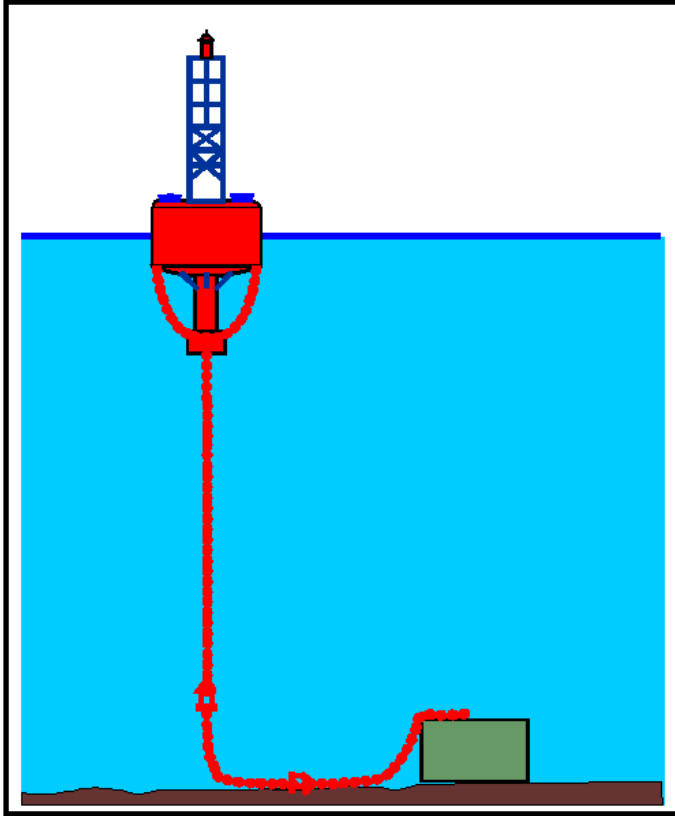**TP 13049E**
Mooring Selection Guide
Program Manual
Prepared for
Transportation Development Centre
Safety and Security
Transport Canada
(by Fleet Techology Limited)
March 1997

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TP 13049E
MOORING SELECTION GUIDE (MSG)

for Buoy Chain Mooring Systems
(version 1.10)

Program Manual

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Prepared for

Transportation Development Centre
Safety and Security
Transport Canada

Canadian Coast Guard
Marine Aids Division

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16. Abstract

A computer program known as the Mooring Selection Guide (MSG) has been developed to provide the Coast Guard with a tool for designing long life buoy mooring systems. The software considers the hydrodynamic loads, the long-term degradation (wear/corrosion) and residual strengths of the riding and thrash chains. In addition, the loads applied to the sinker are used to calculate a minimum required anchor size to hold the buoy on station. The software operates in either French or English, includes a complete menu-driven help system, and allows the user to store and retrieve mooring design data.

This manual presents information for installing and running the program and describes the algorithms included in the design process.

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16. Résumé

Le «Guide de sélection des systèmes de mouillage (GSSM)» est un logiciel mis au point pour la Garde côtière canadienne en tant qu'outil destiné à la conception de systèmes de mouillage à chaînes pour bouées à cycle de vie long. Ce logiciel tient compte de la détérioration à long terne (usure et corrosion) et de la résistance résiduelle des chaînes flottantes et de marnage ainsi que des charges hydrodynamiques imposées à celles-ci. Il utilise en outre les charges imposées aux crapauds pour déterminer la grosseur minimale du corps-mort qui servira à maintenir la bouée en place. Le logiciel peut être utilisé en français ou en anglais, comporte un système d'aide complet piloté par menu et permet à l'utilisateur d'emmagasiner ou de récupérer des données sur les calculs relatifs aux systèmes de mouillage.

Le présent ,anuel contient aussi des renseignements sur l'installation et l'exécution du programme ainsi qu'une description des algorithmes inclus dans le processus de calcul.

17. Mots clés	18. Diffusion
Mouillage, bouée, corps-mort, crapaud, systèmes de mouillage à chaîne	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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1. INTRODUCTION - SOFTWARE DESCRIPTION AND INSTALLATION

This document is the Program Manual for the Mooring Selection Guide (MSG) software developed for the Transportation Development Centre of Transport Canada (TDC) and the Canadian Coast Guard - Marine Aids to Navigation Group, by Fleet Technology Limited. The manual provides the user with information concerning the installation, operation and interpretation of the MSG software.

The manual is divided into the following five sections:

  1) Introduction - Software Description and Installation
  2) User Display Interfaces
  3) Tool Bar Icon Functions
  4) Data Fields
  5) Interpretation of Results

All of the information contained in sections 2 to 5 of this manual is available to the user in the MSG on-line help system.

1.1 MSG Software Development Background

The Marine Aids Division of the Canadian Coast Guard has the responsibility for design, installation and maintenance of navigation buoys. One of the important load carrying components in the buoy system is the mooring chain. In the past, its design requirements and procurement have been based primarily on the use of relatively low strength carbon steel chains.

As a matter of routine practice, the mooring chains have been inspected frequently and if the wastage due to corrosion and/or wear is considered unacceptable, then the chain is replaced. As a consequence of this proactive inspection and maintenance approach, the chain failures have been infrequent and the overall experience to date with mooring chains is considered to be a success.

However, the staff at Marine Aids Division felt that this record of success may not have been entirely cost effective due to chain inspection and replacement costs. About six years ago, the Division therefore set a target that the buoy system and the mooring chains should be able to provide at least five years of unattended service.

Another issue of interest to the Division is the use of higher strength and therefore smaller diametre chains. Use of lower strength, large diametre chains has two disadvantages. One is the increased weight resulting in reduced reserve buoyancy of the buoy which may affect survivability in extreme sea conditions, and the second factor is the added weight which affects handling during deployment and recovery.

To address both these issues, the Marine Aids Division initiated a five-year field study in 1989. In this field experiment, thrash chains made from different steels (carbon steel or alloy steel) or of different diametres (1.125" (28.6 mm) to 1.75" (44.5 mm)) were included in moorings of different lengths for five 2.9 m bell buoys deployed off Halifax Harbour (water depth 150 ft. (approximately 46 m)). All five riding chains in this field study were made from alloy steel conforming to specification MA 2020-E and were nominally 1.125" (28.6 mm) in diametre for the Mooring No. 1 and 1.25" (32 mm) in diametre for the remaining chains. The focus in this study was the degradation of thrash chains, since the greatest inter-link movement and therefore maximum wastage is encountered in the knee region of the thrash chain.

Following the five-year study, Fleet Technology Limited (FTL) of Kanata, Ontario, was contracted to undertake a study that would form the basis of recommending riding chain strength and diametre(s) for use in conjunction with 1.5" diametre thrash and ground chain for mooring 2.9 m bell buoys in water depths ranging from 30 m to 150 m. The longer term objective of this study is to meet the Marine Aids Division's goal of achieving a minimum of five years of unattended service from year-round navigation buoy mooring chains.

The study involved estimation and comparison of the peak steady state and dynamic loads on the riding chain under severe sea conditions and of residual strength of the riding chains of different sizes and qualities after five years of service. The dynamic load estimation was performed for a 10-year wave using the Moordyn program developed and validated by the National Research Council's Hydraulics Laboratories. The peak tension in the riding chain was estimated for selected combinations of riding chain diametres, mooring chain scopes and water depths. It was found that highest dynamic loads are experienced in shallower waters and for smaller mooring chain scopes.

The estimation of the residual strength of the riding chains required the development of an empirical model to predict the inter-link wastage rate due to wear and/or corrosion and another mechanics based model to predict the residual strength of chains as a function of the chain steel strength and wastage that might not be circumferentially uniform. The latter was based on a model developed from the wastage rates observed (in a previous CCG-sponsored study) for thrash and riding chains in the approaches to Halifax Harbour during a five-year service period.

Based on the above analyses and comparisons, it was concluded that Quality 2 chain, of appropriate size, would be suitable for riding chain applications in water depths ranging from 30 to 150 m. The mooring chain break load and material specification requirements in the current CCG chain specification were reviewed and amendments were recommended to reflect the findings of this study. Recommendations were also made concerning the selection of chain diametres and mooring scopes for 2.9 m bell buoys in water depths from 30 to 150 m for various factors of safety (ratio of residual strength of the chain after five years of service and the peak riding chain tension).

1.2 MSG Software Development Objective

The objective of the MSG software development project was to produce a buoy mooring chain selection guide in the form of a computer program which identifies riding, thrash and ground chains capable of providing five years of unattended service for the following CCG buoys:

- 2.9 m Lighted bell buoy
- 2.9 m Lighted whistle buoy
- 1.8 m Lighted buoy
- 1.4 m Lighted buoy

- 3 m Lighted scow buoy
- 1.5 m Lighted discus buoy
- 0.6 m Spar buoy
- 0.8 m Coastal buoy
  (can & conical version)

- 1.2 m Coastal buoy
  (can & conical version)
- 1.6 m Coastal buoy
  (can & conical version)

1.3 Software Features

The mooring selection guide software was developed to incorporate the following features for ease of use, versatility and future development:

Expandability
    Software will allow for the inclusion of further buoys and chain sizes as required by the client.

Chain Sizes
    The appropriateness of: 1/2, 5/8, 3/4, 1, 11/8, 11/4, 11/2 , 13/4 inch diametre riding and thrash chain portions of the mooring will be indicated.

Bilingual Presentation
    The user will be able to select either an English or French interface.

Wear Rate
    The user will be able to vary the typical chain wear rates ranging from 70 to 130 percent of those identified in the previous five-year CCG mooring study.

Service Life
    The user will be capable of specifying any mooring service life between one and five years.

Applicability
    The software will consider fresh and salt water environments.

Chain Materials
    The MSG will allow the user to identify the strength of the chains used in the selection process (i.e. Quality 1 or 2).

Mooring Safety
    The MSG will incorporate a minimum factor of safety of 2 against tensile failure due to conditions associated with a 10-year return period.

Units of Measurement
    Both imperial and SI units will be provided by the software.

Mooring Configuration
    The MSG software will identify acceptable chains for moorings with scopes ranging from 1.5 to 4 in water depths from 20 to 150 m (where appropriate for specific buoy types).

Software Compatibility
    The software will operate in a Microsoft Windows environment on an IBM PC compatible computer.

1.4 Hardware and Software Requirements

The mooring selection guide software was written for use in a Windows 3.1.x operating environment on a IBM PC compatible computer. The software was tested in a Windows 95 operating environment and no significant problems were identified.

The computer on which the software is to be run should be a 486 with a minimum of 8 megabytes of RAM and 10 megabytes of free hard disk space.

1.5 Software Installation

The Mooring Selection Guide Software is provided on four 3.5" floppy disks, individually numbered from 1 to 4. Follow the following steps to install the Mooring Selection Guide (MSG) software:

> 1) Place MSG disk 1 into your disk drive (a:)
> 2) In Windows go to the Program Manager
> 3) Select the "File" menu item
> 4) Select the "Run" menu item
> 5) Type "a:\setup" in the Command line box and press Enter

The user will be asked to approve the name of the MSG software program group name "Mooring Selection Guide". You should accept this name or provide a new one and then select the full program installation option. The user will also be asked to approve the drive and directory in which the MSG software is installed.

The installation program prompts the user to insert each of the four floppy disks as it installs the program files on your hard drive. The following is a list of files installed by the MSG installation software and their respective locations:

\windows\system\	\windows\	\MSG\	\MSG\
msabc200.dll	reg.dat [updated]	masafin.dll	msg010.ico
dao2016.dll	moorings.grp	msain200.dll	soa200.dll
msaexp20.dll	msg010.ini	msajn200.dll	system.ldb
msaje200.dll		msaole20.dll	system.mdg
msjeterr.dll		msarn200.dll	utility.ldb
msjetint.dll		msg.ldb	utility.mdg
		msg.mdb	wrkgadm.exe
		msg010.hlp	

The above file names and locations assumes that the MSG software program group was named "Mooring Selection Guide" and that the user installed the software in the ":\MSG" directory.

2. USER DISPLAY INTERFACES

The Mooring Selection Guide software user interface system was designed to allow the user to view all of the input data and design results at the same time. This arrangement resulted in a software that operates with a minimal number of interface screens. The relationships between the architecture of the major user interface screens are described below in Figure 2.1, and the sections which follow describe the features of these user interfaces.
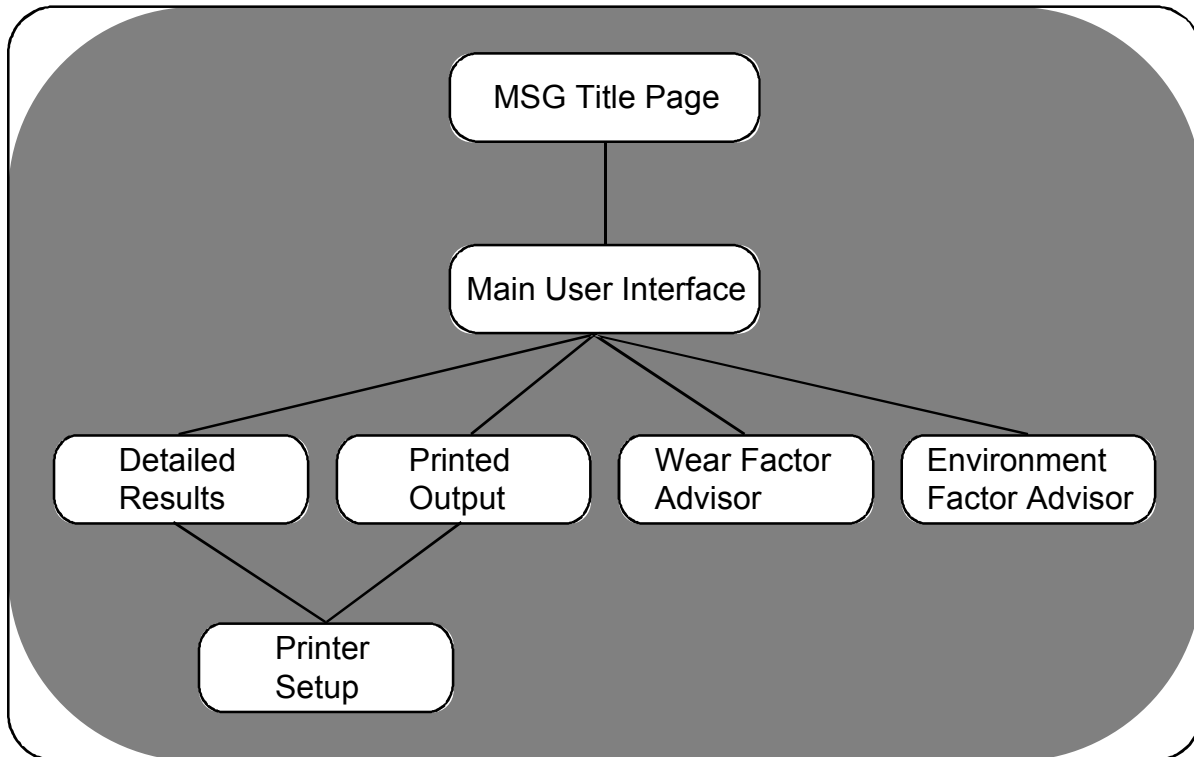
Figure 2.1: MSG User Interface Architecture

2.1 Title Page

The title page is presented to the user after the MSG icon has been selected in the mooring selection guide program group. The title page has the following six active buttons available to the user.

1) Translation - [English/français]
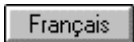
- This button translates the current screen between the English and French format. This button performs the same function as the translate or Language button on the main user interface.

2) Exit

- This button allows the user to exit the software to return to the windows program manager. The function of this button is the same as the Exit button on the main user interface.

3) Start

- Selecting this button will allow the mooring selection guide software to proceed to the main user interface screen where the mooring design data and results are displayed.

4) Canadian Coast Guard (Project Sponsor)

- This button provides the user with a point of contact at the CCG Marine Navigation Services headquarters which participated in sponsoring and developing the mooring selection guide software. Questions or comments concerning the software can be directed to the address, phone and/or fax number provided.

5) Transport Canada (Project Sponsor)

- This button provides the user with a point of contact at the Transportation Development Centre (TDC), Transport Canada, which participated in sponsoring and developing the mooring selection guide software.

6) Fleet Technology Limited (Software Development)

- This button provides the user with a point of contact at Fleet Technology Limited, the consulting firm responsible for the development of the mooring selection guide algorithms and software. Questions or comments concerning the software can be directed to the address, phone and/or fax number provided.

2.2 Main User Interface

The main user interface, shown below, can be divided into the following four areas:

1) Data Entry Area   (4) Tool Bar

(2) Acceptable Design Matrix   (3) Design Notes
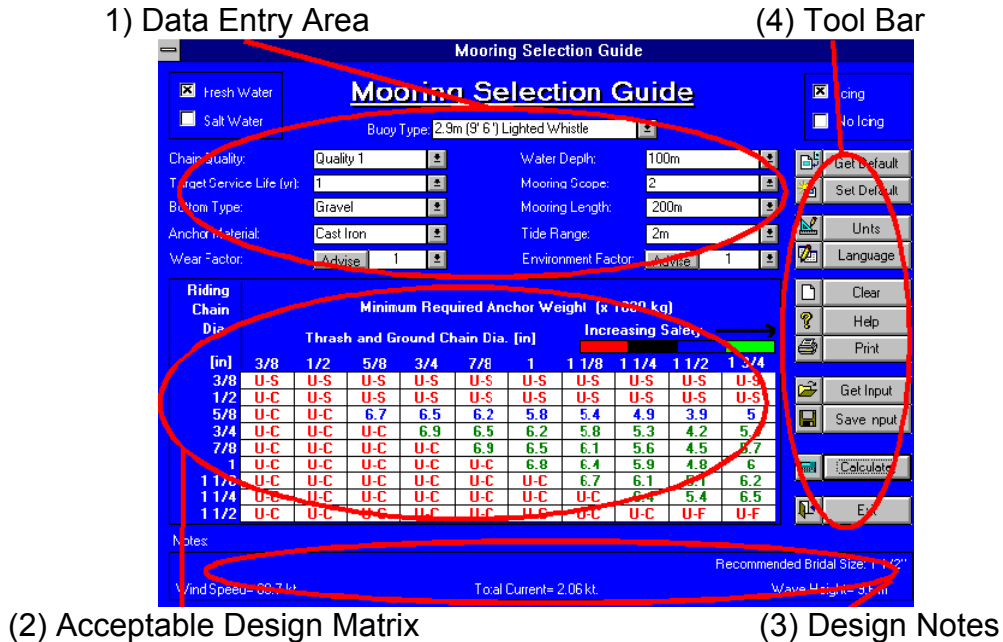
Figure 2.2: Main User Interface Features

(1) Data Entry Area - This area contains all of the mooring data required by the Mooring Selection Guide software. Further information concerning each data field can be obtained by selecting the field named below:

• Buoy Type	• Water Depth	• Mooring Length
• Chain Quality	• Mooring Scope	• Fresh/Salt Water
• Target Service Life	• Bottom Type	• Icing/No Icing
• Environment Factor	• Anchor Material	• Tide Range
• Wear Factor		

(2) Acceptable Design Matrix - Displays the results of the selection process, after the data is entered and the Calculate button has been pressed. The acceptability of all of the riding and thrash chain combinations are identified here. Acceptable results are identified by their minimum required anchor size.

(3) Design Notes - This area of the user interface screen is reserved for software generated design notes for the user.

(4) Tool Bar - includes the following eleven icons or buttons which control the operation of the software.

Exit	Help	Language
Print	Calculate	Units
Get Input	Get Default	Clear
Save Input	Save Default	
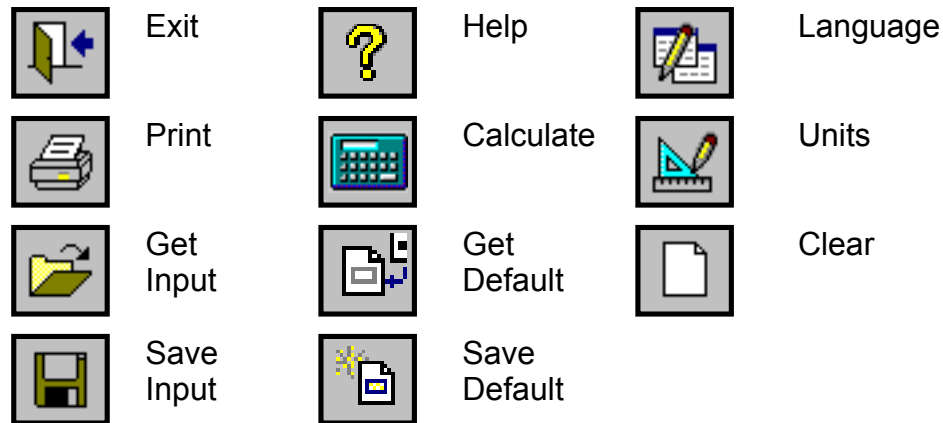
A detailed description of the mooring load and chain degradation used in the selection process can be accessed by selecting the acceptable design matrix cell associated with the riding/thrash chain combination of interest.

2.3 Detailed Results

Further information concerning the results displayed in any cell of the acceptable design matrix can be obtained by selecting the cell. In general, there are five classes of cells:

1) Unacceptable based on the design assumption that the thrash chain must be composed of a chain with a diameter larger than or equal to the riding chain.

2) Unacceptable due to a lack of freeboard. The buoy did not have sufficient reserve buoyancy to support the specified chain size combination under the given site and environmental conditions.

3) Unacceptable based on the level of safety provided. The residual strength of either the degraded riding or thrash chains do not provide the specified factor of safety with respect to their peak mooring loads.

4) Unacceptable based on the required chain strength for anchor retrieval. The residual strength of either the degraded riding or thrash chains do not provide the specified factor of safety (2) with respect to the minimum specified anchor weight. These cells are denoted by a red U-R referring to the minimum required anchor retrieval chain strength.

5) Acceptable solution. The residual strength of the degraded riding and thrash chains both exceed their respective peak mooring loads by at least the specified factor of safety.

Detailed information outlining the mooring loads and degradation data used in the design checks to ensure mooring feasibility can be obtained for the latter two classes of acceptable design matrix cells. The information which is provided is displayed below:
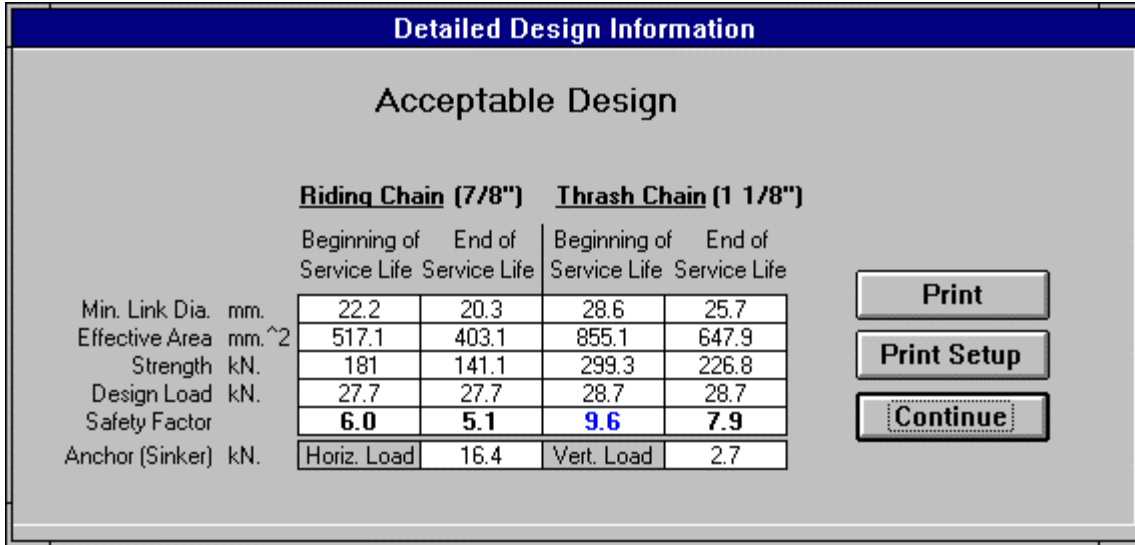
Figure 2.3: Acceptable Design Matrix Detailed Information Screen

The link diameter reported in the acceptable design matrix detailed results is the minimum link cross-sectional diameter for the riding and thrash chain links, which as noted in the design checks may not have a circular cross section. As well, the wear rate of the riding and thrash chains are different due to their different operational environments.

The Effective Area relates the wear factor and residual strength to an assumed circular worn chain cross section.

The detailed information screen for those cells which are unacceptable due to insufficient chain strength will have the title "Unacceptable Design" included.

The user can print the detailed results for the currently selected acceptable design matrix cell by pressing the print button. This action will print all of the information which is displayed on the screen in addition to all of the input data describing the mooring.

The user is provided with a print preview prior to printing to review the data and ensure that it is correct. After reviewing the contents of the preview screen the user sends the job to the printer by pressing the Print icon.

2.4 Wear/Environment Factor Advisors

The wear and environment factor advisors have been included in the software to provide advice to the user in the selection of the wear and/or environment factors. The advisors allow the user to supplement the design information used by the software with personal experiences of chain wear rates and environmental conditions particular to a region or mooring site.

2.4.1 Wear Factor Advisor

When the advisor button, located beside the wear factor data field is pressed, a wear factor advisor screen similar to that shown below, appears.

Figure 2.4: Wear Factor Advisor

The objective of the wear factor advisor is to aid the user in comparing an observed wear rate with the design wear rate estimated by the MSG software. In order to perform this comparison, the wear factor advisor requires that the user describe the mooring configuration being considered in terms of its water depth, mooring scope and bottom type. The default values for these input fields are those displayed on the main user interface prior selecting the advisor, displayed in the system of units used on the main user interface. Alternate values for these data fields can be either entered from the keyboard or selected from the pull-down menus provided.

The user must also provide chain wear information. This data is arranged in two columns, riding and thrash chain information, since the riding and thrash chain sections of the mooring may wear at different rates and thus require different wear factors. The following chain wear information is included in the wear advisor for both the thrash and riding chains:

Nominal Chain Diameter - This data field describes the nominal diameter of the chain of interest at the beginning of its service life. This information can either be entered from the keyboard or selected from the pull-down menu provided.

Duration of Service - This data field indicates the how long the worn chain being used as a point of reference was in service. This information can either be entered from the keyboard or selected from the pull-down menu provided.

Predicted Minimum and Maximum Chain Diameters - This data is provided to inform the user of the worn dimensions being used in the MSG residual chain strength calculation. Minimum and maximum chain diameters are provided to describe the cross section of a chain link as non-uniform wear around a link's circumference may result in a non-circular cross section as shown in Figure 2.5.
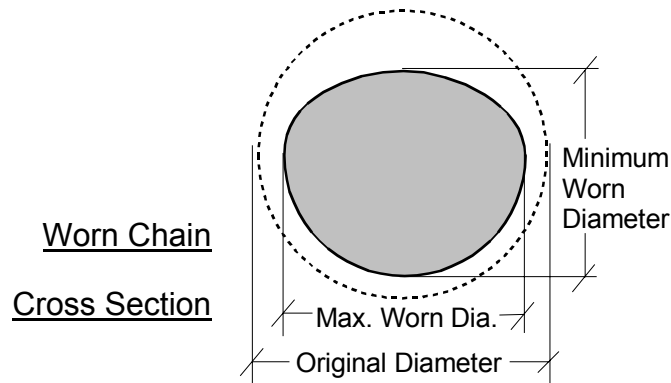
Figure 2.5 - Idealized Worn Chain Cross Section

Observed Minimum and Maximum Chain Diameter - This data is provided by the user to describe the observed chain wear event which occurred during a length of time equal to the duration of service data field. It is only necessary for the user to provide the minimum chain diameter in order to receive advice.

Recommended Wear Factor - This field is filled in by the wear advisor algorithm based on the ratio of the residual strengths of the MSG estimated and user specified worn chain link geometries (nominal, minimum and maximum diameters). This value is updated based on the data provided by the user when the Advise button is pressed.

The recommended wear factor(s) calculated after pressing the Advise button are transferred to the main user interface if the Accept button is selected. If the Cancel button is selected the user will be returned to the main user interface page without making any changes to the wear factor data field.

2.4.2 Environment Factor Advisor

When the advisor button, located beside the environment factor data field is pressed, an environment factor advisor screen similar to that shown below, appears.

Figure 2.6: Environment Factor Advisor

The objective of the environment factor advisor is to aid the user in comparing an observed set of environmental conditions with the design environmental conditions estimated by the MSG software. In order to perform this comparison the environment factor advisor requires that the user describe the buoy mooring being considered in terms of the buoy type, water depth, mooring chain length, Tide Range and riding chain diameter. The default values for these input fields are those displayed on the main user interface prior selecting the advisor; displayed in the system of units used on the main user interface. Alternate values for these data fields can either be entered from the keyboard or selected from the pull-down menus provided. The mooring scope is calculated and displayed in the buoy mooring description for the user's information.

The user must also provide a set of observed High Tide Environmental Conditions. This data is arranged in a column beside the MSG design environmental conditions. The environmental conditions which must be provided include the Wind Speed (kt), Wave Height (m or ft) and Current Speed (kt). The user does not need to fill in all of the environmental conditions. Any fields which are left blank will be <u>assumed to be the same as the design environmental conditions</u> and thus will not affect the environment factor estimation.

The recommended environment factor calculated after pressing the Advise button is transferred to the main user interface if the Accept button is selected. If the Cancel button is selected, the user will be returned to the main user interface page without making any changes to the environment factor data field.

2.5 Printer Setup

Selection of the printer setup option in the Print menu will allow the user to access the printer setup options associated with the current version of Windows. The printer set-up selections and options are the same as those for any Windows application.

2.6 Printed Output

When the user requests printed output by selecting the Print option the software is capable of providing two output formats: Standard and Detailed in either printed or electronic forms.

2.6.1 Standard Output

All of the user input data, mooring description information, design notes and the acceptable design matrix results are printed in a form similar to that shown in Figure 2.7.

Mooring Selection Guide   09-Dec-96
Buoy No.: Num 4   **Lat.:** 442756.0
L.L. No.: 513.500   **Lon.:** 362733.0
Area: Approaches to Halifax Harbour
Notes: Copy of information from CCG buoy mooring database

Buoy Type: 2.9 m (9' 6") Lighted Whistle

Chain Quality: Quality 1	**Water Depth:** 100m
Target Service Life: 1 (yr)	**Mooring Scope:** 2:1
Bottom Type: Gravel	**Mooring Length:** 200m
Anchor Material: Cast Iron	**Tide Range:** 2m
Wear Factor: 1	**Environment Factor:** 1
Water: Salt	**Icing:** No

Riding Chain Dia. [in] — **Minimum Required Anchor Weight (x 1000 kg)**

Thrash and Ground Chain Dia. [in]

Riding Chain Dia. [in]	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2	1 3/4
3/8	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S
1/2	U-C	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S
5/8	U-C	U-C	U-S	U-S	U-S	U-S	U-S	U-S	U-S	U-S
3/4	U-C	U-C	U-C	U-S	U-S	U-S	U-S	U-S	U-S	U-S
7/8	U-C	U-C	U-C	U-C	U-S	U-S	U-S	U-S	U-S	U-S
1	U-C	U-C	U-C	U-C	U-C	7.5	7	6.5	5.5	4.4
1 1/8	U-C	U-C	U-C	U-C	U-C	U-C	7.4	6.9	5.9	4.8
1 1/4	U-C	U-C	U-C	U-C	U-C	U-C	U-C	7.3	6.2	5.2
1 1/2	U-C	U-C	U-C	U-C	U-C	U-C	U-C	U-C	7	5.9

Notes:
Minimum Recommended Anchor Weight Used   Recommended Bridle Size: 1 1/2
    Wind Speed = 68.7 kt   Total Current = 2.06 kt   Wave Height = 9.6 m

Figure 2.7: Sample Standard Printed Output

2.6.2 Detailed Output

All of the user input data, mooring description information, design notes and the acceptable design matrix results are printed in a form similar to that shown for the standard output format along with the following additional detailed mooring selection information. The detailed information printed is that for each cell of the acceptable design matrix which represents an acceptable combination of riding and thrash chain sizes and for which the minimum acceptable sinker size is shown.

The format of the additional mooring selection information provided in the detailed output format is shown in Figure 2.8.

Mooring Selection Guide 09-Dec-96

Nominal Riding Chain Diameter	Nominal Thrash Chain Diameter	**Riding Chain Design Data**			**Thrash Chain Design Data**		
		Effective Area [mm^2]	Residual Strength [kN]	Design Load [kN]	Effective Area [mm^2]	Residual Strength [kN]	Design Load [kN]
1	1	512.4	179.4	43.5	509.5	178.3	34.2
1	1 1/8	512.4	179.4	43.5	647.9	226.8	37.1
1	1 1/4	512.4	179.4	43.5	806.3	282.2	40.1
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•

Nominal Riding Chain Diameter	Nominal Thrash Chain Diameter	**Anchor Design Data**	
		Horizontal Load [kN]	Vertical Load [kN]
1	1	19.9	2.7
1	1 1/8	18.7	2.7
1	1 1/4	17.3	2.7
•	•	•	•
•	•	•	•
•	•	•	•

Figure 2.8: Sample Additional Information in Detailed Printed Output

3. TOOL BAR ICON FUNCTIONS

The operation of the mooring selection guide is controlled by the icons contained in the tool bar at the extreme right hand side of the main user interface screen. The following sections describe the operation of these tool bar icons

	Exit		Calculate		Get Input
	Language		Help		Save Default
	Print		Clear		Get Default
	Units		Save Input		

3.1 Exit

This icon is pressed to leave the mooring selection guide program and return to the Windows environment. The data in the data entry fields entered during the current working session will not be automatically retained for the next working session. All of the data and results which are required for future reference should be printed or saved by pressing the Print or Save Input Data icons before exiting the program.

3.2 Language

This icon is pressed to toggle between English and French versions of the MSG software. The language change affects all of the data fields, headings and help text. On the software title screen the language toggle is operated by depressing the "français" or "English" icon.

3.3 Print

This icon allows the user to produce a printed or electronic record of the current data and results. Pressing the print icon automatically triggers an acceptable design matrix recalculation prior to assembling the output data to ensure that the data fields match the acceptable design matrix results. After the recalculation, a buoy site identification form, similar to that shown below, is presented to the user to complete.

Figure 3.1: Buoy Site Identification Form

The site identification form is set up to organize mooring site identification or location information. As this information is used for record keeping purposes only. The user is free to complete as many or as few of the fields as desired.

The buoy site identification form is arranged into six data fields as follows:

- Buoy No. - the user may enter the CCG buoy number in this 20-character field to identify the buoy and mooring location.

- L.L. No. - this field contains the CCG List of Lights Number which can be used to identify the buoy and mooring location.

- Coordinates

    Lat. - mooring site latitude.

    Long. - mooring site longitude.

- Area - this 20-character field can be used to describe a buoy's area of operation.

• Notes - a 300-character field used to record any comments concerning the design process or mooring location.

• Date - this field is automatically filled by the program with the computer's current date to identify the mooring design date.

After completing the buoy site identification fields the user has five options activated by buttons:

• Save Results - this button allows the user to save the mooring selection guide data and results to a file. The data file which is created is in Rich Text Format (*.rtf) which can be read by most word processors, spreadsheets and database software. The default data file name is "report__.rtf". If the user does not wish to use this name a windows file storage menu similar to that invoked by the "save as" command will be presented to the user to complete.

• Print Standard - this button sends a standard design summary to the printer which includes all of the current mooring design data, results and information visible to the user on the main user interface. After sending the mooring design information to the printer the user is returned to the main user interface screen.

• Print Detailed - this button sends a detailed design summary to the printer which includes the standard output format information plus all of the mooring load and degradation data used in the selection process, displayed as detailed results when a cell in the acceptable design matrix is selected. After sending the mooring design information to the printer the user is returned to the main user interface screen.

• Printer Set-up - this button will call up the windows printer set-up menu to select the printer and configure the printing process.

• Cancel - this button will cancel the printout and return the user to the main user interface screen.

3.3.1 Sending Data to the Printer

The user is provided with a print preview to inspect the data and ensure that it is correct. After reviewing the contents of the preview screen, the user sends the job to the printer by pressing the print icon.

The output file is in "rich text format" which can be read by most word processors, spread sheets and data base softwares. The default file name is "standard.rtf", If the user wants to change the default file name, a Windows file manager screen, similar to the "save as" screen, will appear.

3.4 Units

This icon is pressed to toggle between SI metric, imperial (English) feet and imperial fathoms systems of units for data presentation. The units change affects all of the data fields and results. The chain sizes (diametres) used as headings for the acceptable design matrix are provided in inches only and will not be changed by the units button since these sizes designations are considered to be industry standards.

The table which follows outlines the imperial (English) and SI metric units which are used to present the data and results.

Characteristic	Imperial (English)	SI metric	Conversion
Chain Quality (UTS)	ksi	MPa	1 ksi = 6.894 MPa
Water Depth	ft. or Fm	m	1 ft. = 0.3048 m
Tide Range	ft. or Fm	m	1 ft. = 0.3048 m
Mooring Length	ft. or Fm	m	1 ft. = 0.3048 m
Acceptable Design Matrix			
Chain Diametre	in	mm	1 in = 25.4 mm
Anchor Size	1 000 lbs	1 000 kg	1 lb = 0.453 kg

Note: kg can be converted to kN with the following conversion:

$$kN = kg \times 9.81 \div 1\,000$$

3.5 Calculate

This icon will cause the acceptable design matrix to be updated based on the current design data:

- Buoy Type
- Chain Quality
- Target Service Life
- Environment Factor
- Wear Factor

- Water Depth
- Mooring Scope
- Bottom Type
- Anchor Material

- Mooring Length
- Fresh/Salt Water
- Icing/No Icing
- Tide Range

Updating the acceptable design matrix involves design checks which ensure adequate buoy freeboard and mooring chain residual strength based on the mooring configuration and design assumptions.

Each time any of the input data fields is modified the acceptable design matrix will go blank as it no longer matches the input data.

Selecting the print icon will automatically trigger a recalculation of the acceptable design matrix prior to producing output.

3.6 Help

This icon will activate the help menus to provide further information concerning the program navigation and operation, data fields and interpretation of results.

These help menus operate in the same manner as other Windows applications. Any text displayed in green is "hyper-text" and when selected by clicking with the mouse will provide the user with further information concerning the selected item.

3.7 Clear

This icon allows the user to clear all of the data fields on the main user interface screen at once. All of the data field entries will be erased and new values will have to be entered.

3.8 Save/Get Input Data

These options allow the user to save and retrieve all of the input data on the main user interface screen in a data base for future reference. Each set of MSG input data is associated with the buoy site identification information included in a printout of the computational results. The mooring data is identified by its Buoy number and/or its L.L. number.

3.8.1 Data Retrieval

When the Get Input Data icon is selected, a Mooring Site Identification form similar to that shown in Figure 3.2 appears.

Figure 3.2: Data Retrieval Mooring Site Identification Form

In order to retrieve data the user must provide the Buoy number and/or L.L. of the mooring data to be retrieved. The user may select from a list of either Buoy numbers or L.L. numbers which have previously been used to save input data. The remainder of the mooring site information displayed on the Mooring Site Identification for is displayed to help the user distinguish between sites.

The data which is identified by the Mooring Site Information is placed in the input data fields on the main user interface page only if the user presses the Select button. If the Cancel button is pressed the user is returned to the main user interface without changing the mooring input data.

The user may also delete previously saved input data sets by selecting the record to be deleted and pressing the delete button.

3.8.2 Saving Data

When the Save Input Data icon is selected, a Mooring Site Identification form similar to that shown in Figure 3.3 appears:

Figure 3.3: Save Data Mooring Site Identification Form

In order to save the input data the user must provide a Buoy number and/or L.L. number to identify the data. The remainder of the Mooring Site Identification data helps to identify the mooring site but is not necessary. The data is saved when the Save button is pressed. If the user presses the Cancel button no data will be saved and the user will be returned to the main user interface screen.

If the user tries to save data identified by a Buoy number or a L.L. numbers which has already been used to save data, the user will be asked if he/she wants to overwrite the existing data set. If both the Buoy number and the L.L. number provided by the user to identify the mooring site have already been used to save data, but they were used for two different mooring sites, the user will not be allowed to overwrite the data.

3.9 Save/Get Defaults
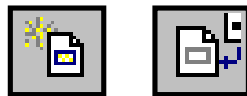
The values displayed in the data fields:

• Buoy Type	• Water Depth	• Mooring Length
• Chain Quality	• Mooring Scope	• Fresh/Salt Water
• Target Service Life	• Bottom Type	• Icing/No Icing
• Environment Factor	• Anchor Material	• Tide Range
• Wear Factor		

when the mooring selection guide software is run, are called the default data. The user can customize the default data set by setting the desired values in the data fields and pressing the save defaults button. The save default function also saves the user's current language and system of units selection.

The default data field values can be recalled at any time by pressing the Get Defaults button. This action will replace the current data field entries with those previously saved as the default values.

4. DATA FIELDS

This section of the user manual provides information on the values displayed in the mooring selection guide main user interface data fields:

- Buoy Type
- Chain Quality
- Target Service Life
- Environment Factor
- Wear Factor

- Water Depth
- Mooring Scope
- Bottom Type
- Anchor Material

- Mooring Length
- Fresh/Salt Water
- Icing/No Icing
- Tide Range

4.1 Buoy Type

This field lists those buoy types for which the mooring selection guide will operate. Below is the buoy type description table which lists all of the buoys considered by the MSG software and categorizes them by their primary usage (i.e. Deep Water, Coastal or Estuary). The CCG drawings associated with each buoy type are listed in the table and the general configuration each buoy is provided after the table. The CCG recommended minimum water depth for each buoy, determined based on operational and buoy draft considerations, is provided in the table along with the CCG recommended bridle size and minimum anchor (sinker) size for each buoy type.

Table 4.1: Buoy Type Descriptions

Buoy Type	CCG Drawing Number	Minimum* Water Depth [m (ft.)]	Bridle* Size [in.]	Min. (Max.)* Anchor Size [kg]
Deep Water Buoys				
2.9 m (9'6") Lighted Whistle	FA-1010	10 (32.8)	1 1/2	2 700 (4 500)
2.9 m (9'6") Lighted Bell	FA-1007	5 (16.4)	1 1/2	1 800 (3 600)
1.8 m (6'0") Lighted	FA-1004	5 (16.4)	1 1/4	1 150 (3 600)
1.4 m (4'6") Lighted	FA-1001	2 (6.6)	1 1/4	500 (2 300)
Coastal Buoys				
0.6 m (2'0") Spar Short	FA-3005	2 (6.6)	N/A	450 (2 700)
0.6 m (2'0") Spar Long	FA-3005	3 (6.6)	N/A	450 (3 600)
0.8 m (2'6") Coastal Conical ver.	FA-2002	2 (6.6)	N/A	225 (2 300)
0.8 m (2'6") Coastal Can ver.	FA-2001	2 (6.6)	N/A	225 (2 300)
1.2 m (4'0") Coastal Conical ver.	FA-2004	2 (6.6)	N/A	450 (900)
1.2 m (4'0") Coastal Can ver.	FA-2003	2 (6.6)	N/A	450 (900)
1.6 m (5'6") Coastal Conical ver.	FA-2006	5 (16.4)	N/A	450 (900)
1.6 m (5'6") Coastal Can ver.	FA-2005	5 (16.4)	N/A	450 (900)
Estuary Buoys				
3.0 m (10'0") Lighted Scow	FA-1015	2 (6.6)	1	450 (1 200)
1.5 m (5'0") Lighted Discus	FA-1019	1 (3.3)	N/A	225 (680)

Notes: * Recommended by CCG.

The primary use designation of each buoy type is used in the determination of the design environmental conditions since different operational environments will have different characteristics. The minimum anchor size limits the anchor size selection process to anchors larger than or equal to those which are commonly used by the CCG.

| 2.9 m (9'6")
Lighted Whistle | 2.9 m (9'6")
Lighted Bell | 1.8 m (6'0")
Lighted | 1.4 m (4'6")
Lighted |
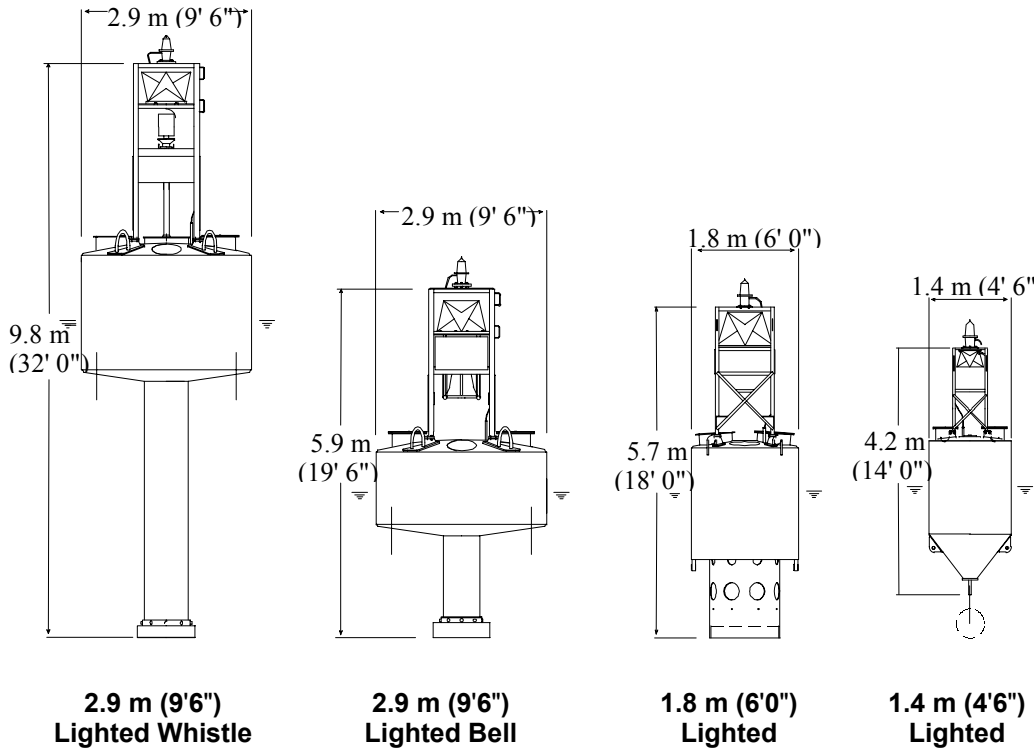
Figure 4.1: Deep Water Buoys

| 0.6 m (2'0")
Spar Long | 0.6 m (2'0")
Spar Short | 1.6 m (5'6")
Coastal Conical ver. | 1.6 m (5'6")
Coastal Can ver. |
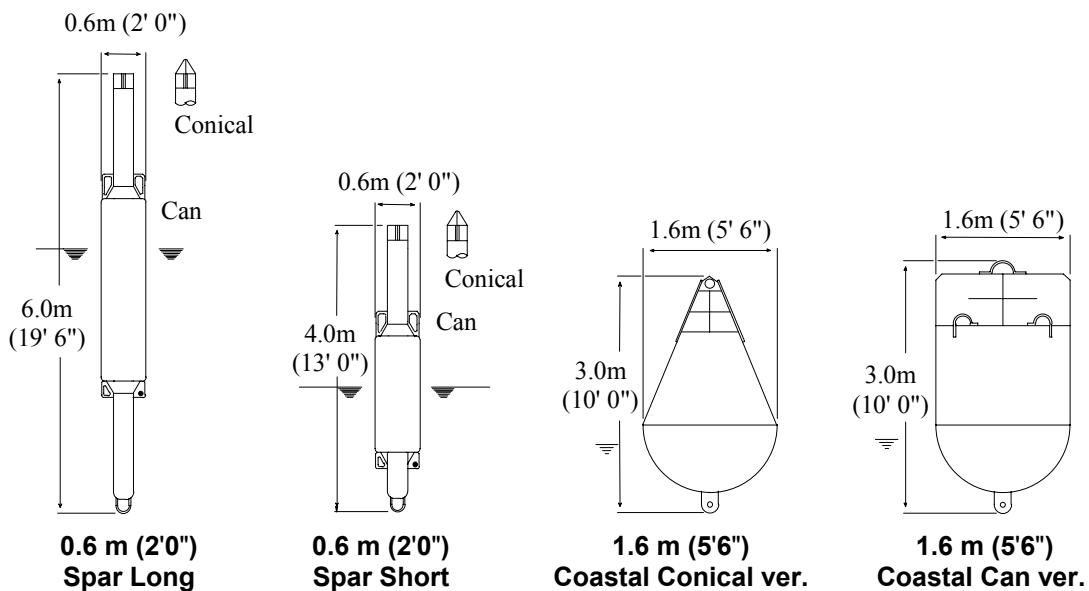
Figure 4.2a: Coastal Buoys

1.2 m (4'0")
Coastal Conical ver   **1.2 m (4'0")**
Coastal Can ver.   **0.8 m (2'6")**
Coastal Conical ver.   **0.8 m (2'6")**
Coastal Can ver.
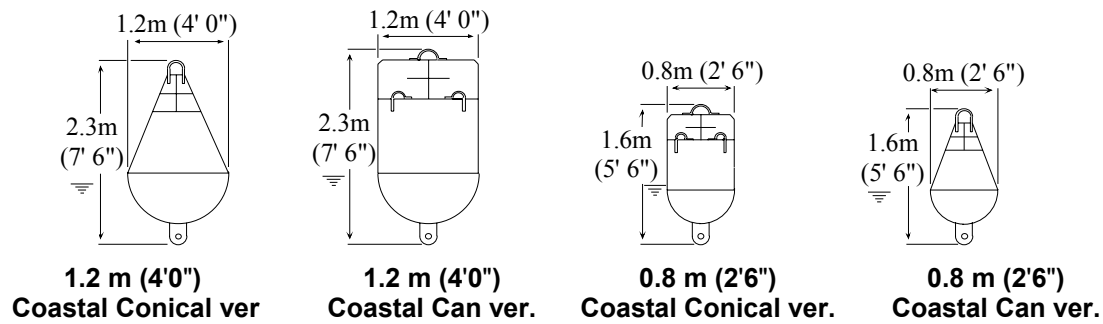
Figure 4.2b: Coastal Buoys

3.0 m (10'0")
Lighted Scow   **1.5 m (5'0")**
Lighted Discus
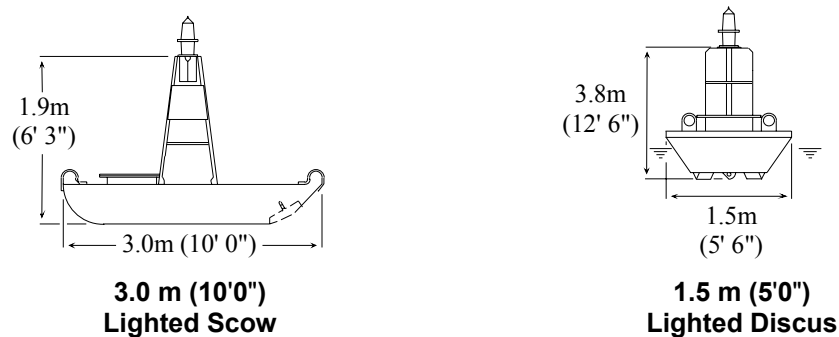
Figure 4.3: Estuary Buoys

4.2 Water Depth

The low tide water depth at the mooring site (in metres, feet or fathoms) is entered in this data field. The minimum recommended water depth for each buoy type is based on the buoy's draft and the mooring site's low tide water depth. The high tide water depth is the sum of the low tide water depth and the tide range.

The program will display a warning message if a water depth below the minimum recommended for the buoy type is selected (see buoy type for information on minimum recommended water depths). The maximum water depth for a buoy is determined based on the minimum buoy freeboard design check.

This field is linked to the mooring scope and mooring length data fields based on the following relationship:

$$\text{mooring scope} = \frac{\text{mooring length}}{\text{water depth}}$$

In mooring scope definition, the mooring length is the chain length. The contributions of the bridle and the buoy draft to the mooring length are ignored in the mooring scope calculation. This approximation is used to simplify the mooring scope calculation and will not significantly affect the mooring scope value in most mooring design cases.

The water depth is used to calculate either the mooring scope or mooring length when the other is provided by the user.

4.3 Mooring Length

This data field allows the user to specify the length of the chain used in the buoy mooring. The mooring chain length includes the riding, thrash and ground chain lengths.

This field is linked to the mooring scope and water depth data fields based on the following relationship:

$$\text{mooring scope} = \frac{\text{mooring length}}{\text{water depth}}$$

In the mooring scope definition, the mooring length is the chain length. The contribution of the bridle and the buoy draft to the mooring length are ignored in the mooring scope calculation. This approximation is used to simplify the mooring scope calculation and will not significantly affect the mooring scope value in most mooring design cases.

When the water depth and either of the mooring length or mooring scope are specified, the remaining field is calculated.

4.4 Chain Quality

This data field allows the user to specify the strength or "Quality" of the steel from which the mooring chains are made. The user can select Quality 1, 2 or 3 chains which are standard chain strength grades used by the classification societies (i.e. ABS, DnV, Lloyd's) denoting the following characteristics:

Table 4.2: Chain Quality

Mooring Chain Quality [MPa]	Minimum Specified Yield Strength MPa (ksi)	Minimum Specified Ultimate Strength J (ft lb)	CVN Toughness @ 0°C
1	no requirement	350 (51)	no requirement
2	295 (43)	490 (71)	27 (20)
3	490 (71)	686 (100)	60 (44)

Alternatively, the user can specify the ultimate tensile strength (UTS) of a material which will be used to fabricate the mooring chain. The UTS should be provided in MPa or ksi for results in metric or imperial units, respectively. It should be noted that the ultimate tensile strength of the material from which a chain is fabricated is not the same as the ultimate strength of the chain.

The software will accept ultimate tensile strength values from 100 to 1 200 MPa and 15 to 175 ksi for metric and imperial data, respectively.

4.5 Mooring Scope

The mooring scope is defined as the ratio of mooring chain length to water depth at the mooring site (length/depth). While the mooring selection guide checks the value of both the high and low tide scopes and estimates mooring chain loads for each, only the low tide scope is displayed in the scope data field. Acceptable mooring scopes are based on the CCG's suggested range of water depth applications for each buoy type. The mooring scopes displayed in the data filed are the numerators of the ratios of mooring length to water depth (i.e. 3 means a ratio of 3 to 1).

The program will display an error message if the mooring scope is above or below the suggested range of scopes (i.e. 1.5 to 4.0). When the error message is cleared the incorrect mooring scope value will be cleared from the input field.

For shallow water moorings, the selection of acceptable chain diameters can be influenced by the mooring scope. For a given site, shorter moorings (i.e. smaller scope) will tend to experience higher peak loads than longer moorings (i.e. larger scope). Increasing a buoy's mooring scope can be used to reduce the peak mooring tension and thus the required mooring chain size when operational requirements allow.

This field is linked to the water depth and mooring length data fields based on the following relationship:

$$\text{mooring scope} = \frac{\text{mooring length}}{\text{water depth}}$$

In the mooring scope definition, the mooring length is the chain length. The contributions of the bridle and the buoy draft to the mooring length are ignored in the mooring scope calculation. This approximation is used to simplify the mooring scope calculation and will not significantly affect the mooring scope value in most mooring design cases.

When the water depth and either of the mooring length or mooring scope are specified the remaining field is calculated.

4.6 Fresh/Salt Water

This pair of check boxes, on the main user interface screen, allows the user to identify the water type (fresh or salt water) for which the mooring should be designed. Only one of either the fresh or salt water check boxes may be selected at a time.

The mooring environment water type effects the buoy reserve buoyancy calculations due to the difference in the density of fresh and salt water which are assumed to be 1 000 kg/m^3 and 1 027 kg/m^3, respectively.

Mooring chain loads do not vary significantly between the fresh and salt water cases. For this reason only the salt water mooring chain loads are calculated and used in the design checks for both fresh and salt water moorings.

4.7 Target Service Life

The mooring chain's target (or desired) service life, time period between replacement, is entered in this field in years (units of 1/10th of a year). The target service life data is used to identify the expected extent of link wear and corrosion at the end of the chain's target service life. This worn cross-sectional geometry is used to assess the residual strength of the mooring chain and is compared to the peak mooring tension to determine the adequacy of the mooring chain in the design checks.

The degradation models used in this software were developed based on geometric data collected in CCG field tests of various mooring chains. The longest CCG field test collected data over a five year period. For this reason the application of the degradation models is limited to a range of one to five years with an extrapolation to six years.

4.8 Bottom Type

The bottom type which exists at the mooring site is entered in this data field. This information is used in the design check calculations for the minimum acceptable anchor (sinker) size. The software includes the following four bottom type descriptions which are associated with the listed soil properties and embedment depth ratios (= depth of embedment/anchor height)(see Table 4.3).

Table 4.3: Bottom Type Soil Property Data

Assumed Soil Property		Solid Rock	Loose Gravel	Coarse* Soil	Fine** Soil
Internal Friction Angle	ϕ	N/A	35	9	21
Unit Weight [kN/m³]	γ	N/A	20	15	18
Cohesion [kN/m²]	c'	N/A	0	10	7
Embedment Ratio	α	0.0	0.25	0.5	1.0
Chain Soil Cover [m]	d	0.0	0.1	0.25	0.25
Bottom Soil Friction Angle					
Concrete Anchor	δ_c	29	22	12	6
Cast Iron Anchor	δ_s	27	20	10	5
Rock Anchor	δ_r	29	24	14	8

Notes:
* The coarse soil ground type represents soft clay bottom conditions
** The fine soil ground type represents silts or fine sand bottom conditions

The bottom soil friction angle is a function of both the bottom type and the anchor material (i.e. concrete, cast iron or rock).

The minimum required anchor weight is calculated when the Calculate icon is pressed and is displayed in the acceptable design matrix for each acceptable thrash and riding chain size combination.

4.9 Icing/No Icing

This data item allows the user to specify if buoy icing should be considered in the mooring chain selection process. If the user elects to include buoy icing in the selection process, the distribution and thickness of the ice applied to the buoy is calculated in accordance with the CCG Stability design rules (TP 7301E). Ice accretion, (accumulation) is dealt with in the Environmental Factors sub-section of the Intact Stability section of STAB 7.

The icing loads, which are a function of buoy surface area, and thus the Buoy Type, are assumed to be applicable to only the four largest lighted buoys. The calculated buoy ice mass for each of the four buoy types are shown in Table 4.4.

Table 4.4: Buoy Ice Loads

Buoy Type	Calculated Ice Mass [kg]
2.9 m (9'6") Lighted Whistle	2 095
2.9 m (9'6") Lighted Bell	1 580
1.8 m (6'0") Lighted	929
1.4 m (4'6") Lighted	394

The effects of icing are incorporated in both the freeboard feasibility design check and in the mooring chain hydrodynamic load estimates. For both of these calculations it is assumed that the ice load is distributed uniformly so as not to affect the buoy's attitude.

4.10 Environmental Factor

The mooring chain loads which are compared by the MSG software to the worn chain residual strengths in the design checks are based on the MSG design environmental conditions (wind speed, current, wave height and period). These environmental conditions are a function of the water depth and buoy type which is assumed to be related to the mooring environment.

The environment factor is used to account for the fact that each mooring location has unique environmental conditions which may be more or less severe, result in higher or lower chain design loads, than those used as the MSG design environmental conditions. The MSG design environmental conditions are displayed in the Design Notes portion of the main user interface.

The environment factor represents the ratio of the peak mooring chain load based on the users observed environmental conditions to that based on the MSG design environmental conditions:

$$\text{Environment Factor} = \frac{\text{Observed Mooring Chain Load}}{\text{MSG Mooring Chain Load Estimate}}$$

If the environmental conditions of the mooring site being considered are more severe and generate higher mooring chain loads than those assumed as the design environmental conditions, then an environment factor greater than 1.0 should be selected. Conversely, values less than 1.0 may be selected for sites with less severe environmental conditions than those used as the design environmental conditions. The software will allow the user to input any value for the environment factor ranging from 0.2 to 5 (i.e. 1/5 to 5 times the strength).

Advice on the selection of an appropriate environmental factor is provided to the user when the Advise button beside the environment factor data entry field is selected.

4.11 Anchor Material

The anchor material field is used to identify the material used to fabricate the mooring anchor. The bottom type, chain diameter and mooring chain tension at the anchor are used in conjunction with the anchor material density to calculate the minimum required anchor weight. The chain diameter and bottom type are used to estimate the drag (holding power) of the ground chain.

The anchor materials which are considered by this program are listed below along with their associated weight densities.

Table 4.5: Anchor Material Properties

Anchor Material	Weight [kN/m³]	Density [lb/ft³]
Cast Iron	71	452
Concrete	23.5	150
Rock	18	115

The minimum required anchor weight is calculated when the calculate icon is pressed and is displayed in the acceptable design matrix for each acceptable thrash and riding chain size combination.

4.12 Tide Range

The tide range is the greatest observed change in water depth at the mooring site in metres, feet or fathoms.

The tidal range is used with the water depth data field to calculate the design mooring depths. Since the water depth data field is the low tide water depth the high tide water depth is the sum of the tide range and the low tide water depth.

The high tide water depth is used to check the buoy minimum freeboard requirements for each chain combination in the acceptable design matrix. The residual strength of the worn mooring chains is compared against the most severe loads generated in both the high and low tide mooring conditions.

4.13 Wear Factor

The degradation models used in this software were developed based on geometric data collected in a number of CCG field tests of various mooring chains. The most significant set of data was collected during the CCG's five-year mooring study carried out in the Halifax Harbour area. The rate of wear in any mooring chain is dependent on the characteristics (bottom type, water depth, etc.) of the site in question, but the data upon which the degradation models are based was collected for test sites including the Halifax Harbour area which is known to have a water depth of approximately 46 m (150 ft.) and a rock bottom type.

The wear factor is used to account for the fact that each mooring location has unique site conditions and bottom types which may be more or less severe in terms of chain wear than those present at the CCG mooring test sites. The following are the environmental conditions for the Halifax Harbour test site:

Table 4.6: Halifax Harbour Mooring Site Environmental Conditions

Description	Units	Average	Once in 10 year
Tide	[m (ft.)]	1.8 (6.0)	2.7 (9.0)
Current	[m/s (ft./s)]	0.6 (2.0)	1.2 (4.0)
Wind	[m/s (ft./s)]	6.4 (21.0)	30.5 (100.0)
Wave Height	[m (ft.)]	1.1 (3.5)	10.7 (35)
Wave Period	[sec.]	9.0	12.0

The sea bottom at the Halifax Harbour test site consists of exposed bedrock with boulders.

The wear factor represents the ratio of the worn chain's residual strength estimated based on the MSG degradation model and the actual chain strength:

$$\text{Wear Factor} = \frac{\text{MSG Residual Strength Estimate}}{\text{Observed Chain Strength}}$$

If the mooring site conditions result in higher chain wear than that estimated by the MSG wear model then a wear factor greater than one should be selected. Conversely, values less than 1.0 may be selected for sites with wear rates lower than expected by the MSG wear model. The software will allow the user to input any value for the wear factor ranging from 0.2 to 5 (i.e. 1/5 to 5 times the strength).

Advice on the selection of an appropriate wear factor is provided to the user when the Advise button beside the wear factor data entry field is selected.

4.13.1 Multiple Wear Factors

It is possible that the wear factors recommended by the wear factor Advisor are different for the riding and thrash sections of the mooring chain. In this case, the entry in the wear factor data field should be entered in the form "1.1/1.4", where the first number (wear factor) "1.1" represents the riding chain wear factor and the second entry "1.4" represents the thrash chain wear factor. If only one wear factor is entered it is applied to both the riding and thrash sections of the mooring chain.

5. INTERPRETATION OF RESULTS

This section describes the assumptions incorporated in the design process and outlines the calculations carried out. The design notes which are used provide the user with additional information used in the design process.

5.1 Acceptable Design Matrix

The principal component of the main user interface screen is the acceptable design matrix which resembles shown in Figure 5.1.

Riding Chain Dia.	Minimum Required Anchor Weight (x 1000 kg)									
	Thrash and Ground Chain Dia. [in]						Increasing Safety →			
[in]	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2	1 3/4
3/8										
1/2	U-C									
5/8	U-C	U-C								
3/4	U-C	U-C	U-C							
7/8	U-C	U-C	U-C	U-C						
1	U-C	U-C	U-C	U-C	U-C					
1 1/8	U-C	U-C	U-C	U-C	U-C	U-C				
1 1/4	U-C	U-C	U-C	U-C	U-C	U-C	U-C			
1 1/2	U-C	U-C	U-C	U-C	U-C	U-C	U-C	U-C		

Figure 5.1: Acceptable Design Matrix

Each column of the acceptable design matrix is associated with a ground and thrash chain size (diameter) while the rows are associated with a riding chain size.

Each entry in the acceptable design matrix represents a riding and thrash chain design combination. A cell which contains a "U" is an unacceptable design based on the design checks performed by the software which include: buoy freeboard and chain residual strength requirements. Any cell containing a numerical value represents an acceptable design. The numerical value is the minimum anchor/sinker size required for the current input data(i.e. buoy type and bottom type, etc.) given in 1 000 kg or 1 000 lb. for metric or imperial units, respectively.

Further information concerning the results displayed in any cell of the acceptable design matrix can be obtained by selecting the cell. In general, there are five classes of cells:

1) Unacceptable based on the design assumption that the thrash chain must be composed of a chain with a diameter larger than or equal to the riding chain. These cells are denoted by a red U-C referring to the relative chain sizing criterion.

2) Unacceptable due to a lack of freeboard. The buoy did not have sufficient reserve buoyancy to support the specified chain size combination at high tide. These cells are denoted by a red U-F referring to the minimum required buoy freeboard criterion.

3) Unacceptable based on the level of safety provided. The residual strength of either the degraded riding or thrash chains do not provide the specified factor of safety with respect to their peak mooring loads. These cells are denoted by a red U-S referring to the minimum required safety criterion.

4) Unacceptable based on the required chain strength for anchor retrieval. The residual strength of either the degraded riding or thrash chains do not provide the specified factor of safety (2) with respect to the minimum specified anchor weight. These cells are denoted by a red U-R referring to the minimum required anchor retrieval chain strength.

5) Acceptable solution. The residual strength of the degraded riding and thrash chains both exceed their respective peak mooring loads by at least the specified factor of safety and the freeboard is not less than the pre-determined minimum allowable.

The acceptable mooring chain designs are colour coded based on their level of conservatism (factor of safety), as shown in Table 5.1 and in the bar chart of increasing safety in the acceptable design matrix.

Table 5.1: Acceptable Design Matrix Factors of Safety

Acceptable Design Category	Factor of Safety	Color
Efficient	≥ 2	Black
Conservative	≥ 2.5	Blue
Extremely Conservative	≥ 3	Green

Detailed results outlining the mooring loads and degradation data used in the design checks to ensure mooring acceptability can be obtained for the latter two classes of acceptable design matrix cells by selecting the appropriate cell.

The most economic mooring chain combination would be the acceptable riding and thrash chain combination located nearest to the top left of the acceptable design matrix. This combination represents the lightest mooring chain combination.

5.2 Design Assumptions

The Mooring Selection Guide program identifies feasible riding and thrash chain size combinations based on user specified design data:

- Buoy Type
- Chain Quality
- Target Service Life
- Environment Factor
- Wear Factor

- Water Depth
- Mooring Scope
- Bottom Type
- Anchor Material

- Mooring Length
- Fresh/Salt Water
- Icing/No Icing
- Tide Range

which is assumed to apply to a mooring similar in configuration to that shown in Figure 5.2.
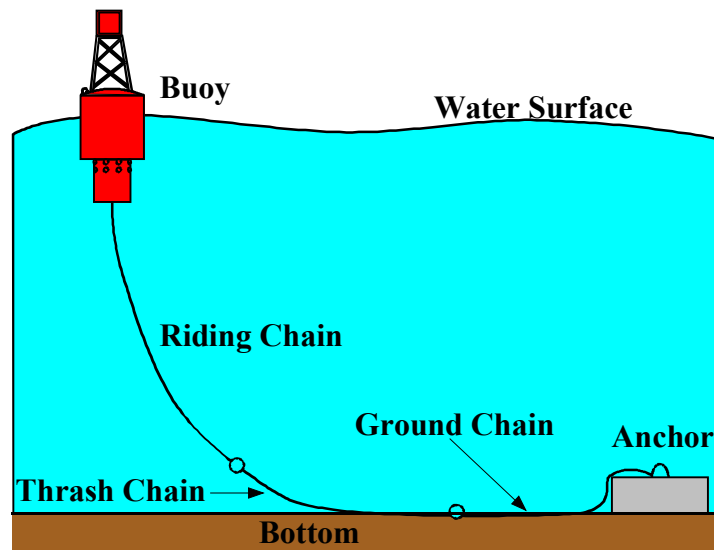
Figure 5.2: Idealization of Buoy Mooring System

The acceptable design matrix is generated by applying freeboard and chain residual strength design checks on the mooring configuration displayed above. In order to efficiently perform the required calculations the following assumptions have been made regarding the behaviour and characteristics of the design moorings.

- The ground chain and thrash chain are assumed to have the same size (diameter) links.

- The thrash chain should have links larger or equal to those in the riding chain.

- The length of the riding chain is assumed to be 90 percent of the minimum (low tide) water depth.

- The buoy motions and thus the mooring chain loads are approximated by the numerical model which omits the roll and pitch buoy motions.

- The peak chain load and degradation are assumed to occur at the same location: directly under the buoy for the riding chain and at the riding/thrash chain connection for the thrash and ground chains. This assumption is generally true for the riding chain and is a conservative design assumption for the thrash chain.

- In estimating the minimum anchor size the anchor is conservatively assumed to be a cube.

- The difference between the fresh and salt water mooring chain loads is negligible.

- The mooring design calculations are performed for each buoy based on 10 year return period design wave, wind and current environmental conditions associated with each buoy type.

Further information outlining the reasoning and sensitivity studies behind these assumptions and approximations are provided in the CCG/TDC reports associated with the development of this software.

5.3 Design Environmental Conditions

The Mooring Selection Guide design process is based on environmental conditions representing the worst wind, wave and current conditions in a ten year period. As these environmental conditions vary with location (i.e. estuary, coastal and deep water), the environmental conditions were estimated for these three location types which are associated with the primary usage of each buoy type. The design environmental conditions associated with the selected buoy type and water depth are displayed on the main user interface in the design notes area.

5.3.1 Estuary Buoy Design Environmental Conditions

The estuary mooring location is typically characterized by high currents and relatively low wave heights and wind speeds due to the sheltered nature of the mooring location. While the environmental conditions shown below vary as a function of water depth from 1 to 150 metres, the expected range of application of estuary type buoys is in the 1 to 20 metre water depth range.

Figure 5.3: Estuary Buoy Design Environmental Conditions

5.3.2 Coastal Buoy Design Environmental Conditions

The coastal mooring location is typically characterized by high wind speeds and wave heights which are moderated by the coastal environment. While the environmental conditions shown below vary as a function of water depth from 1 to 150 metres, the expected range of application of coastal type buoys is in the 5 to 45 metre water depth range.

Figure 5.4: Coastal Buoy Design Environmental Conditions

5.3.3 Deep Water Buoy Design Environmental Conditions

The deep water mooring location is typically characterized by relatively low currents and high wave heights and wind speeds due to the exposed nature of the mooring location. While the environmental conditions shown below vary as a function of water depth from 5 to 150 metres, the expected range of application of deep water type buoys is in the 30 to 150 metre water depth range.
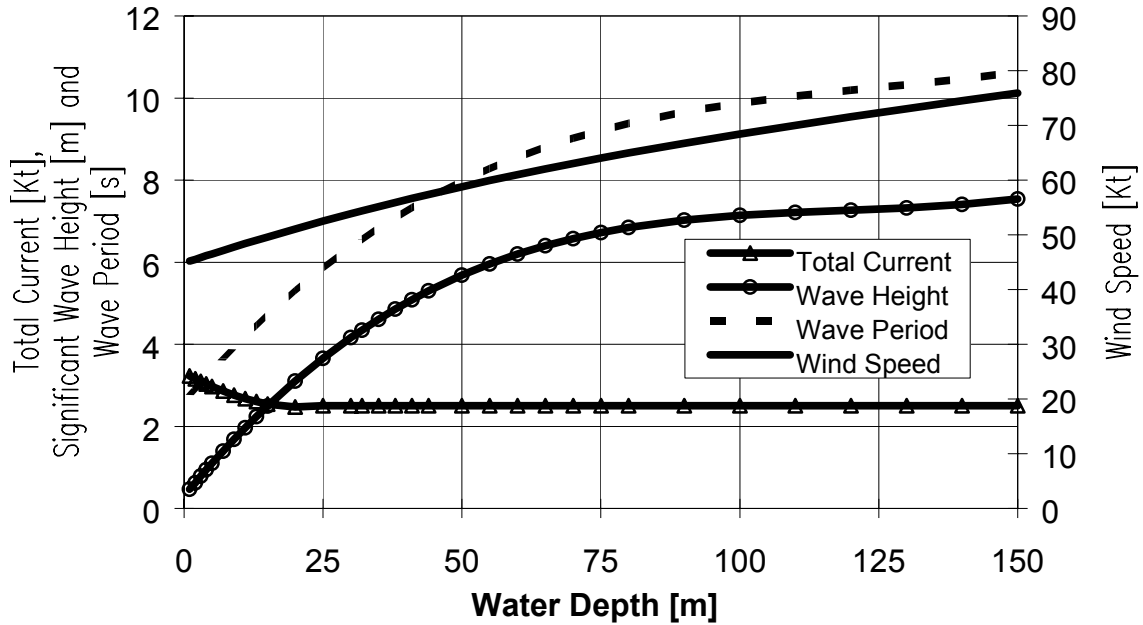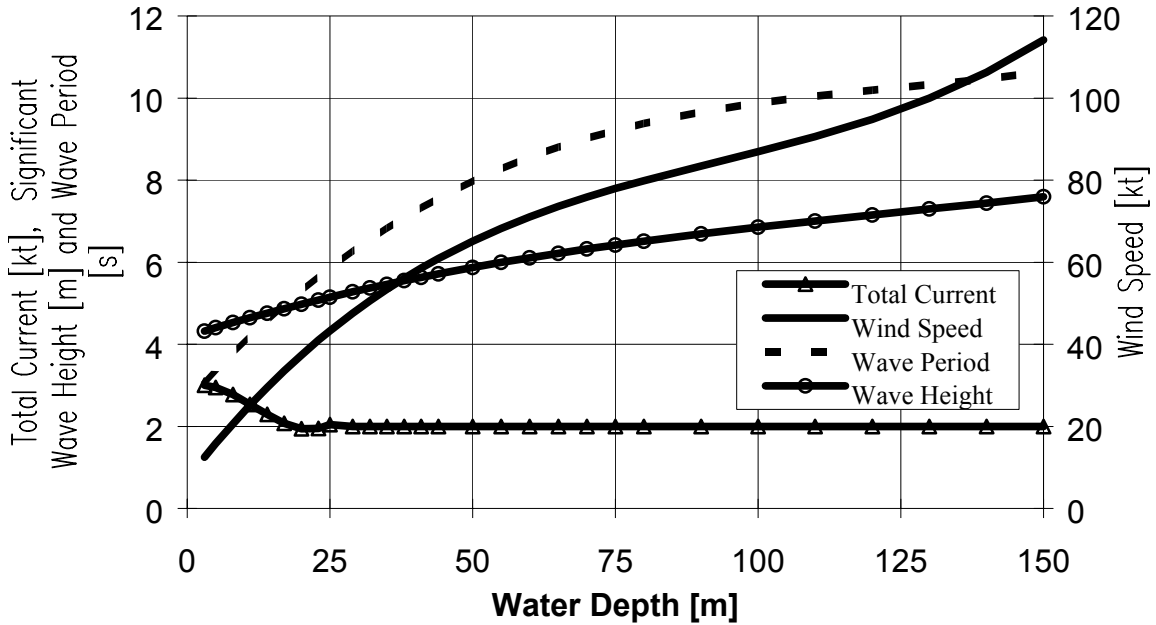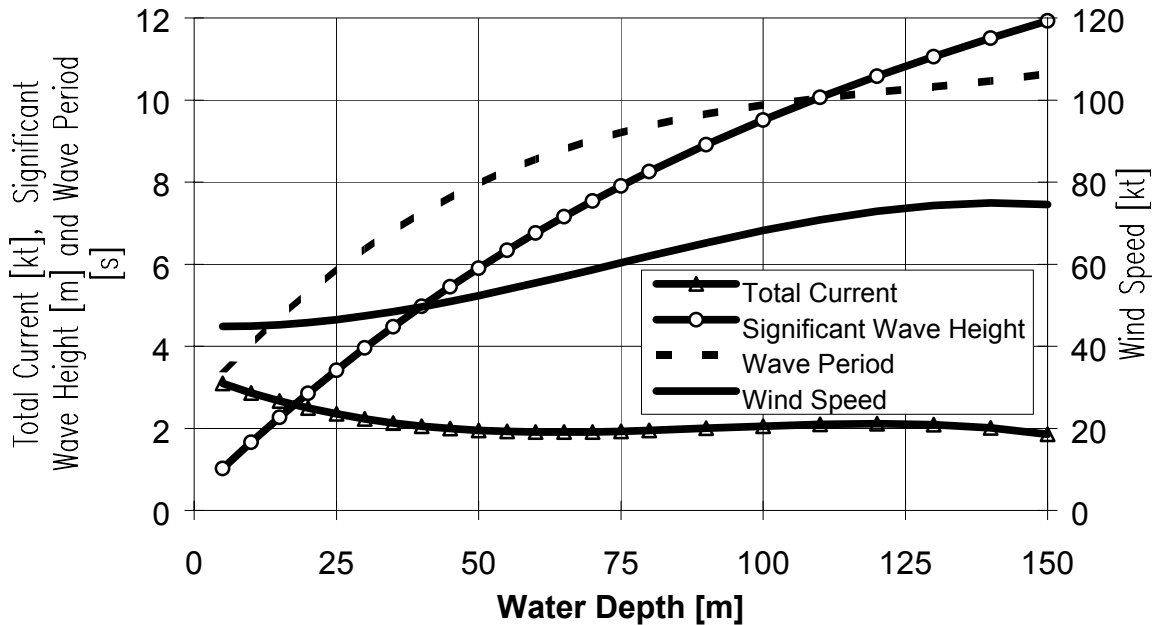
Figure 5.5: Deep Water Buoy Design Environmental Conditions

5.4 Design Notes

Design notes are used to provide guidance to the user. The following is a list of notes which the user may encounter.

Non-Standard Steel Strength - If the user selects a steel Quality or inputs a steel ultimate tensile strength in the chain quality field other than Quality 1 or 2 this message will appear. This message is used to alert users that they have selected a chain other than that specified in the CCG mooring chain material specification (MA 2080).

Minimum Anchor Size Selected - If any of the calculated anchor sizes shown in the acceptable design matrix are based on the CCG's minimum specified anchor sizes associated with the buoy type this design note will appear.

Recommended Bridle Size - This message provides the bridle chain diameter recommended by CCG for use with each buoy type.

Design Environmental Conditions - The design wind, current, wave height and period used in estimating the mooring design loads are displayed here. This information can be used as the basis for selecting an environment factor.

The design notes will appear on the both the printout and the main user interface screen below the acceptable design matrix.

5.5 Design Checks

The feasibility of each riding chain and thrash chain size (diameter) combination displayed in the acceptable design matrix is checked to ensure that the selected buoy type supporting the mooring chain has sufficient freeboard, the thrash and riding chains can support the peak mooring load at the end of their service life, and that the anchor/sinker will hold the buoy on station. The design process steps are listed and described below:

5.5.1 Check Minimum Buoy Freeboard

The effects of the mooring chain weight, current, wind drag and buoy self weight are considered in this design check which ensures that the buoy's CCG minimum specified freeboard requirement is maintained at the high tide water depth.

5.5.2 Determine Peak Mooring Chain Loads

The design loads for the anchor (sinker), riding and thrash chains are determined based on a catalogue of mooring design loads which were generated for each buoy type, chain size, water depth and mooring scope combination and the design environmental conditions. The riding chain design load is the peak tension which occurs just below the buoy. The thrash chain design load is assumed to be the peak tension at the junction of the thrash and riding chains. The anchor design load is the peak tension at the mooring chain attachment to the sinker.

The environment factor is used to account for the difference in peak mooring chain loads associated with the design environmental conditions and those observed by the user.

5.5.3 Estimate Mooring Chain Target Service Life Degradation

During the service life of a mooring chain the cross-sectional area of the chain links is reduced through a combination of mechanical wear and corrosion. The models used in this design process to predict the maximum degradation of the mooring chain links at any time during their target service life were developed based on geometric data collected in CCG field tests of various mooring chains.

Due to the mechanical wear and corrosion which have been observed to occur during the service life of a mooring chain, the cross sections of the links do not remain circular. Figure 5.6 illustrates the difference between the original and degraded cross section of a chain link. The surface of the cross section with the greatest wear in the riding chain is associated with the inner wearing surface of the chain link.
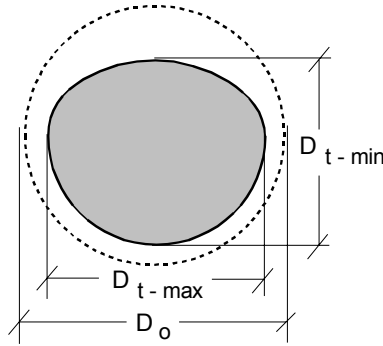
Figure 5.6: Idealized Worn Link Cross Section

where:

D_o	Link original nominal diameter or link diameter at time t = 0
$D_{t\,min}$	Minimum chain link diameter at time t
$D_{t\,max}$	Maximum chain link diameter at time t
D_r	Ratio of minimum link diameter at time = $t\,\left(D_{t\,min}\right)$ to the link's original diameter $\left(D_o\right)$
t	target service life in months

The semi-empirical models used to predict thrash and riding chain wear, Figure 5.7, (diameter ratio (D_r) = minimum diameter/nominal diameter = D_{min} / D_o), based on the data from the CCG five-year field test and other chain wear data, are shown below:

$$D_r = \frac{\dfrac{C_1 D_o t}{\sqrt{1+t}} + C_2 t^2 + C_3 t}{C_4 Depth + C_5} + 1$$

where: C_1, C_2, C_3, C_4 and C_5 are regression coefficients,(Table 5.2) t, D_0 and Depth are the duration of service (in months), new chain nominal diameter and water depth, respectively.

Table 5.2: Wear Model Regression Coefficients

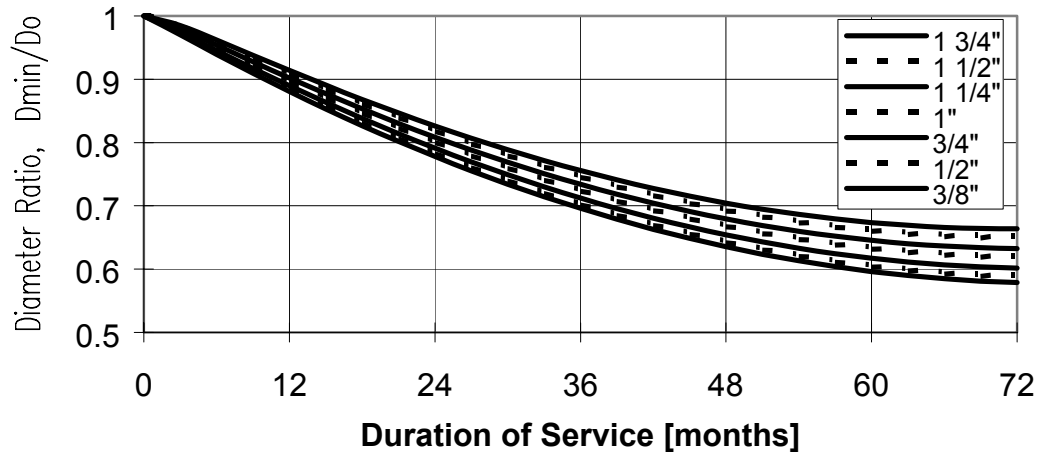|	Thrash Chain	Riding Chain
C_1	7.332×10^{-3}	2.080×10^{-3}
C_2	7.569×10^{-5}	4.962×10^{-5}
C_3	-1.162×10^{-2}	-7.336×10^{-3}
C_4	0	-1.179×10^{-2}
C_5	1	1.555

Figure 5.7: Thrash Chain Link Wear Model

In order to determine the maximum link diameter, the following function describing the ratio of the minimum link diameter to the maximum link diameter (D_{min} / D_{max}) was developed:

$$\frac{D_{min}}{D_{max}} = 0.4202 \frac{D_{min}}{D_{nominal}} + 0.5798$$

The wear factor is used to adjust the effects of wear for specific sites where the conditions and bottom types may be more or less severe than those used to calibrate the wear model. Advice on the selection of a wear factor is available by pressing the advise icon beside the wear factor data field.

5.5.4 Calculate Chain Residual Strength

An analytical model was developed based on the theory of curved beams to estimate the breaking load of chain links with non-circular cross sections. This model calculates the Von Mises-Hencky effective stress at the point of maximum shear stress within the link cross section at the location of maximum wear. A rigid perfectly plastic material behaviour is used to relate the chain link breaking load with link cross section complete plasticity.

The ultimate tensile material strength of the link is specified by the chain quality data field while the chain degradation is calculated from the degradation model shown in 5.3.3 above and the specified target service life. The original geometry of the links, based on their nominal dimensions is given in the CCG mooring chain material specification (MA 2080).

Further information outlining the link ultimate strength model are provided in the CCG/TDC reports associated with the development of this software.

5.5.5 Estimate Mooring Safety

The ratio of the chain residual strength (breaking load) to the peak mooring chain load is the factor of safety associated with the use of the mooring chain under the specified conditions. The factor of safety, including the wear and environment factors is calculated as follows:

$$\text{Factor of Safety} = \frac{\text{Re sidual Chain Strength}}{\text{Peak Mooring Chain Load}} \frac{1}{\text{Wear Factor} \times \text{Environment Factor}}$$

Those moorings chain combinations which provide a factor of safety greater than or equal to 2 for both the riding and the thrash chain residual strengths are considered acceptable. Solutions that are not acceptable are denoted in the acceptable design matrix by U's while the minimum required anchor size is displayed for acceptable solutions.

The safety associated with each mooring (riding and thrash) chain combination shown in the acceptable design matrix is indicated by the color. The color coding system is described in the acceptable design matrix help item.

5.5.6 Minimum Anchor/Sinker Size Calculation

The anchor material, indicating the sinker material density, and the bottom type, indicating the soil properties of the ground at the mooring site, are used to calculate the minimum required sinker size to resist movement caused by the mooring load at the anchor.

The holding power of an anchor against horizontal displacement (being dragged off station) is ensured by balancing the horizontal and vertical anchor and ground chain derived resistive forces with the horizontal and vertical applied mooring chain loads as illustrated below:
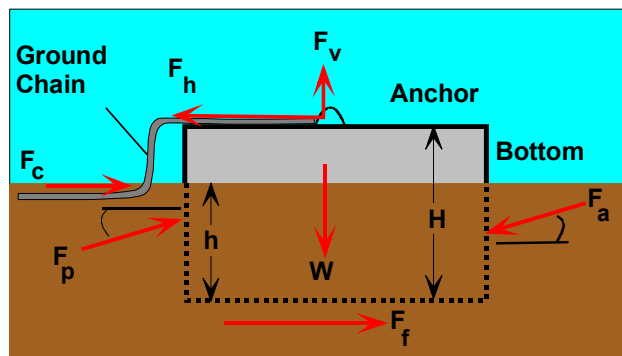

Figure 5.8: Anchor Resistance

F_h	mooring chain horizontal load	F_v	mooring chain vertical load
F_c	ground chain friction	F_p	soil passive pressure
F_a	soil active pressure	W	wetted (buoyant) anchor weight
F_f	anchor sliding frictional force	H	anchor height
h	depth of anchor embedment	α	embedment depth ratio = h / H

The frictional force generated by movement of the ground chain is estimated based on the buoyant weight of the chain and the weight of the depth of cover assumed for each bottom type. The total chain friction force which is used to reduce the horizontal load applied to the anchor is estimated as follows:

$$F_c = \left(\text{soil and chain weight}\right)\tan\delta \cdot \text{ground chain length}$$

$$= (((\gamma_{chain} - \gamma_{water})A + 2\gamma_{soil}W_s d)\tan\delta)L$$

$$\text{where:} \qquad L = \frac{\text{Depth} \times \text{Scope} - .9\text{Depth}}{2}$$

Z =	chain weight per unit length	L_g =	length of ground chain
W_c =	width of chain links	γ_w =	unit weight of water
d =	depth of chain soil cover	γ_c =	unit weight of the chain (steel)
δ =	bottom / Soil friction angle	γ_s =	unit weight of the soil

The depth of soil cover was assumed to be a soil property which is associated with each bottom type.

Estimation of the soil forces (passive, active and frictional) are calculated according to Coulomb's earth-pressure theories using the soil properties (d, f, g) and depth of embedment assumed for each bottom type. The soil active and passive forces are calculated as follows:

$$F_a = \frac{1}{2}\gamma h^2 K_a H \qquad\qquad F_p = \left(\frac{1}{2}\gamma h^2 K_p + 2c'\sqrt{\frac{K_p}{2}}\right)H$$

where:

$$K_a = \frac{\sin^2(90 + \phi)}{\sin(90 - \delta)\left[1 + \sqrt{\frac{\sin(\phi + \delta)\sin(\phi)}{\sin(90 - \delta)}}\right]^2} \quad \text{and} \quad K_p = \frac{\sin^2(90 - \phi)}{\sin(90 + \delta)\left[1 - \sqrt{\frac{\sin(\phi + \delta)\sin(\phi)}{\sin(90 + \delta)}}\right]^2}$$

and the soil/anchor frictional force resisting sliding is estimated based on contributions from the bottom and sides of the anchor as follows:

$$F_f = F_{bottom} + F_{sides}$$

$$F_{bottom} = N \tan \delta \qquad F_{sides} = \frac{1}{3} \gamma h^3 (1 - \sin \phi) \left[\sqrt{\frac{K_p}{2}} + \sqrt{K_a} \right] \tan \phi$$

where N, the effective anchor weight, is the sum of the vertical forces acting on the anchor.

$$N = W - F_v - F_p \sin \delta + F_a \sin \delta$$

The minimum acceptable anchor size is one which ensures that the anchor is not displaced (i.e. the sum of the horizontal forces applied to the anchor is zero).

$$\Sigma F_x = (F_h - F_c) + F_a \cos \delta - F_p \cos \delta - F_f = 0$$

$$= \left(\frac{1}{2} \gamma h^2 K_p + 2hc' \sqrt{\frac{K_p}{2}} \right) H \cos \delta - \frac{1}{2} \gamma h^2 K_a H \cos \delta$$

$$+ \left[\left((\gamma_a - \gamma_w) H^2 + \frac{1}{2} \gamma h^2 K_a \sin \delta - \left(\frac{1}{2} \gamma h^2 K_p + 2hc' \sqrt{\frac{K_p}{2}} \right) \sin \delta - F_v \right) H \tan \delta \right]$$

$$+ \frac{1}{3} \gamma h^3 (1 - \sin \phi) \left(\sqrt{\frac{K_p}{2}} + \sqrt{K_a} \right) \tan \phi - F_h$$

By conservatively assuming that the anchor is a cube, the horizontal force balance is used to determine the minimum required anchor size. It should be noted that the anchor volume and thus its dry weight are a function of the anchor material density.

The calculated minimum anchor size is compared with CCG minimum anchor size recommendations, which are dependent on the buoy type. The largest of either the minimum recommended or calculated anchor size is reported in the acceptable design matrix.

5.6 Environmental Advisor Chain Tension Calculation

The following is a description of the calculation process used to compare the mooring chain loads generated by a user specified set of environmental conditions and the design environmental conditions assumed by the MSG software and thus calculate an environment factor.

5.6.1 Environmental Advisor - Mooring Chain Load Estimation

Estimation of the loads in a mooring chain requires that the configuration/shape of the chain is known. If the wind speed and current are relatively low the mooring chain assumes a catenary shape (i.e. some of the mooring chain remains on the ground), whereas, high wind and current values result in a mooring configuration which no longer has a catenary shape, as shown below:
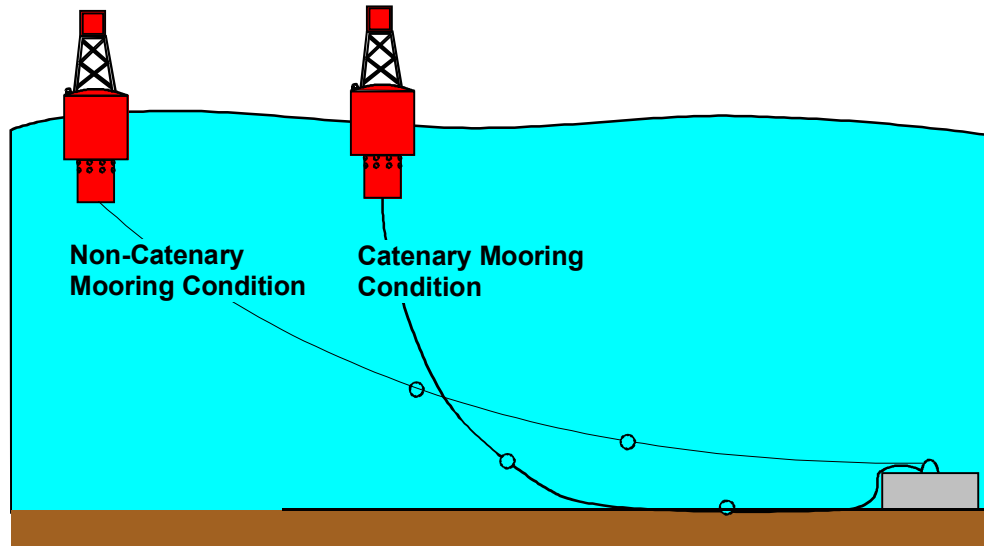

Figure 5.9: Catenary and Non-Catenary Mooring Configurations

The International Association Lighthouse Authority (IALA) bulletin no. 64 - 1975-4 provides some information on estimating the loads on a submersed chain segment and based on these, methods for estimating the tension along the length of a mooring chain were developed for the catenary and non-catenary mooring conditions. In both solution approaches the loads on the mooring system are idealized based on a static analysis of the load components shown in Figure 5.10.
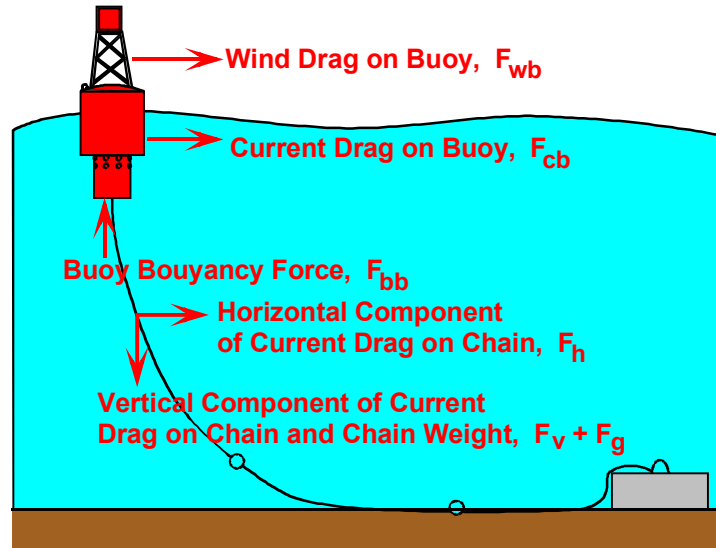
Figure 5.10: Forces on Buoy and Mooring System

5.6.2 Wind and Current Drag on the Buoy

Following the I.A.L.A. recommendations the wind (F_{wb}) and current (F_{cb}) forces acting on the buoy, based on the wind speed (V_w) and current (V_c) (in m/s), are estimated using the following equations, for the buoys considered by the mooring selection guide:

$$F_{wb} = \text{Wind Cons}\tan t \times V_w{}^2 \qquad \text{and} \qquad F_{cb} = \text{Current Cons}\tan t \times V_c{}^2$$

Table 5.3: Wind and Current Drag Buoy Constants

Buoy Type	Wind Constant	Current Constant	Buoy Type	Wind Constant	Current Constant
2.9 m Lighted Bell	3.949	3302.5	2.9 m Lighted Whistle	4.750	3302.5
1.8 m Lighted	3.085	1272.5	1.2 m Coastal Conical ver	0.264	597.5
1.4 m Lighted	1.373	769.5	1.2 m Coastal Can ver.	0.343	565.5
0.6 m Spar (long)	0.196	141.5	0.8 m Coastal Conical ver	0.135	251.5
0.6 m Spar (short)	0.197	141.5	0.8 m Coastal Can ver.	0.065	251.5
1.6 m (cone)	0.450	1029.5	3.0 m Lighted Scow	0.791	654.5
1.6 m (Can)	0.660	1005.5	1.5 m Lighted Discus	1.044	529.8

5.6.3 Current Drag on the Chain

The horizontal and vertical components of the chain current drag force (dF_h & dF_v) are estimated for a segment of the chain, having a link width (w) and length L_s, based on the following equations:

$$dF_t = \frac{1}{2}p_o V^2 C_t dS \quad \text{and} \quad dF_n = \frac{1}{2}p_o V^2 C_n dS$$

where V is the current velocity, p_o is the density of water (1027 kg/m³) and C_h and C_v are the drag coefficients which are a function of the chain segment's orientation with respect to the current direction (assumed to be horizontal). These coefficients are calculated as follows:

$$C_h = \left(0.049 + 1.273\,Sin\theta - 0.637 Sin^2\theta\right)Sin^2\theta + \left(0.069 + 0.124\,Sin\theta\right)Cos^2\theta$$

$$C_v = \left[\left(0.049 + 1.273\,Sin\theta - 0.637 Sin^2\theta\right) + \left(0.069 + 0.124\,Sin\theta\right)\right]Cos\theta\,Sin\theta$$

Table 5.4: Characteristic Chain Data

Nominal Diameter [in]	Buoyant Unit Mass [kg/m]	Link Width [m]	Nominal Diameter [in]	Buoyant Unit Mass [kg/m]	Link Width [m]
3/8	2.113	0.0286	1	11.252	0.0762
1/2	3.029	0.0381	1 1/8	14.281	0.0857
5/8	4.723	0.0476	1 1/4	17.956	0.0953
3/4	6.372	0.0572	1 1/2	25.420	0.1143
7/8	8.764	0.0667	1 3/4	34.184	0.1334

5.6.4 Chain Mass

The mass of each segment of chain is accounted for based on their buoyant unit mass which are listed in the table above.

5.6.5 Chain Tension in the Catenary Mooring Condition

The shape of the mooring chain which is suspended from the buoy can be described by the following equation:

$$y = \frac{H}{w}\left[Cosh\left(\frac{wx}{H}\right) - 1\right]$$

in which H is the horizontal component of tension in the chain, w is the buoyant unit weight of chain and x and y are the coordinates of the middle of the chain segment with respect to the origin located at the point where the suspended chain first touches the bottom.

If the length of the suspended mooring chain is divided into segments of length L_s then the distance between the centres of each segment can be calculated using:

$$x_2 = \frac{aH}{w} \text{Sinh}\left\{\left[L_s + \frac{H}{w}\text{Sinh}\left(\frac{w X_1}{H}\right)\right]\frac{w}{H}\right\}$$

and the angle between the current and the chain segment, used to estimate the current drag coefficients is:

$$\theta = \text{Tan}^{-1}\left\{\text{Sinh}\left[\frac{w\left(x_1 + \frac{x_1 + x_2}{2}\right)}{H}\right]\right\}$$

The horizontal force (H), supported by the anchor and ground chain, needed to maintain a catenary shape can be expressed as a function of the length of suspended chain L_w, buoyant unit weight of chain (w) and the depth of water (z) as follows:

$$H = \left[\left(\frac{L_w}{z}\right)^2 - 1\right]\frac{w z}{2}$$

The forces in a catenary shape mooring chain are identified by varying the length of suspended chain (L_w) until the required horizontal force required to maintain a catenary shape is equal to the sum of the horizontal components of the wind and current drag on the chain segments and the buoy.

5.6.6 Chain Tension in the Non-Catenary Mooring Condition

In this condition all of the mooring chain is raised off the ground and the catenary chain load formulation does not apply and a more general approach is needed. In this case the shape of the mooring chain is described based on the length of each segment (L_s) and their orientation (q) with respect to the current direction (assumed to be horizontal), as shown in Figure 5.11, for an eight segment mooring chain example.
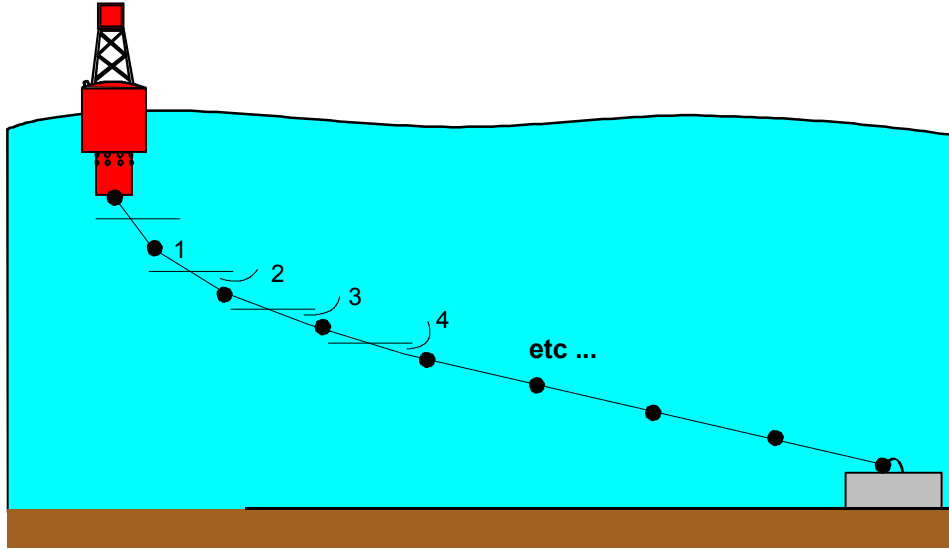
Figure 5.11: Non-Catenary Mooring System Chain Segment Description

In this approach, the orientation of the first segment (q_1) is assumed to estimate the vertical buoyant force provided by the buoy based on statics as follows:

$$F_{buoyancy} = \left(F_{wb} + F_{cb}\right) Tan\theta$$

The horizontal and vertical components of the mooring chain tension force at the intersection of segments 1 and 2 are calculated by summing the horizontal and vertical components of the buoy wind and current drag, current drag and weight of chain segment 1. The orientation and thus the current drag on subsequent chain segments is estimated by ensuring static equilibrium, shown in Figure 5.12 for the ith segment of the mooring chain.

Vertical Force Equlibrium

$$V_i = -v_{i-1} - V_{drag\ and\ weight}$$

Horizontal Force Equlibrium

$$H_i = -H_{i-1} - H_{drag}$$

Moment Equlibrium

$$H_i L_s Sin\theta_i + V_i L_s Cos\theta_i + H_{drag} \frac{L_s}{2} Sin\theta_i +$$
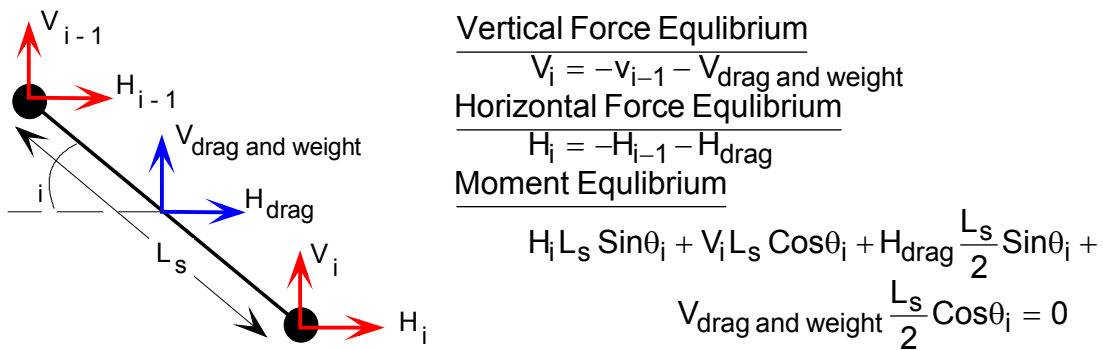$$V_{drag\ and\ weight} \frac{L_s}{2} Cos\theta_i = 0$$

Figure 5.12: Non-Catenary Chain Segment Equilibrium

Since the forces and the moment equilibrium equation are functions of the orientation (q_i) of the chain segment, the segment's orientation is changed until the moment equilibrium equation is satisfied. Once the orientation of the segment is known, the segment forces V_i and H_i can be calculated.

These chain segment static equilibrium calculations to determine chain segment orientations are repeated for all segments to determine the shape of the mooring chain. If the vertical distance between the ends of the mooring chain is equal to the water depth then the correct mooring chain shape has been identified. If the vertical distance between the ends of the mooring chain is larger or smaller than the water depth then the assumed orientation of the first chain segment is changed and the entire process is restarted.