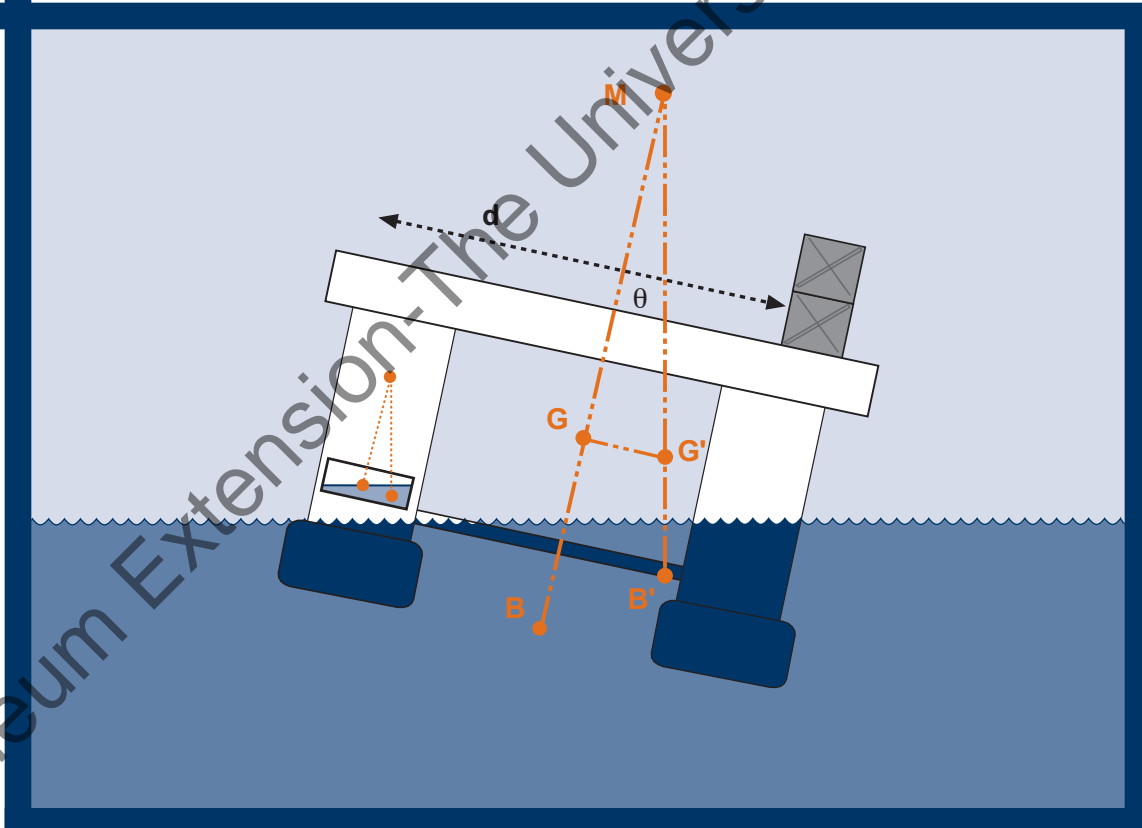




# Advanced Stability

First Edition



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

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## 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).

It is advisable for any person *without* a marine education or a bachelor degree in science first to read *Comprehensive Stability*, available from Petroleum Extension Service, 512-471-5940 or 1-800-687-4132.

A person with an unlimited marine deck license (master, mate) or with a bachelor degree in science should be able to read and comprehend *Advanced Stability* without first reading *Comprehensive Stability*.

## 1.2 CONTENT

*Advanced Stability* covers the fundamental stability theory in eight chapters with individual exercises for each chapter. The instruction, evaluation, and exercises cover the following subjects:

- Units of measurements, definitions, and basic stability
- Environmental forces
- Hydrostatic properties and daily stability calculations
- The mooring system
- Stability at large angles—stability curves
- Damage stability
- The ballast system
- 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.
- As an overall 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 daily stability calculations including the effect of the anchor mooring system.
- Be able to calculate the various sections and forces within the catenary mooring system.
- 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

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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 *Advanced Stability*.

**TABLE 1.0—STCW REQUIREMENTS**  
**Table with Indication of Training in Accordance with A.891(21)**  
**Covered in *Comprehensive Stability* and *Advanced Stability* for OIM, BS, BCO**

Knowledge Understanding and Proficiency as Required by A.891(21)		OIM	BS	BCO	Covered in <i>Comprehensive Stability</i> Chapter–Section	Covered in <i>Advanced Stability</i> Chapter–Section
Knowledge of and ability to apply relevant international and national standards.		×	×	×	Chapt. 1, 1.1–1.3, Chapt. 8, 8.1–8.11	Chapt. 1, 1.2, Chapt. 2, 2.1–2.18, Chapt. 5, 5.1–5.20, Chapt. 6, 6.1–6.13
Use of loading stability information from stability and trim diagrams, MOM, and/or computerised loading/stability programs.		×	×	×	Chapt. 1, 1.3, Chapt. 5, 5.1–5.12, Chapt. 6, 6.1–6.6, Chapt. 9, 9.1–9.5	Chapt. 1, 1.39–1.57, Chapt. 3, 3.1–3.19
Understanding of fundamental principles-theories-factors affecting trim and stability to preserve trim and stability and measures to preserve trim and stability.		×	×		Chapt. 1, 1.1–1.3, Chapt. 2, 2.1–2.16, Chapt. 3, 3.1–3.4, Chapt. 5, 5.1–5.12, Chapt. 6, 6.1–6.6	Chapt. 1, 1.1–1.57, Chapt. 3, 3.1–3.18, Chapt. 6, 6.12–6.13
Static and dynamic stability criteria for MOUs, environmental limits, and criteria for survival conditions.		×	×	×	Chapt. 4, 4.1–4.8, Chapt. 8, 8.1–8.11	Chapt. 2, 2.1–2.18, Chapt. 5, 5.1–5.20
Understanding of inclining experiment, deadweight, and their use.		×	×	×	Chapt. 1, 1.3, Chapt. 7, 7.1–7.5	Chapt. 1, 1.59
Use of daily loading calculations.		×	×	×	Chapt. 5, 5.1–5.12, Chapt. 8, 8.1–8.11	Chapt. 3, 3.1–3.19
Knowledge of the effect	1) Trim and stability of MOUs in event of damage and consequent flooding and countermeasures.	×			Chapt. 8, 8.2, 8.9–8.11	Chapt. 6, 6.1–6.13
	2) Of loading supplies and ballasting in order to keep the unit's stress within the acceptable limits.	×			Chapter 9, 9.4 Chapter 11, 11.1–11.15	Chapt. 3, 3.14–3.19 Chapt. 8, 8.1–8.15
	3) Mooring system and mooring line failures.	×			Chapt. 9, anchor system correction only in 9.3	Chapt. 4, 4.1–4.18
	4) Preloading and leg stresses on JUs	×			Chapter 11, 11.1–11.15	Chapt. 8, 8.1–8.15
	5) Loss of buoyancy	×			Chapter 10, 10.1–10.13	Chapt. 6, 6.1–6.13
Knowledge of	1) The emergency response for flooding due to damage, fire fighting, loss of buoyancy, and the effect on trim and stability.	×	×	×	Basics only in Chapt. 8, 8.9–8.10	Chapt. 6, 6.1–6.13
	2) Countermeasures for damage stability.	×	×	×	Basics only in Chapt. 8, 8.9–8.10	Chapt. 6, 6.12–6.13
	3) Effectively communicate stability-related information.	×	×	×	Chapt. 9, 9.1–9.5	Chapt. 1, 1.4–1.64, Chapt. 3, 3.1–3.19, Chapt. 4, 4.18, Chapt. 5, 5.1–5.20, Chapt. 6, 6.12–6.13
The effect of trim and stability of cargo and cargo operations.		×	×		Chapt. 1, 1.3, Chapt. 3, 3.1–3.4, Chapt. 5, 5.8–5.12, Chapt. 9, 9.1–9.5	Chapt. 1, 1.23, 1.38–1.42, 1.47–1.63, Chapt. 3, 3.13–3.19, Chapt. 5, 5.19–5.20

# CHAPTER 1

## Units of Measurement, Definitions, and Basic Stability

### 1.1 INTRODUCTION

This chapter is a summary to refresh the knowledge of the units of measurement, definitions, and basic stability as discussed in *Comprehensive Stability*.

### 1.2 UNITS OF MEASUREMENT IN THE METRIC AND CONVENTIONAL SYSTEMS

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; i.e., 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 <sup>2</sup>	metre per sec per sec	m/sec <sup>2</sup>
Area	square feet	ft <sup>2</sup>	square metre	m <sup>2</sup>
Density	pound per cubic ft	lb/ft <sup>3</sup>	kilogram per cubic m	kg/m <sup>3</sup>
Force	pound force	lb <sub>f</sub>	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 <sup>2</sup> ) kilogram/square cm	Pa kg/cm <sup>2</sup>
Temperature	degree Fahrenheit	°F	degree Celsius	°C
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 <sup>3</sup> gal bbl	cubic metre	m <sup>3</sup>
Work	foot-pound	ft-lb	joule Newton-metre	J N-m

## CHAPTER 2 Environmental Forces

### 2.1 INTRODUCTION

The objective of this chapter is to introduce the fundamental concepts of the effect on stability caused by environmental forces on a floating MODU. The environmental data is an important part of the rig design criteria to meet the required stability criteria.

### 2.2 ENVIRONMENTAL FORCES

The environmental forces acting on a MODU are caused by:

1. waves.
2. wind.
3. current.

### 2.3 MOTIONS

The floating drilling unit will respond on a single or a combination of the environmental forces with six types of motions (fig. 2.1):

Three rotational motions:

1. Roll
2. Pitch
3. Yaw

Three translational motions:

1. Surge
2. Sway
3. Heave

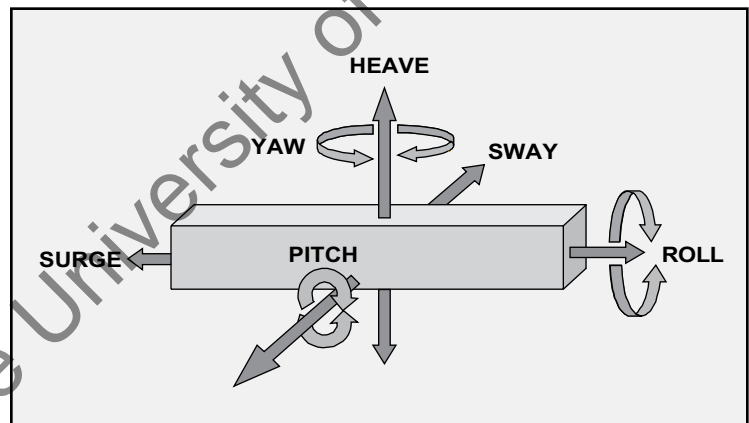


Figure 2.1 Rig motions

### 2.4 WAVE FORCES

All waves other than waves caused by earthquakes are generated by wind. The wind changes the water surface from ripples of 0.1 m (.25 ft) for light winds to exceptionally high waves of more than 14 m (46 ft). There are two types of waves:

1. Wind waves are waves generated by the wind at the location.
2. Swells are waves away from the area they were generated.

### 2.5 WAVE PROFILES

The explanation of the wave theory is based on a regular wave profile (fig. 2.2).

A regular wave is defined by

1. The *wave height* ( $H$ ) – The vertical distance between the top of a crest and the bottom of the trough in metres or ft. It is twice the *amplitude* which is the distance from still waterline to the top of the crest or the bottom of the trough.

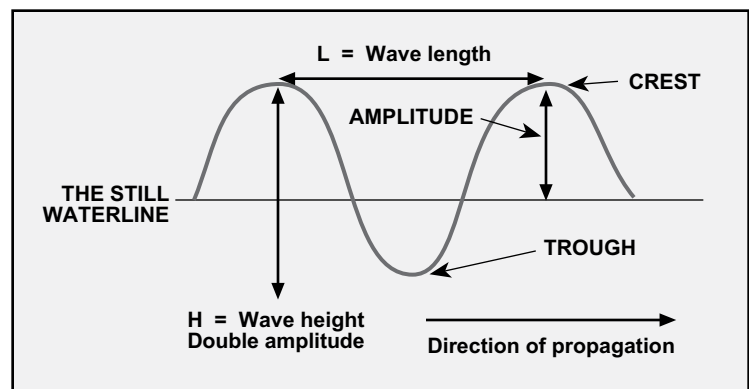


Figure 2.2 Wave profile

## CHAPTER 3

### Hydrostatic Properties and the Daily Stability Calculations

---

#### 3.1 INTRODUCTION

During the design and building stage, the naval architect calculates, with special computer generated programs, the rig's hydrostatic data.

The details of the hydrostatic data are tabulated in the hydrostatic properties. In addition, curves of stability are analyzed to confirm that the stability criteria is in accordance with the standards of the IMO, classification society, flag regulations, and local regulations. The information from the hydrostatic properties is used to perform the daily stability calculations.

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.

#### 3.2 HYDROSTATIC PROPERTY INFORMATION

Tables 3.1, 3.2, and 3.3 are typical examples of hydrostatic tables of two semisubmersibles and one drilling vessel.

The information in Imperial or metric system includes:

1. Draft in ft or m.
2. Displacement in st or mt (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 (TCF).
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 or one cm ( $MT1^\circ$  or MCT).
13. The moment to change the heel one degree or one cm ( $MH1^\circ$  or MCH).

#### 3.3 DRAFT

The draft is calculated at intervals of feet and metres or parts thereof.

## CHAPTER 4

### The Mooring System

---

#### 4.1 INTRODUCTION

The main purpose of the mooring system is to maintain the rig position over the well within the operating limits of the BOP and riser system. For all conditions, the rig will move off the zero position until the restoring forces of the mooring system are equal to the energy applied by the environmental forces.

#### 4.2 OPERATION CONDITIONS

Under normal operation conditions, the restoring forces from the mooring system maintain the rig position within the operating limits of the drilling equipment.

#### 4.3 MAXIMUM OPERATING CONDITIONS

The maximum operating condition is restricted to the

1. maximum allowable angle between the marine riser system and the BOP.
2. maximum stroke of the heave compensating system.
3. capacity of the riser tensioning system.
4. pretest tension.

The maximum allowable offset is, in most cases, expressed in percentage of water depth. The mooring analysis includes the anchor tension corresponding with the maximum allowable offset.

#### 4.4 SURVIVAL CONDITION

In addition to the operation conditions, the mooring system capacity must be able to maintain the rig safely moored in severe weather and current conditions with the riser system disconnected from the seabed.

#### 4.5 THE MOORING SYSTEM LIMITS

The mooring system itself is limited by the

1. holding power of the anchor.
2. length of the deployed chain.
3. safe cable tension.

#### 4.6 THE ANCHOR SYSTEM TENSIONS

The anchor system tension values and corresponding restoring forces are based on the

1. survival condition tension.
2. maximum operating tension.
3. optimum operating tension.

## CHAPTER 5

### Stability at Large Angles—Stability Curves

#### 5.1 INTRODUCTION

Until now, we described the theory of initial statical stability in the vertical, transverse, and longitudinal planes. Initial stability is the stability for small angles up to about  $8^\circ$  to  $12^\circ$ . For small angles, the intersection of the vertical through  $B$  with the centerline of the rig may be considered to be a fixed point. This point is called the metacenter ( $M$ ).

As a quick reminder, the interaction between  $G$  and  $M$  determines the amount of 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. 5.1).

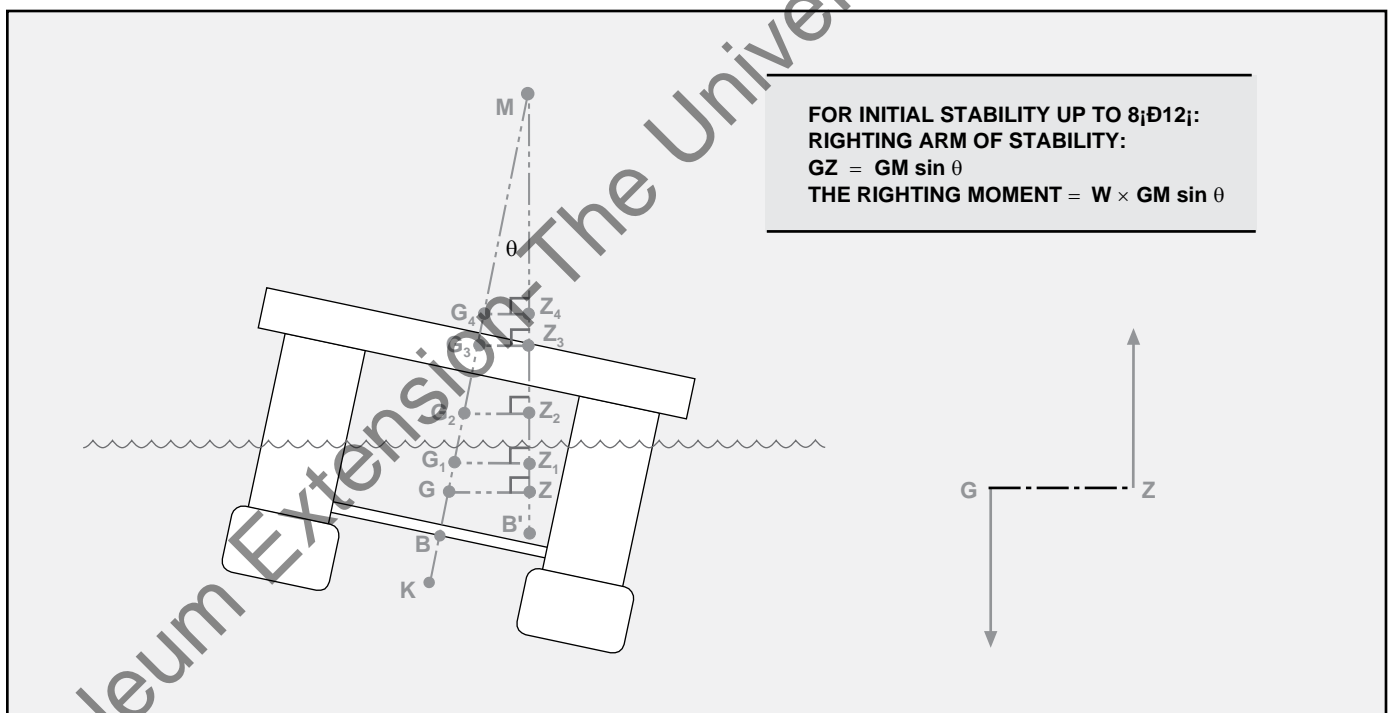


Figure 5.1 Stability couple—Change in the value of the stability arm

## CHAPTER 6

### Damage Stability

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#### 6.1 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.

#### 6.2 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.

#### 6.3 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.

#### 6.4 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 7 The Ballast System

### 7.1 INTRODUCTION

Ballast systems on board vessels were developed to enable a vessel to float at a specific draft required for transit. In addition, forward and aft trim tanks would give the vessel the possibility to use the most efficient trim condition for transit. A subdivision of a double bottom provided for the necessary amount of tanks, each connected with pipelines and valves to pumps to fill or empty the tanks.

With the arrival of jackups, submersibles, and semisubmersibles in the offshore drilling world a sophisticated ballast system was developed over the years to interchange the draft of the mobile offshore units from transit draft to operations draft. Jackup ballast systems are mainly used to trim the rig during transit and to preload the jackup to test the soil strength before the start of the drilling operation.

In this chapter, mainly the ballast systems used on semisubmersibles are used as an example to explain the principles of ballast systems.

### 7.2 THE MAIN BALLAST SYSTEM COMPONENTS

The main components of a ballast system on a semisubmersible are:

1. *The ballast tanks.* Each pontoon is divided identically by watertight bulkheads into a set of tanks. A specific amount of tanks are designated as ballast tanks. The remaining tanks may be for drill water or fuel tanks. Figures 7.1 and 7.2 are typical tank divisions for Rig Type 1 and Rig Type 2.

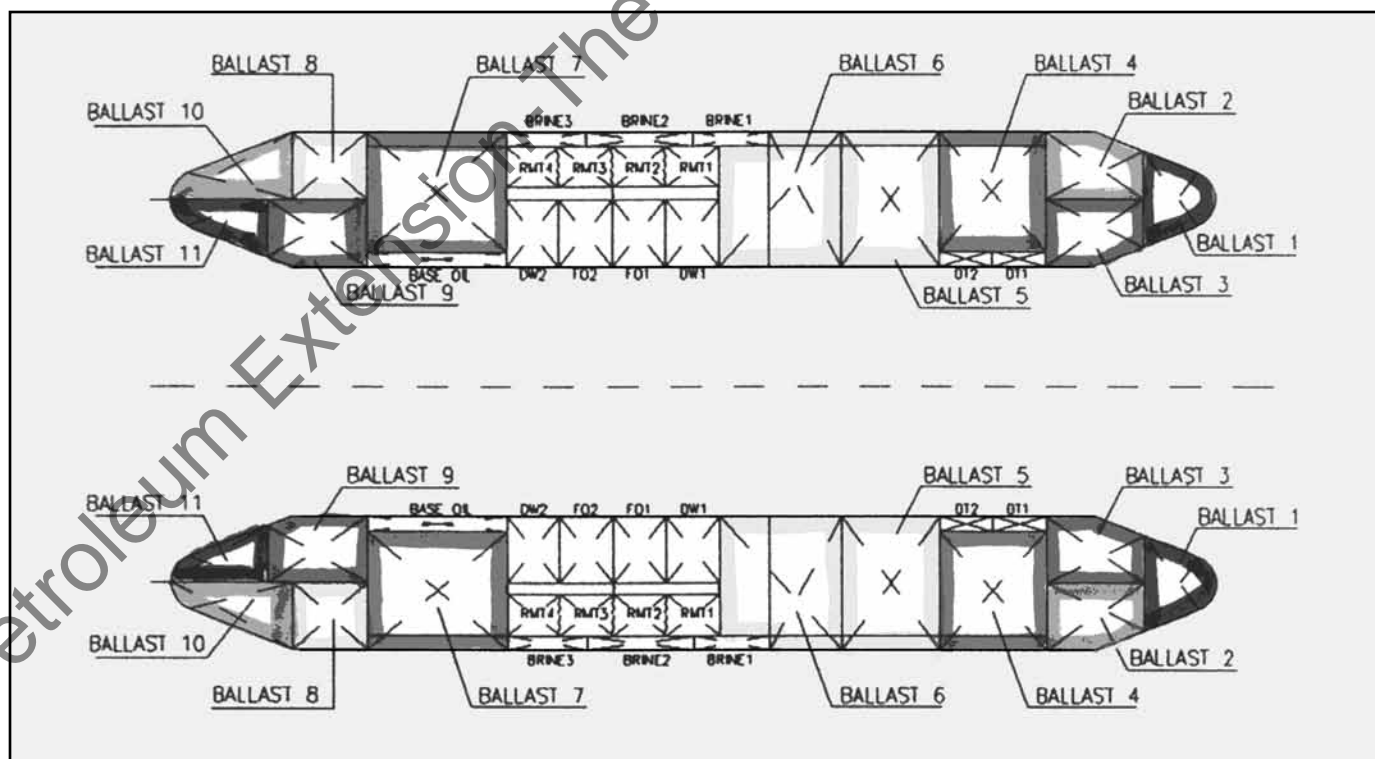


Figure 7.1 Example tank division Rig Type 1

## CHAPTER 8

### Design and Construction

#### 8.1 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.

#### 8.2 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 static or dynamic.

1. *Static 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.

#### 8.3 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/cm<sup>2</sup>. 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.

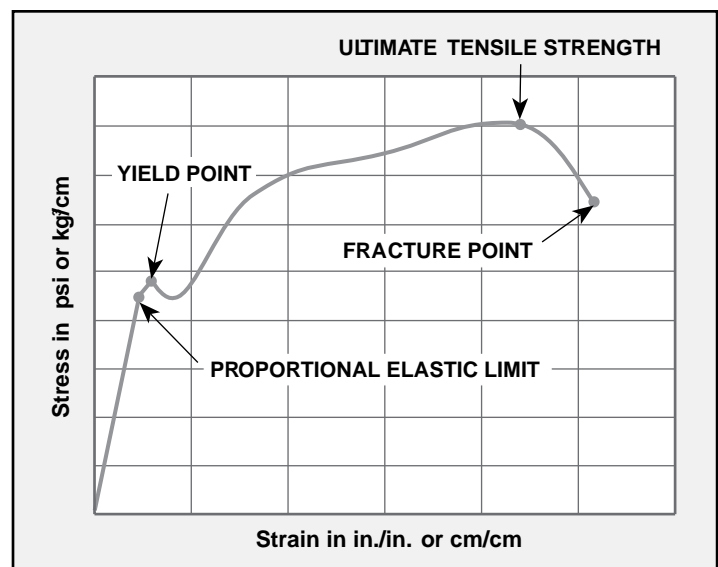


Figure 8.1 Example of a stress-strain diagram

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