters it is known that:

1. The position of *G* lightship is determined by the naval architect. Without any changes to the rig construction, *G* lightship is a fixed point.
2. The actual position of *G* in operations depends on the weight distribution of the variable load added to the lightship weight configuration in addition to the lightship weight configuration.
3. The position of *B* above *K* depends on the draft. The naval architect calculates the position for a range of drafts. The results are tabulated in the hydrostatic properties.
4. The position of *M* is a fixed point for small angles. The range *BM* is computed and tabulated in the hydrostatic properties.
5. The positions of *G, B*, and *M* are expressed in the vertical longitudinal and vertical planes.

In this chapter the principles to determine the positions of *G, B*, and *M* and their relations with the stability calculations will be further explained.

4.2 THE EFFECT OF WEIGHT SHIFTS ON THE CENTER OF GRAVITY (G)

It is known that the position *G* depends on the distribution of the total weight of the rig construction and the added variable load. The effect of the shift of *G* depends on—

1. the direction of the weight change.
2. the distance of the weight change in respect of the initial *G*.
3. the amount of weight change.

Two types of calculations may be used to find the new position of *G* after a change in weight distribution.

1. Calculation for each weight shift with a weight shift formula
2. Calculations with the principles of moments

If a weight *w* is moved over a distance *d*, the center of gravity will move from *G* to *G′* (fig. 4.1). Because of the moment *w•d*, the rig will heel in this case to the right. The rig stabiles under an angle with a new position of *G′*. The stabilizing angle is the position when the moment

$$w \bullet d = W \bullet GG'$$

The movement of *G* to *G′* is always parallel to the movement of the weight *w*. In this case the move is horizontal.

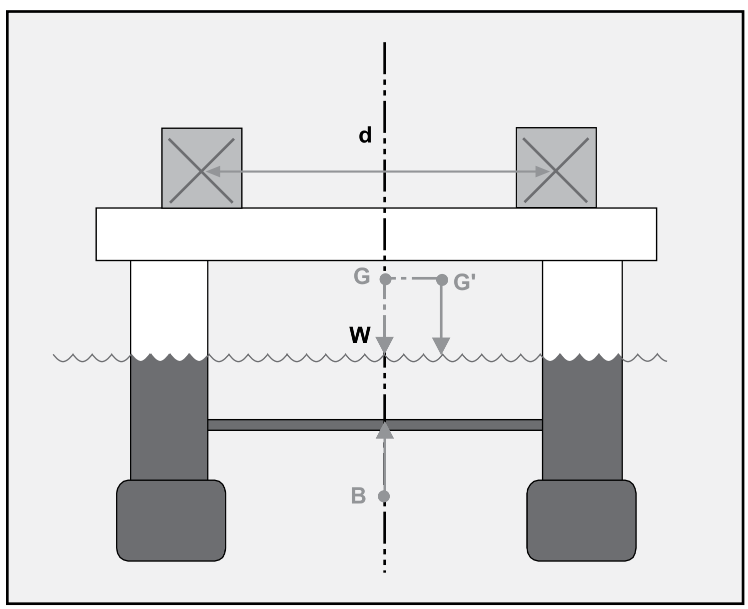

Figure 4.1 Shift of G to G'

CHAPTER 5
Hydrostatic Properties

5.1 INTRODUCTION

An important part of the responsibility of the naval architect assigned to the new building project of a rig is to analyze all data concerning the stability of the rig. During the design stage he prepares all the information through computer programmed calculations. The final results must be in accordance with the international regulations and classification society specifications.

The details of the information are tabulated in the hydrostatic properties and on curves. The tabulated information is more common and more accurate. In addition, curves of stability are analyzed to confirm that the stability criteria are in accordance with the International Maritime Organization (IMO) standards.

Separate information not part of the hydrostatic properties may be:

1. Tank capacity curves or tables.
2. Capacity, weight, and moment of flooded compartments.
3. Free surface effect of hull and ballast tanks.
4. The lightship information and history.
5. The allowable VCG values.

5.2 HYDROSTATIC PROPERTY INFORMATION

Table 5.1 and Table 5.2. are examples of hydrostatic tables of two semisubmersibles. The information in Imperial or metric system includes:

1. Draft in ft or m.
2. Displacement in st or tonnes (Displ).
3. Vertical center of buoyancy in ft or m. (VCB or KB).
4. Longitudinal center of buoyancy in ft or m (LCB).
5. Transverse center of buoyancy in ft or m (TCB).
6. Waterplane area in square ft or square m (WPA).
7. Short tons per inch (TPI) or tonnes per cm (TPC).
8. Longitudinal center of flotation in ft or m (LCF).
9. Transverse center of flotation in ft or m (LCF).
10. The height of the longitudinal metacenter in ft or m (KM_L).
11. The height of the transverse metacenter in ft or m (KM_T).
12. The moment to change the trim one degree of one cm (MT1deg or MCT).
13. The moment to change the heel one degree or one cm (MH1deg or MCH).

5.3 DRAFT

The draft is calculated at intervals of feet and metres or parts thereof. For example, for the draft on the pontoons the interval can be tens of feet while drafts around the columns is in one-foot intervals. In the example of the metric system, ten centimetre intervals are used from light draft to deep draft.

CHAPTER 6
Free Surface Effect

6.1 THE FREE SURFACE EFFECT ON STABILITY

A drilling rig has many tanks, which may contain fluid in the form of seawater, fuel, drilling water, or a mixture of mud and water. Any of these tanks may be full, empty, or partly filled.

If a tank is completely full (with fluid up into the sounding pipe) the fluid acts as a solid weight. The fluid does not have freedom to move. A change of heel or trim will not have any effect on the stability of the rig.

The situation changes if a tank is partially filled. This is called a slack tank. The fluid in the tank has the freedom to move from one side to another side. If the rig moves by external forces, the fluid will move backwards and forwards in the same cycle as the movement of the rig. This movement produces an effect of inertia. An inclination caused by a weight shift or external force will move the fluid in the same direction as the inclination.

The transverse section of a semisubmersible in Figure 6.1 shows that there is no change in the stability condition if an external force heels the rig and the bottom tanks are completely filled. The only difference is the change of the position of *B*. The value of *GM* remains the same. As explained, the value of *GM* indicates the amount of stability.

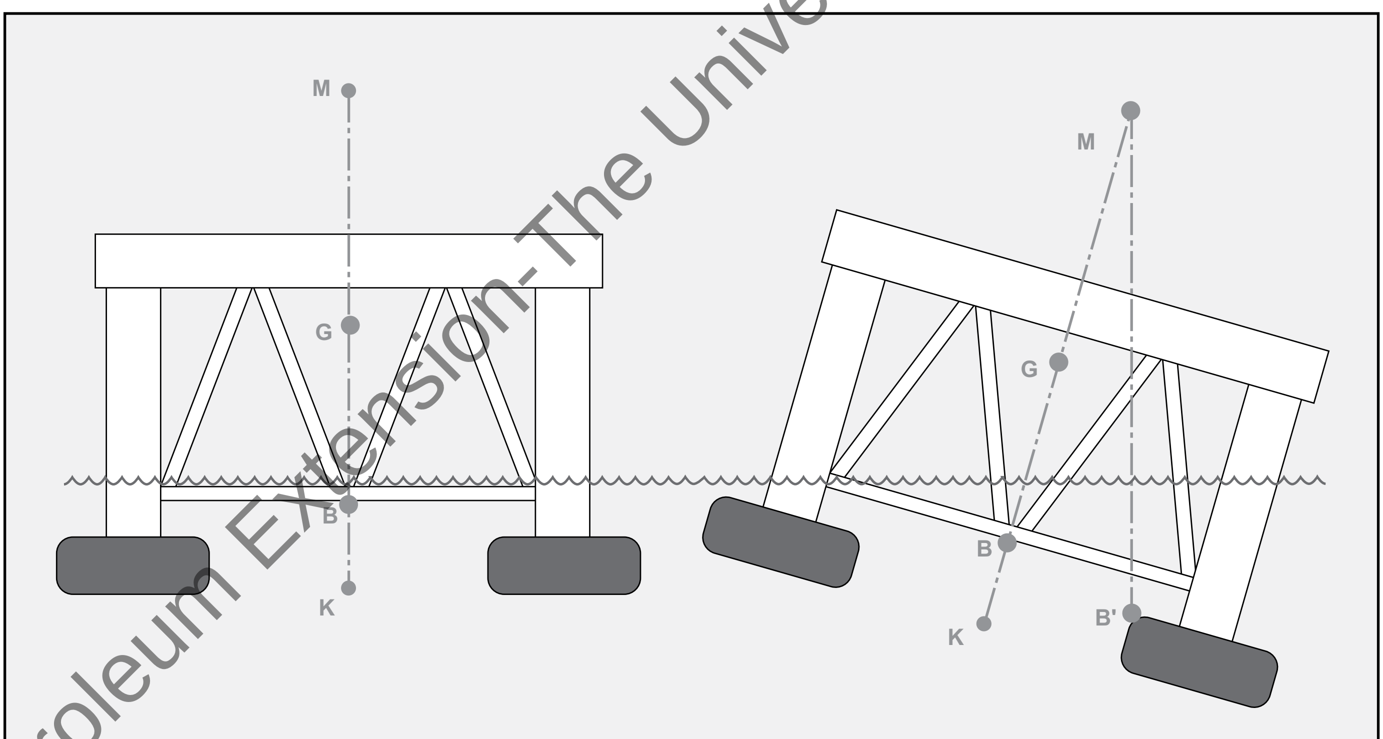

Figure 6.1 Full tanks and heel

Now have a look at what happens if there are slack tanks. From the moment the rig inclines, the fluid in the tank moves and forms a new surface as shown in Figure 6.2. The center of gravity of the fluid in each tank shifts from *g* to *g′*. The movement of the free surface has the effect of a weight shift. The effect is as if the weight of the water is suspended from a higher point *M* and can swing free like a pendulum.

CHAPTER 7
The Inclining Experiment

7.1 INTRODUCTION

Although it is possible to calculate the theoretical position of the center of gravity (G) of a rig design, the actual position of G for the structure and all permanently installed equipment needs to be confirmed at the end of the construction period.

To confirm the actual position of KG, an *inclining experiment* is carried out.

The inclining experiment is required by international regulations. Specific regulations are applicable for MODUs in accordance with the IMO and Classification Societies regulations. In addition, local authorities may have their own regulations to comply with before a rig is approved to operate within the country's jurisdiction.

7.2 THE PREPARATION OF THE INCLINING EXPERIMENT

As mentioned, the purpose of the inclining experiment is to establish the actual value of the center of gravity for the vertical (KG or VCG), transverse (TCG), and longitudinal (LCG) position.

The weight of the vessel or rig is considered to be the lightship weight.

The inclining experiment requires a thorough preparation by the shipyard and the project manager with his construction team. To ensure accurate results, certain conditions are required to perform a good inclining experiment.

1. The displacement of the rig should be as close as possible to the lightship weight.
2. All loose equipment not part of the lightship weight should be discharged.
3. Any loose equipment that needs to remain on board should be secured and accurately recorded on weight and position.
4. At the start, the rig should be without any heel or trim.
5. All tanks and void spaces need to be inspected.
6. All tanks should be empty and stripped or full. No free surface.
7. The location should be sheltered.
8. The weather should be calm with only light winds and no wave action.
9. Any mooring lines should be slack. The rig should float free from the quayside.
10. Except for the inclining crew all personnel should leave the rig. Any persons to stay on board should remain at their assigned positions.
11. The density of the water in which the rig floats should be confirmed by measurement.

CHAPTER 8
Stability at Large Angles—Stability Curves

8.1 INTRODUCTION

Until now we described the theory of initial statical stability in the vertical, transverse, and longitudinal planes. Initial stability in this respect is the stability for small angles up to about 8°. As explained, up to about 8°, the metacenter (*M*) is a fixed point.

As a quick reminder, the interaction between *G* and *M* determines the amount of statical stability.

1. The position of *G* depends on the weight distribution.
2. The position of *M* depends on the rig configuration under the waterline.

For a specific displacement, only the position of *G* can be controlled (within limits) on the rig.

The moment of the righting couple and corresponding arm *GZ* is an indication of the amount of stability. Any vertical change of the position of *G* will increase or decrease the amount of stability because of the change in the length of *GZ* (fig. 8.1).

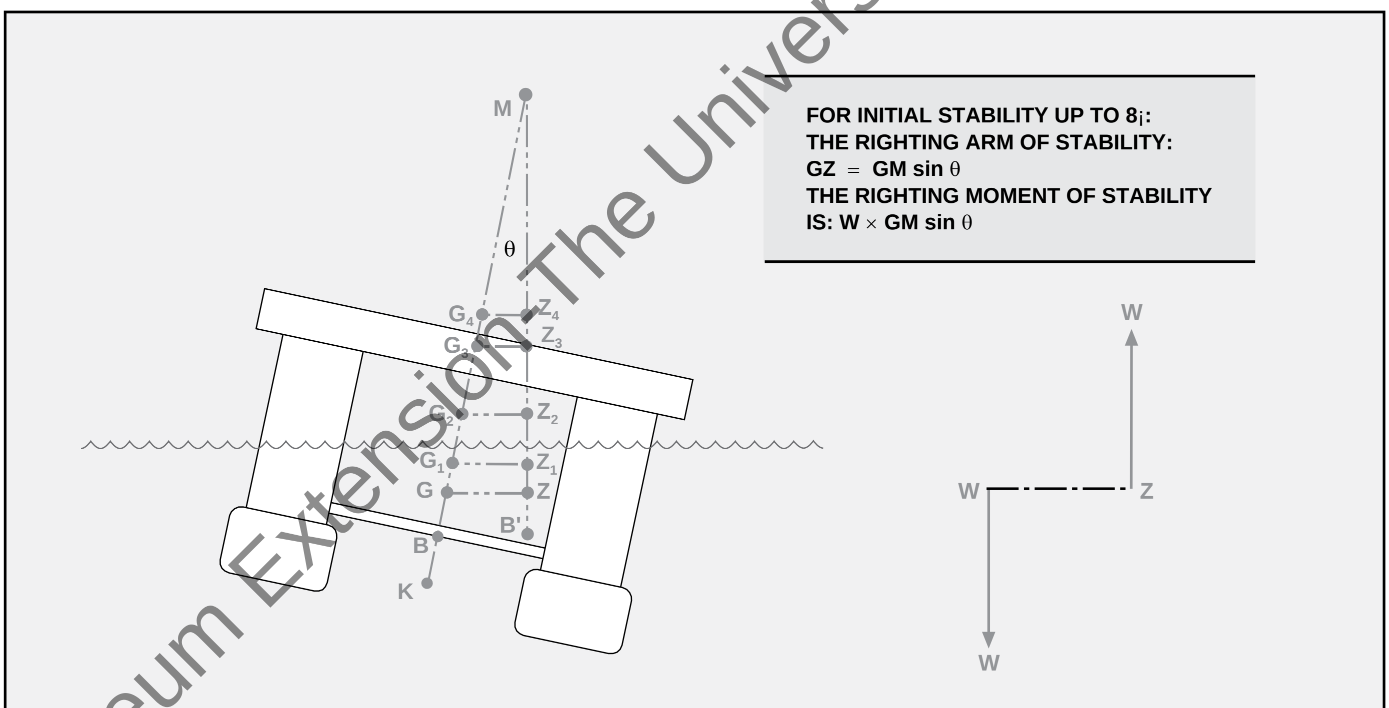

Figure 8.1 Stability couple—change in the value of the stability arm

CHAPTER 9
Stability Calculations on Board

9.1 INTRODUCTION

To monitor the stability of the rig, daily calculations are carried out. On most rigs the stability calculations are now computer programmed. The manual calculation should be done at regular intervals to verify that the computer calculations are correct. It is good practice to perform manual calculations because the computer inputs can be verified, and it also keeps the crew familiar with manual calculations in case of a computer breakdown.

The formats of the computer and manual calculation are basically the same.

9.2 LOADING CONDITIONS

In most cases the loading conditions are based on three draft situations:

1. Transit draft
2. Operation draft
3. Survival draft

The values of the maximum allowable VCG for each of the three situations are different. See Chapter 8, Figures 8.10 and 8.11.

Other factors that have an effect on the loading calculations are:

1. The free surface effect.
2. The set of ballast tanks to be full or empty corresponding to each draft situation.
3. The maximum allowable deck load.
4. The corrections for the anchor, chain run out, and anchor tensions.
5. The specific operating draft for the drilling location.
6. The level of ballast in the trim tanks to maintain an upright position at all times.

Note: In addition to the specified maximum allowable VCG values for the different situations, the maximum allowable deck loads may be subject to change with the situation too. Table 9.1 is such an example of Rig Type 2A.

CHAPTER 10
Damage Stability

10.1 DEFINITION OF DAMAGE STABILITY

A vessel or rig is in a damaged stability condition whenever uncontrolled flooding of any compartment develops or exists. In the marine world, this is also called bilging based on a holed compartment below the waterline.

10.2 CAUSES OF DAMAGE STABILITY

A damage stability condition may be caused by:

1. Collision
2. Grounding
3. Free flooding between one or more compartments through a normally closed opening such as a watertight door or manhole.
4. Flooding through a burst waterline, leaking valve, or leaking flange.
5. Cracks in structural members followed by flooding.
6. Failure of the ballast system combined with uncontrolled filling of ballast tanks.
7. Icing if the buildup of ice weight results in a neutral or negative stability.
8. Water buildup in a compartment from water used to extinguish a fire.

10.3 CONSEQUENCES OF DAMAGE STABILITY

The effect of damage stability will include one or any combination of the following changes:

1. Change in heel.
2. Change in trim.
3. Change in mean draft.
4. Change in reserve buoyancy.
5. Change in anchor tensions.
6. Elimination of part of the ballast system caused by flooding in the pump room.

It is important to realize that the analysis of a damaged stability condition is based on the theory that the vessel or rig remains afloat with positive stability after the damage to enable successive, controlled counteraction to save the unit from sinking or capsizing.

10.4 PERMEABILITY

Permeability in marine terms is the percentage of water a compartment can contain after it has been flooded. A void space without any equipment could be filled with a volume of water equal to the volume of the void space. Its permeability is close to 100%. The permeability of a pump room with a considerable amount of built-in equipment may be only 60%. A higher value of permeability results in a higher amount of loss of buoyancy. To calculate the effect of flooding, the permeability of a compartment must be known.

CHAPTER 11
Design and Construction

11.1 INTRODUCTION

The design of the primary structure of the offshore units involves the sizing, geometrical arrangement, and selection of material for the structural members and their connections. This means that the structure and connections have acceptable fatigue lives and that the allowable stresses are not exceeded when subjected to the maximum loading the unit is expected to withstand.

The units are designed in accordance with accepted practices specified in detail by international regulations such as IMO, Classification Societies, and government authorities.

The rigs are not overdesigned; therefore, the restrictions pertaining to structural safety prescribed in the rig's marine operations manual must be respected.

11.2 FORCES WORKING ON THE FLOATING UNIT

The structure of an offshore drilling rig in operation or under tow is subjected to many forces during its lifetime. These forces or loads can be statical or dynamic.

1. *Statical loads* are loads such as the weight of the rig and its components, the buoyancy force, and the pressure by water.
2. *Dynamic loads* are loads caused by the environmental forces and the rig movement such as roll, pitch, yaw, sway, heave, and surge.

The various combinations of these loads will tend to bend and twist the rig structure. The bending and twisting loads are transferred to the structural members of the rig, which are essential to the overall integrity of the unit.

11.3 STRESS, STRAIN, AND YIELD

An axial pulling load applied to a steel sample produces stress within the material. If the axial pulling progresses, the steel sample starts to elongate. Stress is expressed in load per area, i.e., psi or kg/cm3. The elongation of the specimen represents the strain in the material. Strain is expressed in in./in. or cm/cm.

The proportional relationship of stress to strain continues until a certain point, and from thereon is not proportional anymore. This is called the *proportional elastic limit* of the material. Before this point, the specimen returns to its original size if the force is removed. After this point, the specimen is permanently deformed.

Continuation of the axial load beyond the point of proportional elastic limit shows that the sample material will elongate without almost any additional load. This is the *yield point* or *tensile yield strength* of the steel sample.

Any additional pulling results in further elongation until the pulling reaches maximum value and then decreases. The material reaches the *ultimate tensile strength* and shortly afterwards the *fracture point*. The various points are displayed in the graph of Figure 11.1.

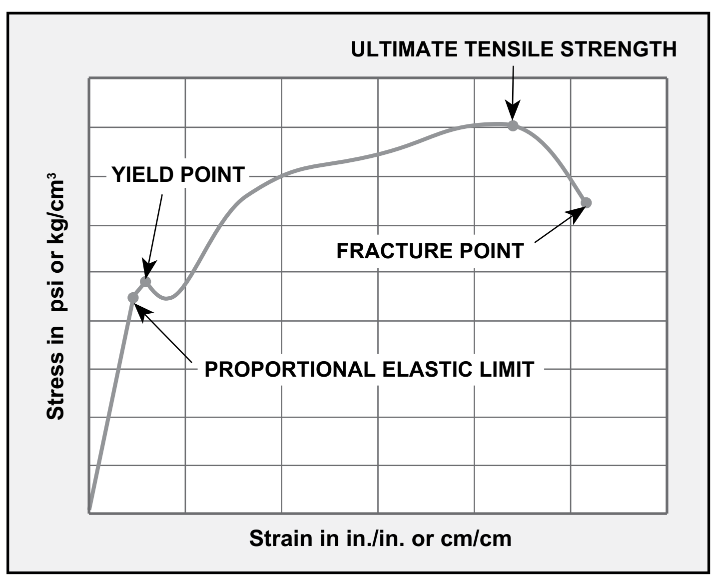

Figure 11.1 Example of a Stress-Strain diagram

To obtain additional training materials, contact:

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ISBN 0-88698-214-6
9 780886 982140

1.11010
0-88698-214-6