



NAVAL FACILITIES ENGINEERING SERVICE CENTER  
Port Hueneme, California 93043-4370

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# Contract Report

## CR 96.018

### PRELIMINARY DESIGN: BARGE CONNECTION SYSTEM

An Investigation Conducted by:

MCA Engineers, Inc.  
Costa Mesa, CA

April 1996

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**PRELIMINARY DESIGN: BARGE CONNECTION SYSTEM**

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## PRELIMINARY DESIGN: BARGE CONNECTION SYSTEM

### Executive Summary

This report has been written to summarize MCA efforts under NFESC Contract N47408-95-C-0241 to develop a preliminary design for a modular barge connection system. The contracted effort included the following distinct tasks:

- (1) Perform a time-domain analysis of two barge modules in a Sea-State 3 to estimate key connection system performance parameters.
- (2) Develop a barge connection system capable of withstanding hull girder shears and moments in a Sea-State 3 with barge configurations up to 240 feet in length uniformly loaded to a 4-foot draft.
- (3) Develop a system for drawing together and aligning two barge modules in a Sea-State 3 to facilitate engagement of the connection system.

All three tasks have been successfully completed. The attached drawings depict MCA's design for the ratchet winches and connection system. Appendices A and B include key calculation summaries for the equipment. Results for each task are summarized in the following paragraphs.

### Time Domain Analysis

The dynamic motion of two barge modules coupled together using MCA's connection system in a Sea-State 3 was modeled using Excel spreadsheet calculations and Visual Basic programming. Barge module hydrodynamic characteristics were taken from NFESC report TM-2024-AMP(CR) by C. J. Garrison. Hydrodynamic interactions were not included. The analysis showed that two ratchet engines pulling through corner roller chocks were sufficient to draw the modules together. Key performance parameters included:

Starting separation distance:	40.0	Feet (per NFESC)
Maximum time to come together:	21.5	Seconds (no waves)
Maximum relative approach velocity	10.9	Feet/Second
Winch Relief Setting	2,000 - 4,000	Pounds
Maximum Relief Energy	4,800	Ft-Lb.

Maximum conditions occur in head-on conditions. The model showed some pendulation as the barges near each other due to conservation of energy, resulting in a design consideration for the fenders to engage before the lines become two-blocked.

## Ratchet Engine (Winch) Preliminary Design

The winch design was based on the previously listed modeling-derived performance requirements and NFESC-mandated constraints, including:

- Mandatory use of wire rope
- 40-foot initial separation between barges
- Maximum load relief feature
- Set-up and connection in less than 30 minutes

Additional design goals included:

- Portability by one man
- Alternative power sources (12 VDC, air, other)

The resulting design is shown on MCA drawing P9544-NFESC-002. The winch is provided with 72 feet of 1/2" wire rope (40' active). The drum is powered through a 16:1 Gilmer drive belt ratio by either a 12VDC or air motor to provide a 100-lb. line tension at speeds up to 11 feet per second. The constant tension drive overhauls through a pawl-and-ratchet assembly that prevents winch payout at tensions up to the brake relief setting. The brake (and cable drum) relieve at an adjustable tension of 2,000 to 4,000 pounds. The winch is composed of two assemblies, each weighing 70 pounds or less. The first module includes the drum, cable, and end plate, which can be rapidly assembled onto the drive shaft/substructure module. The light weight was not easily obtained, requiring significant use of Aluminum, 17-4 Stainless Steel, and Titanium. Three modes of powering are accommodated: air, DC-electric, and manual. Manual operation will generally not provide the same line speed as air or electric.

## Connection System

Once the barge modules have been drawn together using the ratchet engines, full-strength shear and moment connectors are engaged to allow the barges to be operated in lengths up to 240 feet. The connection system includes three elements: retracting fenders, shear connectors, and moment connectors. The fenders are extended during the initial barge coupling process, absorbing impact energy. The fenders are then easily retracted to allow alignment and engagement of the shear and moment connectors. The shear connectors are set first. The radiused paddle design allows sailor-powered lateral and vertical alignment until the shear connectors lock in place. Then the moment connectors are set: first the upper pins, then the remotely-actuated lower pins. All connection system components are illustrated on MCA Drawing P9544-NFESC-001, attached. The connectors incorporate shock mitigation design features, and can be tightened using either air-powered tools or hand tools.

The complete system - winches, connectors, and underlying analysis - has been orchestrated to provide maximum utility and flexibility at minimal cost. Portability is obtainable for a premium, but proof-of-concept can be established using heavier, less expensive materials. The design and analysis are sufficiently developed to support review and Phase II proposal efforts.

## PRELIMINARY DESIGN: BARGE CONNECTION SYSTEM

### 1.0 Introduction

NFESC is developing a new pontoon system based on modular componency. The basic building blocks, or barge modules, measure 40 feet by 24 feet by 8-foot depth, and weigh about 32 long tons. The barge modules will be carried to operational sites by Military SeaLift vessels. The modules will be connected on open waters to form rigid barges, ferries, and pontoons measuring up to 240-feet by 72-feet, and possibly longer using pinned connections.

As part of its development effort, NFESC issued a BAA in 1995 for the development of rigid barge connection systems. MCA Engineers responded with a 3-phase proposal to design, construct, and field-test a barge rigid-connector system to meet all NFESC operational requirements. This report documents the results of the first phase, a time-domain analysis to quantify connection system performance requirements, plus the preliminary design of ratchet engine and rigid connector hardware.

The system development effort was constrained by a combination of analytical results, NFESC mandatory requirements, and proposed design goals. These criteria are listed below:

#### NFESC Mandatory Criteria:

Barge dimensions:	40' x 24' x 8'
Barge lightship draft	1.2' (32 Long Tons)
Maximum barge length with rigid connectors:	240'
Loaded barge draft	4', evenly loaded
Operational Sea State	SS-3, 5-Ft Significant Wave Height
Winch line	Wire rope only
Tension limits	Winch <u>must</u> have overload relief
Initial separation distance	40'

#### NFESC Design Goals:

Required connection time	< 30 minutes
Auxiliary tugs	Available if needed

#### Proposal Design Goals:

Multiple power sources	Air, 12 VDC, manual
Portability	Assemblies <= 70 Lb.
Simplicity	Manually activated connectors

Given the above design constraints, the first step was a time-domain analysis of the proposed connection system to estimate design loads, relative velocities, and impact energies.

## 2.0 Time Domain Barge Motion Analysis

A three-dimensional time domain analysis was incorporated in the preliminary design for several key reasons. Although the analysis effort was originally proposed to be performed using TUTSIM, the final code was developed using Visual Basic to provide improved graphics and error checking. The primary reason for the three-dimensional simulation was determining peak winch design loads and snap-load brake relief loads. The secondary reason was proving the ratchet engine concept and arrangement for various wave scenarios. The program was designed to analyze 58 wave heading and frequency combinations for a Sea State 3 (Significant wave height  $H_s = 5$  ft). The wave data was prepared by Dr. C. J. Garrison (NFESC report TM-2024-AMP) and provided to MCA by NFESC. Data included the barge module force, phase, added mass, and damping coefficients needed for the three-dimensional barge motion analysis.

### Program Description

The program consists of three modules and was developed using Microsoft Visual Basic for Windows 3.1. The first main screen (page 6) includes the input data provided by Dr. Garrison. The boxes contain the 6 DOF coefficients for force, phase, added mass, and damping (uncoupled). The input screen also includes the following barge data: Mass, Water Plane Area, Delta T (Time Step). The input data can then be stored under an individual file name for use in subsequent runs or can be recalled later.

Screen Number 2 (page 7) consists of data to be used in the next barge motion simulation. The screen scale controls the size of the barge display in the main window (Elevation View). The display size can be adjusted to check the barge contact point in detail. Animation time controls the length of the run; however, the run stops automatically on barge contact. Significant wave height is a key variable to simulate different sea states. For this analysis a wave height of 5.0 feet (equal to  $H_s$ ) was used. The starting barge distance variable allows the user to control the initial distance between barges (specified as 40 feet by NFESC technical personnel). The winch relief variable is the snap-load release mandated by NFESC technical personnel, and serves to limit line tension in lieu of a softer synthetic line spring rate. The barge winches should be activated when the relative velocity is zero or closing to prevent initial snap loads (although the winches are designed to handle this situation).

Screen Number 3 on page 8 displays the near real time results to the user with continuous updates on winch relief data, barge rope lengths, rope tensions, and closing velocity. The wave period and wave incidence angle are shown at the top of the screen. The main window shows an elevation view of the two barges and shows the heave, surge and pitch motions. Forward is to the right of the screen so the view is looking to port. Two wave profiles are shown; the green sinusoidal line is the wave profile along the barge port side, the blue wave line is the starboard profile. The view directly above the elevation is the Plan View to display yaw, sway and surge motions. The two straight green lines are the wire ropes connecting the two barges. The wire rope lines are color coded based on line tension:

Green = Constant Tension (100 lbs)  
Red = Tension > 100 lbs and < Relief Value  
Magenta = Tension > Relief Value.

When the winches relieve, the line color is displayed in magenta and relief distance and relief time are displayed. The blue lines across the Plan View window represent the wave crest and show the actual wave incidence angle. The two end views on either side of the Plan View show the roll and sway motions. These views look forward at the aft and forward barges respectively.

### Program Results

The three-dimensional barge motion analysis achieved the two main goals of the program development: Quantify connection system performance requirements and demonstrate the connection system feasibility. The mathematical model successfully assessed barge impact velocities and speeds. The model was also used to calculate winch relief data used in the brake design, and line tension loads necessary for equipment size and design. The results show that the time for the barges to close 40 ft. from the initial position takes between 9 and 22 seconds. The bar graph on page 10 shows Wave Period Vs. Closing Time for a 40 ft initial separation in head seas. Hand calculations verify the closing time for a 100-pound winch line constant tension case and no wave. Closing speed (and other parameters) varies with wave incidence angle and wave period. An animation sequence for a case (Wave Period = 4.17 seconds, Wave Incidence Angle = 30°) is shown on page 9. This case shows a typical barge motion simulation 2 second intervals. The screen display is updated 10 times per second. The calculation "Delta Time" can be varied, but was set at 1/100 seconds ( $dT = 0.01S$ ) for this analysis.

Complete results for 58 wave combinations ( $H_s = 5$  ft) are summarized in a table on page 11. They are categorized by wave period, starting with the longest waves (12.5 seconds) and proceeding to the smallest wave analyzed (3.85 seconds). The data for each wave period begins with a wave heading of 0° and increasing in increments of 15°. Data is provided for: Close Time, Max. Rope Tension, Winch Relief Distance, Winch Relief Time, and Contact Energy. The relief values for the tow winches were set at 2000 lbs. This value was selected after numerous trials, although anywhere in the range of 2,000 to 4,000 pounds appears acceptable. When the relief value was set too high, the line stored too much energy opposing surge and caused the barges to accelerate toward each other. Settings too low resulted in excessive amounts of heat to be absorbed by the winch brakes. Results indicate the fastest close times occur when the barges are aligned in a head sea condition (Wave Angle = 0°). The fastest close times and highest contact energies occurred in the 5-6 second wave period range. These cases were found to have closing relative velocities near 11 fps. The fenders have been designed with these velocities in mind, however barge connection in these conditions should proceed with caution.

# Barge Motion Input

## Barge Input Data

Wave Angle  
[.5236]

### Force Coefficients

Surge [2.2727] Heave [2.3125] Sway [1.927] Roll [.4024] Yaw [.0992] Pitch [1.6833]

### Phase Angle

Surge [-1.7987] Heave [-.8738] Sway [-1.6322] Roll [-1.6355] Yaw [3.1348] Pitch [1.3431]

### Added Mass Coefficients

Surge [.0856] Heave [4.311] Sway [.1489] Roll [.803] Yaw [.1028] Pitch [2.74]

### Damping Coefficients

Surge [.028] Heave [2.535] Sway [.0481] Roll [.162] Yaw [.0033] Pitch [.7402]

Barge Mass [2289] Water Plane Area [960] Delta T [.01] MT1 [1000]

Wave Period [4.167] Wave Heading [0] GMT [1000] GML [1000]

Show Barge Motion

Start

Stop

Read File

Write to File

File Name

[F9H3.BAR]

Barge Motion

Enter Screen Scale (Decimal Value)   
Enter Total Length Of Time For Animation   
Enter Frames per Second   
Enter Significant Wave Height   
Enter Starting Distance Between Barges (ft)   
Enter Winch Relief Value (lbs)   
Enter Time for Initial Winch Relief

Run Time (Sec)

Heave Amplitude (Ft)

Port Rope Tension (Lbs)

Port Max. (Lbs)

Port Rope Length (Ft)

Stbd Rope Tension (Lbs)

Stbd Rope Tension (Lbs)

Stbd Max. (Lbs)

Stbd Rope Length (Ft)

Closing Velocity (FPS)

Port Relief Dist (Ft)

Port Relief Time (Sec)

Start Animation

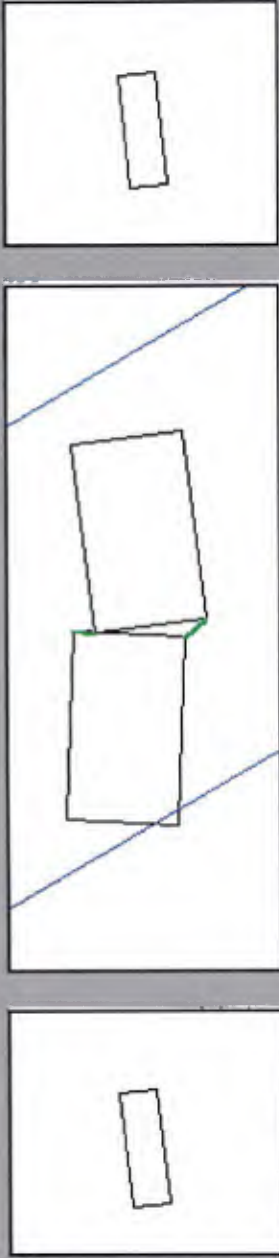
Return to Input Screen

Stbd Relief Dist (Ft)

Stbd Relief Time (Sec)

Barge Motion

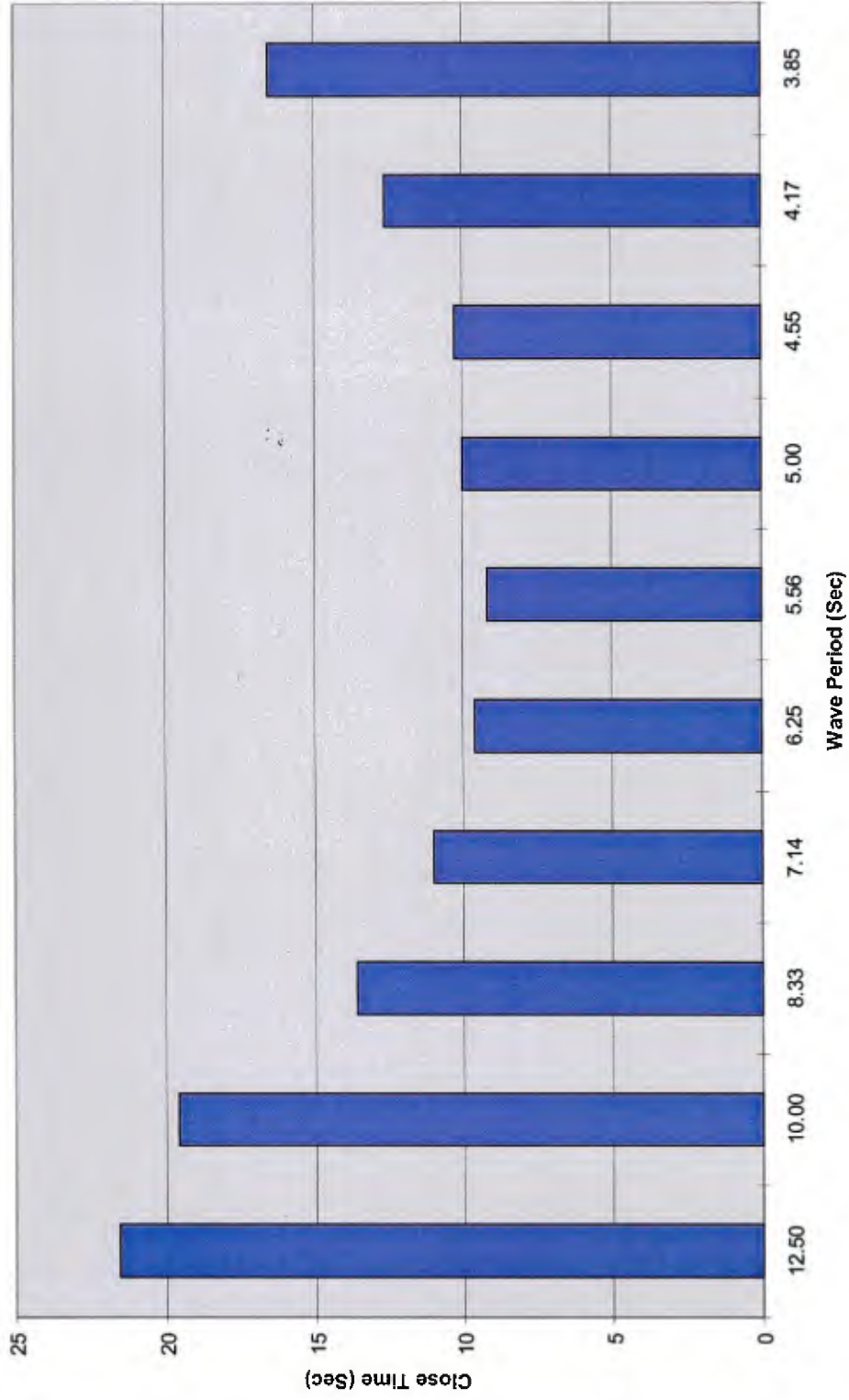
Wave Period = 4.17 Sec. Wave Angle = 30 Deg.



Run Time (Sec)	12.19	Heave Amplitude (Ft)	1.42	Port Rope Tension (Lbs)	100.0	Port Max. (Lbs)	2000.0	Port Rope Length (Ft)	2.4
Run Again	Stop	Closing Velocity (FPS)	6.08	Stbd Rope Tension (Lbs)	100.0	Stbd Max. (Lbs)	2000.0	Stbd Rope Length (Ft)	5.0
						Port Relief Dist(Ft)	0.12	Port Relief Time (Sec)	0.19
						Stbd Relief Dist(Ft)	0.56	Stbd Relief Time (Sec)	0.51



**Time Domain Barge Analysis  
Wave Period Vs. Closing Time (40 ft)  
Head Seas**



### 3-Dimensional Barge Model Results Time Domain Analysis

Wave Period	Wave Angle	Closing Time (Sec)	Port Max Rope Tension (Lbs)	Port Winch Relief Dist (Ft)	Port Winch Relief Time (Sec)	Stbd Max Rope Tension (Lbs)	Stbd Winch Relief Dist (Ft)	Stbd Winch Relief Time (Sec)	Contact Energy (Ft-lbs)
12.5	0	21.56	100	0	0	100	0	0	4627.62
12.5	15	21.48	100	0	0	100	0	0	4391.33
12.5	30	21.45	100	0	0	100	0	0	4465.73
12.5	45	21.47	100	0	0	299.7	0	0	4619.57
12.5	60	21.6	100	0	0	2000	0.03	0.05	4837.64
10	0	19.59	509.3	0	0	509.3	0	0	3686.67
10	15	19.97	462.1	0	0	420	0	0	4485.49
10	30	20.91	267.6	0	0	275.1	0	0	6110.53
10	45	21.69	148.5	0	0	100	0	0	7012.78
10	60	21.93	100	0	0	100	0	0	6905.07
8.333	0	13.59	1571	0	0	1571	0	0	5770.01
8.333	15	13.93	1505.3	0	0	1441.2	0	0	5842.23
8.333	30	9.9	2000	0.69	0.7	2000	0.79	0.89	10237.52
8.333	45	17.2	861	0	0	895.4	0	0	8131.57
8.333	60	20.9	210.1	0	0	2000	0.12	0.12	9114.87
8.333	75	21.6	103.5	0	0	150.8	0	0	7195.88
7.14	0	11	2000	0.29	0.56	2000	0.29	0.56	9567.5
7.14	15	11	2000	0.26	0.47	2000	0.43	0.53	9769.71
7.14	30	11.6	2000	0.05	0.16	2000	0.01	0.06	8055.07
7.14	45	13.8	1483.5	0	0	2000	0.09	0.21	8839
7.14	60	16.75	643.3	0	0	836.1	0	0	11680.6
7.14	75	21.7	904.7	0	0	2000	1.23	0.58	11164.89
6.25	0	9.61	2000	1.31	1.02	2000	1.31	1.02	13261.64
6.25	15	9.7	2000	0.95	0.88	2000	1.37	1.04	11766.37
6.25	30	9.9	2000	0.69	0.7	2000	0.79	0.89	10237.52
6.25	45	10.9	2000	0.49	0.51	2000	0.03	0.21	7867.56
6.25	60	13.9	1557.8	0	0	2000	0.12	0.08	13965.88
6.25	75	21.1	324.1	0	0	208.2	0	0	11128.85

Wave Period	Wave Angle	Closing Time (Sec)	Port Max Rope Tension (Lbs)	Port Winch Relief Dist (Ft)	Port Winch Relief Time (Sec)	Stbd Max Rope Tension (Lbs)	Stbd Winch Relief Dist (Ft)	Stbd Winch Relief Time (Sec)	Contact Energy (Ft-lbs)
5.56	0	9.2	2000	2.43	1.19	2000	2.43	1.19	5725.22
5.56	15	9	2000	1.76	1.07	2000	2.65	1.18	7241.93
5.56	30	10.3	2000	1.01	0.85	2000	2.81	1.58	7969.41
5.56	45	10.3	2000	0.79	0.66	2000	1	0.91	8937.25
5.56	60	11.5	2000	0.27	0.34	2000	0.35	0.12	14445.53
5.56	75	18.2	2000	0.19	0.19	576.7	0	0	12428.47
5	0	10	2000	2.79	1.16	2000	2.79	1.16	13942.79
5	15	9.6	2000	2.03	1.04	2000	3.22	1.14	7758.34
5	30	9.5	2000	1.28	0.87	2000	2.94	1.09	7875.1
5	45	10	2000	0.78	0.65	2000	1.88	0.96	13744.41
5	60	10.9	2000	0.44	0.41	2000	0.52	0.69	19623
5	75	16.4	1054.2	0	0	1009.4	0	0	14844.4
4.55	0	10.26	2000	2.06	0.92	2000	2.06	0.92	27760.97
4.55	15	10.1	2000	1.46	0.81	2000	2.64	0.96	26611.37
4.55	30	10.1	2000	0.87	0.66	2000	2.57	0.94	26435.71
4.55	45	10.4	2000	0.45	0.45	2000	1.83	0.84	25858.92
4.55	60	10.9	2000	0.14	0.22	2000	0.7	0.67	20120.92
4.55	75	15.7	2000	0.05	0.08	2000	0.16	0.17	14214.87
4.17	0	12.6	2000	0.52	0.44	2000	0.52	0.44	16957.85
4.17	15	12.1	2000	1.17	0.94	2000	2.67	1.4	12835.04
4.17	30	12.2	2000	0.12	0.19	2000	0.56	0.51	10585.73
4.17	45	12.7	1806.6	0	0	2000	0.2	0.31	16856.03
4.17	60	13.7	1209.7	0	0	1860.1	0	0	20645.94
4.17	75	17.1	861	0	0	1323.5	0	0	12662.12
3.85	0	16.5	2000	0.03	0.09	2000	0.03	0.09	18844.09
3.85	15	16.4	1729.1	0	0	2000	0.1	0.22	20768.8
3.85	30	16.4	2000	0.02	0.07	2000	0.13	0.14	21595.68
3.85	45	16.5	2000	0.12	0.18	2000	0.21	0.18	22600.4
3.85	60	16.4	2000	0.81	0.45	2000	0.07	0.09	23713.39
3.85	75	15.1	2000	1.77	0.64	1109.5	0	0	14272.3

### 3.0 Ratchet Engine Design

As described in MCA's proposal, the basic approach to drawing the barge modules together would be ratchet engines. These devices are relatively simple winches with low tension, high speed drives running through a pawl-and-ratchet device that allows the winch to remove slack from the cable, but resist much higher pay-out tensions. The proposal design emphasized synthetic line and a worm gear drive to meet the concurrent requirements of snap-load relief and manual back-up power. After the kick-off meeting, NFESC cognizant technical personnel stated that synthetic line would not be allowed, and that a snap-load tension relief device would be mandatory. These changes impacted several winch design aspects, which bear explanation herein to document the preliminary design. The design is a product of time-domain analysis performance results, NFESC product constraints, and general marine design practice. The ratchet winch design is illustrated on MCA Drawing P9544-NFESC-002, and supporting calculations are provided in Appendix A.

#### Cable/Drum System

The prohibition against synthetic lines mandated the use of wire rope on a steel or titanium drum (wire ropes brinell aluminum drums). NFESC specified a minimum of 40-foot working length between barge modules at the start of the connection process. Providing an additional 20-feet of cable to fairlead from a winch located amidships and 12 feet for cable end termination, a total of 72 feet of cable (52 stored on the drum) was required. The proper cable is a 6x19, 1/2" diameter Extra Improved Plow Steel (EIPS), Independent Wire Rope Core (IWRC) either greased or galvanized (the cable is subject to seawater immersion, but for a brief duty cycle). Drum diameter was selected as 30:1 for longer cable life and to reduce added weight associated with groove pitch.

#### Drive System

A Gilmer belt drive was selected for light weight, adjustable gear ratio (if field experience shows greater or lesser rope speed is required), and quiet running. Pulleys will generally be modified to remove weight, although a Proof-of-Concept system may use stock pulleys to reduce cost. The gear ratio is nominally 16.8:1, but by changing pulleys can be easily reduced to 10:1 or increased to 25:1. Final decisions will also depend on power source selection.

#### Drive Motor

The Ratchet Engine can be powered either by air or 12 VDC battery. This makes the design uniquely portable, not dependent on host craft power. SCUBA tanks can be carried aboard and regulated to 100 Psi to drive a light air motor, or 12 VDC batteries can be carried aboard to drive a commercial light-weight 2900 RPM electric motor. The intermediate ratio shaft will be provided with a manual drive socket. The drive system is designed to provide 100 lbs. at 11 feet/per second at the cable, for a net 2 corner horsepower (duty cycle is extremely light, hence smaller motor ratings are acceptable).

The design will accept either air or electric power. Electric drive has the advantage of greater stall torque, air drive has the advantages of potentially higher line speed and

lighter weight. The 100-lb. line tension capacity was selected as the minimum to overcome winch inertia, fairlead friction, and remove slack. Two winches working at 100 pounds will draw two 40-foot barge modules together within 22 seconds without any wave assistance. Draw times in waves are typically 40% to 60% of this limiting value.

#### Ratchet Assembly

The ratchet assembly consists of a spring-loaded pawl and overrunning ratchet ring. This design allows the “constant tension,” high-speed drive to power the drum past the ratchet. However, when line tension exceeds the drive capability, the drum will stop and reverse, locking up the pawl. The drum cannot pay out until tension exceeds the disc brake capacity. A toggle switch is provided to release the engagement spring, allowing line to be pulled off the drum in preparation for operations (see Section 5).

#### Disc Brake

The required snap-load tension relief is provided by a static disc brake between the drum and drive train. A belleville washer is used to provide disc pressure, and can be adjusted by screwing in the pressure ring bolts. The time-domain study indicated optimal settings between 2,000 and 4,000 pounds cable tension, which helps limit cable size and drum weight. The mass of the brake was checked for temperature rise based on the maximum relief energy to be absorbed for any wave condition.

#### Support Structure

The structure is currently envisioned as 17-4 Stainless Steel to allow welding of the shaft and other high-stress components, and to eliminate corrosion margins. Light steel work in stainless often reduces painting/maintenance costs as well. As currently configured, the base winch (minus drum and cable) weighs 70-lbs., the US Navy maximum for one person to carry. Weight control and high-strength material selection will have to be maintained to keep this weight limit. The air motor is 6 pounds lighter, and would allow cost reduction in other components if used.

#### 4.0 Rigid Barge Connectors

The connection system includes four permanent components activated in sequence during a barge connection operation:

- (a) Fenders
- (b) Shear Connectors
- (c) Upper Moment Pin Connectors
- (d) Lower Moment Pin Connectors

All components are designed for retraction into the barge envelope for storage and to provide a smooth deck during operations. Moving components are typically light-weight, high strength to facilitate actuation by sailors. The following paragraphs, reviewed in conjunction with MCA Drawing P9544-NFESC-001, explain the connection system design. Supporting calculations are provided in Appendix B.

##### Fenders

The fenders were designed to absorb the maximum impact energy calculated during the time-domain study. The fenders are conventional D-shaped rubber pieces arranged vertically at the corners of the barge ends. This insures at least one will engage when the barges come together. The fenders are extended before the winches are engaged. The extended position allows barge connection before the winch lines become critically “two-blocked,” which was shown in the analysis to produce a pendulum energy conservation “whip.” When the fenders engage 1 to 2 feet before the barges contact, this “whip” is eliminated (however, the winch design is based on the fenders not being extended).

##### Shear Connectors

The observed tendency (during time domain simulation) for one barge to “shear” off any extending connector led to the decision to use a retracted shear connector which is engaged only after the barge modules have been drawn together by the ratchet engines. The shear connectors are used like paddles to bring the barges into alignment. Sailors use 6-foot torque bars to rotate the shear paddles into place, although a spring toggle allows wave action to do most of the work. Sized to withstand maximum relative sway forces, the shear connectors contain shear pins to limit the forces fed back to the sailor.

##### Upper Moment Pin Connectors

Each barge module is connected at each end using four sets of pin connectors on 6-foot centers (4 lock-sets/barge). The connectors are activated by hand-flipping the pins into position, and then tightening the nuts. The pins include belleville springs to absorb any snap loads until the barge can respond at its own natural spring rate. All 4 upper pins are flipped into place (the spherical seat design allows 2 inches misalignment between barges), and then tightened using either air tools or a socket built into the end of the 6-foot torque tool. The pins, seats, and supporting structure have been designed for service as the middle connectors in a 240-foot barge in a Sea-State 3.

### Lower Moment Pin Connectors

The lower pin design is very similar to the upper pin design, modified for remote activation. There are two remote rods. The first is the spring bias activator that either tries to engage or disengage the connector. The activator is operated using a hand/foot lever located in the upper pin trough. Pulling up on the lever ratchet-set lever exerts about 200 inch-pounds of activating (flip-down) torque to place the pin in position. Stepping down on the lever accomplishes the reverse. A pin position visual indicator located in the trough tells the sailor whether the lower connecting pin is engaged. The second remote rod tensions the lower connecting pin. Basically a socket drive, this remote set rod can be driven manually or by air tools. The remote rod incorporates the same spring protection against snap loads.

## 5.0 System Operation

The preceding sections described the connection system component design. With that knowledge in place, it is now possible to explain the overall barge connection process.

### 5.1 Installation

After placing the base and receiving barge modules (Barge “A” and Barge “B” on Drawing P9544-NFESC-001) in the water, the following steps are taken to prepare for barge connection:

#### Personnel:

At least one sailor is required on each barge module

#### Preparation:

The winches, chocks, and torque tools must be placed on their respective barges. Loading can be done manually (all components weigh 70-lbs. or less) or by crane, either before the barges are placed in the water or afterward. The winches and chocks can be moved from module to module after the connection process starts.

#### Procedure:

- a. All fenders on both barges are extended. The 6-foot torque tool is used to rotate the fenders into place until the locking pawl engages. (1/2 minute)
- b. The portable cable chocks are erected on the base barge, and the cable terminations are installed on the receiving barge. (1/2 minute)
- c. The winches are installed and assembled. The winch foundation module is secured to the deck, and the drum module assembled on the winch. The air or electrical power source is connected. (3 minutes)
- d. The 40' of working cable are pulled off the drum and reeved through the corner chock. (1 minute)
- e. A messenger line is attached to the wire rope end and tossed to the sailor on the receiving barge. The receiving barge sailor removes the messenger and attaches the wire rope spelter fitting to the cable termination. (2 minutes)

### 5.2 Barge Connection

- a. The winches are powered and slack removed from the wire rope. Sailors should stand clear of the lines and barge ends during this part of the operation. The winches and waves work together to bring the barges into alignment. The process actually works more smoothly with the barges beam-to towards the waves, but the increased roll motion may be more discomforting. Relative motions are definitely less with beam conditions, and connector lock-up should be easier in this attitude. (1 minute)
- b. Once the barges have been drawn together, all fenders are retracted. (1 minute)

- c. The sailor on the receiving barge crosses to the base barge, and each uses a torque tool to set one of the two shear connectors. If the barges are misaligned by several inches, the shear connectors can be used to pull them into alignment simply by trying to rotate to the locked position. The locking pawl position indicates when the shear connectors are set. (2 minutes)
- d. Each sailor flips two Upper Moment Pin Connectors into the engaged position. This is done by rotating the pin, and letting the head drop into the mating slot on the receiving barge. Using either an air gun or a socket drive in the end of the 6-foot torque tool, the four upper connectors are tightened until the disc washers start to take a load. Barge alignment is verified by observing marks on the deck. (2 minutes with air, 4 without)
- e. The Lower Moment Pin Connectors are engaged by pulling up on the plunger handles. The barges must be in a flat or hogged position when this is done. Engagement and rotation angle are visually verified by a position indicator in the Upper Connector trough. (1/2 minute)
- f. All Upper and Lower Connectors are fully tightened. (2 minutes with air, 5 without)
- g. Power to the ratchet winches is secured.
- h. Winches, chocks, and terminations are stowed or transferred for another barge connection operation. The Upper Moment Connector Pin troughs are covered to provide a flush deck.

The process, equipment, and procedures represent trade-offs among cost, limited support capabilities, and available personnel to accomplish a difficult mooring operation under difficult conditions. For trained personnel, the operation is relatively simple and quick. For untrained personnel, the learning curve will be rapid.

The connection system analysis and design has progressed to the point where proof-of-concept can be undertaken through prototype manufacture and field evaluation.

**Appendix A.**  
**Supporting Calculations for**  
**Ratchet Winch Preliminary Design**

**RATCHET ENGINE PRELIMINARY DESIGN**

**1. GENERAL PERFORMANCE PARAMETERS**

[a.] Assume the following maximum sinusoidal relative motion:

Amplitude = 9.65 Ft  
 Period = 5.56 Seconds  
 $\Omega = 2 * \pi / T = 1.13 \text{ Rad/sec}$

Displacement =  $a * \sin(\Omega * t)$  9.65 Ft (max)  
 Velocity (from time study) = 10.90 Ft/Sec (max)  
 Acceleration =  $- a * \Omega^2 * \sin(\Omega * t) = 12.34 \text{ Ft/Sec}^2 \text{ (max)}$

[b.] Winch weight estimate

Item	Weight (lbs)	Actual Radius	Cable Radius	Weight at Cable Radius
Cable	34.6	7.5	7.5	34.6
Drum	20.2	7.3	7.5	19.5
Brake/plates	24.0	5.0	7.5	16.0
Ratch/Pul	7.0	5.0	7.5	4.7
Bearings	2.0	1.5	7.5	0.4
Other	<u>2.0</u>	7.5	7.5	<u>2.0</u>
Totals	89.8			77.2

[c.] Drum Parameters

Assumed Tread Diameter 14.5  
 Assumed Rope Center Diameter 15.0 In  
 Length / Coil =  $\pi * D = 47.1 \text{ In}$   
 Minimum Active Length (per Erick Huang)= 40.0 Ft  
 Active coils =  $L_{min} / \text{Coil length} = 10.2 \text{ Coils}$   
 Dead-end coils 4.0 Coils  
 Total Coils = 14.2 Coils  
 Cable Diameter (max) 0.50 In  
 Pitch (D + 3/16") 0.69 In  
 Drum Length = Pitch x total coils = 9.75 In

With wire rope, drum will be either 17-4 SS or Titanium with 100 Ksi minimum yield

1. GENERAL PERFORMANCE PARAMETERS (Continued)

[d.] Power Requirements

Total Mass at cable radius = Weight / 32.2 =	2.40 Slugs
Required Acceleration =	12.34 Ft/sec <sup>2</sup>
Minimum force at cable: F=ma=	29.59 Lbs
Minimum Torque = Force x Dia / 2 =	221.89 In-Lbs
Nominal Constant Tension	100.00 Lbs
Nominal Torque =	750.00 In-Lbs, = 62.50 Ft-Lbs
Required Velocity:	10.90 Ft/Sec, = 654.00 Ft/Min
Length / wrap =	3.93 Ft
Max Drum RPM =	166.54 RPM
Corner (peak) HP = 2 x pi x T x RPM / 33,000 =	1.98 HP net
Average HP (1/2 cycle) = C-HP x pi / 8 =	0.78 HP net

Note: since duty cycle is < 1 minute, a rating of 0.8 is justified.

[e.] Drive Train

After reviewing McMaster-Carr and Grainger catalogs, we can obtain either a 12-VDC snow plow motor (1-3/4 HP, Wt = 14 lb, RPM = 2900) or a rotary-vane air motor (1-1/2 HP, 3000 RPM free, stall torque = 4.67 ft-lb) to drive the winch. For a design RPM of 2800, we obtain the following drive train parameters:

Design driver RPM	2800.00 RPM
Design drum RPM	166.54 RPM
Design ratio	16.81
Torque at driver:	3.72 Ft-lb

We will use a gilmer (toothed) belt gear train to reduce weight and noise.

From the Morse catalog for timing belt drives:

Drum Reduction:

Driven pulley = 1/2 pitch, Morse 72H100SF, 1" wide, 72 tooth.	
Driving pulley = 1/2 pitch, Morse 14H100JA, 14 tooth	
Driving RPM = Drum RPM x (72/14) =	856 RPM
Allowable HP (pg H8) =	2.10 HP, ok
Ctr-ctr distance with 420H belt:	9.1 In.

2nd Reduction:

Driven pulley = 3/8" pitch, 44L100SDS, 44-tooth	
Driving Pulley = 3/8" pitch, Morse 14LF100, 14-tooth	
Driving RPM = Drum RPM x (44/14) =	2692 RPM
Allowable HP (pg H8) =	1.93 HP, ok
Ctr-ctr distance with 210L belt:	4.7 In

## 2. WIRE ROPE SELECTION

The 2-D motion analysis indicates acceptable performance with a brake release between 2,000 and 4,000 pounds. Although field experimentation will be required to determine the optimum value, a design based on 3,000-pounds plus 33% release variance, in combination with standard industry safety factors, is reasonable at the preliminary design stage.

Design maximum tension $=4000 \cdot 4/3 =$	5333 Lb
Drum strength eff. factor at 30:1	0.95
Design rope tension	5614 Lb
Factor of Safety:	4.00
Required breaking strength =	11.23 tons

From Jack Rubin & Sons, Tan Strand, 1/2" EIPS IWRC wire rope has a nominal breaking strength of 13.3 short tons. Select this rope. See Section 1.[c].

## 3. PRELIMINARY STRESS ASSESSMENT

The following paragraphs provide a preliminary stress analysis of the drum, shaft, brake, pawl, and other key components. Design factors of safety will be the Design Max. Tension (including brake variance) at 35% of yield. The following material properties are assumed:

<u>Material</u>	<u>Yield</u>
K-Monel	100 Ksi
17-4 HT 1200	120 Ksi
Titanium 6/4	110 Ksi
6061-T6 (ann.)	34 Ksi
18-8 Stainless	34 Ksi

### [a.] Drum

Max net rope tension is	5333 Lbs
Assume a minimum friction coefficient (greased cable)	0.15
$T[2]/T[1] = e^{f \cdot \theta} =$	2.57
Therefore second wrap =	2078 Lbs

If we consider 3 grooves, the first is zero tension, the second is max design tension, and the third is the reduced ( $T2/T1$ ) tension. Required area will be based on the average for the three grooves (see next page):

3.[a] Drum Stress Assessment (continued)

Tangential Force (add the three tensions) =	7412 Lbs
Allowable stress at 35% for titanium:	38.5 Ksi
Minimum section area at allowable stress	0.19 In <sup>2</sup>
Permissible length (2 grooves)	1.375 In
Average thickness = A / L =	0.140 In

We will design to a 1/8" base barrel plus grooving.

[b] Drum Diaphragm

The drive-side diaphragm can take the full design torque. The minimum radius outside the brake is

Min Radius =	5.25 In
Torque Multiplier =	1.43
Torque shear force =	7619 Lb
Shear area (1/4" plate) =	8.2 In <sup>2</sup>
Shear stress =	0.9 Ksi, ok in Aluminum

[c.] Main Support Bearing

The bearing selected is a Torrington needle roller bearing, No. HJ405224, with a 2.5" bore, 3.25" OD, 1.5" length, and load capacity of 21.5 kips per ISO 281.

[d.] Pawl / Ratchet

Applied Torque	40,000 In-lbs
Pawl torque arm =	2.5 In
Pawl axial force	16.0 Kip
Allowable stress in K-Monel at 35%:	35.0 Ksi
Required area =	0.46 In <sup>2</sup>

Use a 1/2" thick x 1" wide pawl and seats

[e.] Shaft (17-4 SS HT1200)

Shaft OD	2.5 In
Shaft ID	2.0 In
Area	1.77 In <sup>2</sup>
Applied shear	5.3 Kip
Shear stress = $2.0 \cdot V/A$ =	6.0 Ksi
Z =	1.8 In <sup>3</sup>
Torque =	40 In-Kip
Torsion = $T / Z$ =	22.1 Ksi
Total shear stress	27.4 Ksi
Allowable shear at 65% tensile allowable:	27.3 Ksi, OK, fill shaft at pawl arm

[f.] Brake Design

Nominal brake release tension:	4.0 Kip
Mean brake disc radius:	4.0 In
Torque at slip:	30.0 In-Kip
Coefficient of friction (pressed glass/steel)	0.35
Total required Normal force:	21.4 Kip
Number of friction surfaces for 7 steel discs:	6 ea
Required axial spring force:	3.6 Kip
Disc area	37.7 In <sup>2</sup>
Disc pressure	94.7 Psi, <250 ok

Belleville washer: Century CDM20010255 (4710 lbs at 1/4 deflection)

## Energy absorption:

The duty cycle is very light, but the brake is uncooled. From the 2-D analysis, we have (for two winches, assume concentrated into one)

Disc thickness:	0.0625 In
Brake disc weight =	4.7 Lb
Specific Heat =	81.0 Ft-lb/lbm/F
The max relief energy (2 kip, 1.2', 5 sec wave, 2 winch)	4800.0 Ft-lb
Temperature rise =	12.7 Deg F - OK

Keyway Design Torque =	40.0 In-Kip
Minimum radius	3.25 In
Key shear force	12.3 Kip
Key Width	0.25 In
Key Length = 2 x disc thickness =	0.19 In
Key shear area =	0.05 In <sup>2</sup>
For 100 ksi steel, allow shear stress =	22.8 Ksi
Total shear area required:	0.54 In <sup>2</sup>
Number of keys required:	11.5 each, machine 12

This is about a 1.7" pitch - circular keyways and tabs

Spring bolts: 4 each Gr 5 (88 ksi yield, 4:1 FS)

Nominal force	3.6 Kips
Allowable tensile stress (88 / 4)	22 Ksi
Stress area/bolt =	0.041 In <sup>2</sup>

Use 4 ea 5/16" bolts

The remaining winch structure is sized by experience and approximate calculations.

4. WEIGHT ESTIMATES

Drum Assembly: Item	Density (Lb/In <sup>3</sup> )	Volume (Cu.In or Ft)	Weight (Lbs)
Drum	0.161	125.6	20.2
Cable	0.46	72.0	33.1
Termination (clsd spelter)			1.5
End Plate+bearing	0.1	73.5	8.8
			<b>63.6</b>

Winch Drive Item	Density (Lb/In <sup>3</sup> )	Volume (Cu.In or )	Weight (Lbs)
Free End Spt Assy	0.098	20.0	2.0
Assy Nut	x	x	0.2
Drum/Brake Diaphram	0.098	55.4	5.4
Delrin Bushing	0.08	7.1	0.6
Bushing hardware	x	x	0.2
Brake discs	0.283	14.1	4.0
Brake/shaft diaphragm	0.098	65.2	6.4
Belleville washer	0.283	7.9	2.2
Brake clamp plate/bolts	0.098	4.1	0.5
Needle bearing	0.16	5.1	0.8
Shaft	0.283	16.8	4.8
Pawl seat plate	0.283	1.8	0.5
Pawl	0.3	1.1	0.3
Misc Pawl hardware	x	x	0.8
Ratchet Ring	0.16	17.3	2.8
Main Drive Pulley	0.283	13.8	3.9
Main Pulley web	0.098	15.0	1.5
1st Pinion + belt	x	x	1.1
2nd driven pulley (mod)	x	x	2.0
2nd pinion & belt	x	x	1.0
2nd shaft & bearing	x	x	1.0
Motor	x	x	14.0
Motor mounting	x	x	1.0
Drive casing	0.283	28.1	7.9
Guards	x	x	0.5
Support Fdn	0.283	14.3	4.1
Keeper/handle			0.5
<b>Total</b>			<b>70.0</b>

Weights are very close to the typical US Navy 70-lb limit for one man. These values are obtained using high-strength materials (titanium, 17-4SS) hence light weight will come at a cost.

**Appendix B.**  
**Supporting Calculations for**  
**Connection System Preliminary Design**

**1. HYDROSTATICS**

[a] Basic Dimensions:

Per Eric Huang, base barge dimensions are:

Length =	40.0 Ft.
Beam =	24.0 Ft.
Depth =	8.0 Ft.
Light Draft =	1.2 Ft.
Dsgn Draft =	4.0 Ft.

[b] Displacement:

Assume 64 lbs./cuft, 35cuft/LT

Ltshp Disp =	32.91 LT
Dsgn Disp. =	109.71 LT

[c] Waterplane Properties:

Area =	960 Ft <sup>2</sup>
TPI = A/420 =	2.29 Ton/In
=	5.12 Kip/In
I[t] =	46,080 Ft <sup>4</sup>
I[l] =	128,000 Ft <sup>4</sup>

[d] Lightship Stability

BM[t]=I[t]/Disp=	40.0 Ft.
KB = T/2 =	0.6 Ft.
Free Surf =	0.0 Ft.
KG =	4.0 Ft (Estimate)
GM[t] = KB+BM-FS-KG =	36.6 Ft.
BM[t]=I[t]/Disp=	111.1 Ft.
KB = T/2 =	0.6 Ft.
Free Surf =	0.0 Ft.
KG =	4.0 Ft (Estimate)
GM[t] = KB+BM-FS-KG =	107.7 Ft.

[e] Motion Spring Rates (Lightship):

The spring rate in heave equals TPI: 5.12 Kip/In  
 For small angles, GZ = GM\*sin(theta) = GM\*theta

Roll (Torque) Spring Rate =	1205 Ft-Tons/Rad
Pitch (Torque) Spring Rate =	3545 Ft-Tons/Rad

**2. WAVE BENDING MOMENTS**

We need to calculate quasi-static wave bending moments for various barge configurations and wave superpositions. Simpson's 1st rule will be used in the following table format.

<u>Barge:</u>	<u>Wave:</u>
Length            160 Ft	Length            160 Ft
Beam              24 Ft	Period            5.59 Sec
Mn Draft         4 Ft	Omega            1.12 Rad/Sec
Pitch             0 Deg	Height            5
Depth            8 Ft	Shift             120

Station	Depth	Rev Depth	S.Mult.	1st Prod	2nd Prod	Intermediate 1st Prod	Conn. Point 2nd Prod
0	6.50	6.50	1	6.50	78.00	6.50	78.00
1	6.41	6.41	4	25.66	282.25	25.66	282.25
2	6.16	6.16	2	12.33	123.30	12.33	123.30
3	5.77	5.77	4	23.07	207.63	23.07	207.63
4	5.25	5.25	2	10.50	83.99	10.50	83.99
5	4.65	4.65	4	18.59	130.10	18.59	130.10
6	4.00	4.00	2	8.00	47.99	4.00	24.00
7	3.35	3.35	4	13.41	67.05	0.00	0.00
8	2.75	2.75	2	5.50	22.00	0.00	0.00
9	2.23	2.23	4	8.93	26.78	0.00	0.00
10	1.83	1.83	2	3.67	7.34	0.00	0.00
11	1.59	1.59	4	6.34	6.34	0.00	0.00
12	1.50	1.50	2	3.00	0.00	0.00	0.00
13	1.59	1.59	4	6.34	-6.34	100.64	929.26
14	1.84	1.84	2	3.67	-7.34		
15	2.23	2.23	4	8.93	-26.79		
16	2.75	2.75	2	5.50	-22.00		
17	3.35	3.35	4	13.41	-67.06		
18	4.00	4.00	2	8.00	-48.00		
19	4.65	4.65	4	18.59	-130.12		
20	5.25	5.25	2	10.50	-84.00		
21	5.77	5.77	4	23.07	-207.64		
22	6.17	6.17	2	12.33	-123.30		
23	6.41	6.41	4	25.66	-282.25		
24	6.50	6.50	1	6.50	-78.00		
<b>Totals</b>				<b>287.99</b>	<b>-0.10</b>		

Total Buoyancy =	15359.72	Ft <sup>3</sup> =	438.85	L.Tons
Hinge Point Buoyancy =	5367.619	Ft <sup>3</sup> =	153.36	L.Tons
Hinge Pt Buoy. Mom =	330,404	Ft <sup>3</sup> =	9440.12	Ft-Tons

2. WAVE BENDING MOMENTS (Continued with 5-foot wave)

The following table lists the quasi-static barge hull girder bending moment in Foot-tons.

**HULL GIRDER BENDING MOMENTS (Ft-Tons)**

Tmean	Barge Length	1st Connector		2nd Connector		3rd Connector	
		Hog	Sag	Hog	Sag	Hog	Sag
1.2	80	379	-379	---	---	---	---
1.2	160	654	-862	1516	-1516	---	---
1.2	240	<b>658</b>	<b>-1001</b>	2411	-2753	3412	-3411
4	80	556	-556	---	---	---	---
4	160	1112	-1111	2223	-2223	---	---
4	240	1250	-1251	3751	-3751	5001	-5000

The maximum design moment during connection is indicated in bold, and is about one-fifth the maximum operational design load. We also need to know vertical shear loads for the "shear gate" design calculations.

**HULL GIRDER SHEAR (Long Tons)**

Tmean	Barge Length	1st Connector		2nd Connector		3rd Connector	
		Hog	Sag	Hog	Sag	Hog	Sag
1.2	80	0.0	0.0	---	---	---	---
1.2	160	-31.2	31.2	0.0	0.0	---	---
1.2	240	-32.9	44.2	-44.2	32.9	0.0	0.0
4	80	0.0	0.0	---	---	---	---
4	160	-43.7	43.6	0.0	0.0	---	---
4	240	-56.7	56.7	-56.7	56.7	0.0	0.0

The following pages define the connection hardware to withstand these loads. Refer to drawing P9544-NFESC-001 for the associated hardware. The following material properties will be used throughout:

Material	Yield	240-Ft Barge at ABS/SS3		120-Ft Barge at 35% Yld	
		Tensile	Shear	Tensile	Shear
A-36 Steel	36.0	21.6	14.4	12.6	7.6
HTS Steel	51.0	30.6	20.4	17.9	10.7
K-Monel	100.0	60.0	40.0	35.0	21.0
Titanium	110.0	66.0	44.0	38.5	23.1
17-4 HT120	120.0	72.0	48.0	42.0	25.2
Al 5086/545	34.0	20.4	13.6	11.9	7.1

For the maximum barge length, we have assumed allowable stresses similar to AISC, typical of ABS for maximum design sea states (we have SS3 versus ABS' North Atlantic). For the more operational 120-ft barge length, we consider a typical USN allowable of 35% of Yield. Since stresses more than double for the 240-ft barge, the former (ABS/AISC) constraint governs.

### 3. SHEAR CONNECTORS

The 2-D dynamic time-domain analysis showed a tendency for one barge to "whip" relative to the other as the connection wire length shortens. We therefore selected a retractable design that can be used to pull the barges into alignment once the barge ends have come together. Garrison's work indicates relative sway would be only a Kip or so, and the preceeding analysis quantifies design vertical shear values.

In this design, the sailor-powered 6-foot cheater bar is used on the shear connector to pull the barges into lateral alignment after the fenders are retracted. The sway portion of the design will limit (using shear pins) the maximum torque that can be fed back through the structural system to the sailor.

Available sailor force (2 x 100 lb)	200 Lb
Torque Arm	72 In
Available sway force at 6" contact radius:	<b>2400 Lb</b>

This is consistent with Garrisons sway forces and the ratchet engine capacity.

Shear Pin size:

Material:	Brass
Ultimate:	42 Ksi shear
No. shear surfaces (2 pins):	4
Shear radius	1.25 In
Shear Pin area	0.069 In <sup>2</sup>
Pin Diameter =	<b>0.30 In</b>

**Use 5/16" Naval Brass shear pins**

Once the shear connectors are set, the locking pawl dictates side shear capacity. Assume the lateral capacity must be 33% of the vertical:

Shear force (240-ft barge)	42.3 Kip
Torque arm after barges connected:	4.0 In
Max Design Sway Torque:	169.3 In-Kip
Locking Pawl Radius:	3.8 In
Locking Pawl shear	45.2 Kip
Allowable shear stress for K-Monel:	40.0 Ksi
Required Pawl Area =	<b>1.13 In<sup>2</sup></b>

**Use either 1.25" Dia or 1" x 1.125" rectangular configuration**

Max torque tube shear = resultant of sway shear & pawl =	61.9 Kip
Torque Tube OD	2.5
Torque Tube ID	2.0
Area	1.8
Shear stress	<b>35.0 Ksi</b>
Allowable for 17-4 SS HT1200:	<b>48.0 Ksi, OK</b>

### 3. SHEAR CONNECTORS (Continued)

For vertical shear, the load is:		127.0 Kip
If all load goes through one connector "paddle," the required compression area for 17-4 SS is:	Allowable =	72.0 Ksi
	Min. Area =	1.8 In <sup>2</sup>
The paddles are 2" wide with 1/4" skins, faced top and bottom with 1-inch plate. The required landing area around the tube is about	Bearing ID =	3.0 In
	Bearing OD =	3.5 In
	Bearing Area =	2.6 In <sup>2</sup>
The vertical load vector is:	Vertical =	12.0 In
	Lateral =	3.5 In
Max load vector multiplier is		1.04

The preceding calculations are not materially affected by the slight increase in load caused by the angled load vector. Since maximum shear does not coincide with maximum hull girder bending, the lateral load is not additive to the moment connectors.

### 4. UPPER MOMENT CONNECTORS

There are four sets of connectors at each barge joint: four upper and four lower. The connectors are deployed after the barges have come together and the shear connectors have been set. Key design criteria include light weight to allow hand deployment by a sailor, and shock mitigation. Loads during activation (1.2' barge draft) are only about one-fifth the maximum loaded barge center connector.

Max Hull girder bending moment (240-ft barge)	5,001 Ft-tons, =
	11,203 Ft-Kip
Moment arm 'tween bottom shell & upper connector:	7.6 Ft
Force in 4 connectors:	1469.2 Kip
Force / Connector =	367.3 Kip
Connector is 3.25-8 UN, Titanium. Stress area =	7.7 In <sup>2</sup>
Stress =	47.9 Ksi
Allowable =	66.0 Ksi, OK
Minor Diameter =	3.1 In
Nut Height	1.5
Shear Area =	14.6 In <sup>2</sup>
Shear Stress =	25.2 Ksi
Allowable shear stress =	44.0 Ksi, OK
Minimum Nut bearing area =	12.0 In <sup>2</sup>
Greater than tensile area, OK	

The potential exists for "snap" loads during connection until all four pins are set. The pins therefore include Belleville washers (combined K = 887 LT/Ft or 52,000 Ft-Tons/Rad), stiff compared to a far softer barge pitch spring rate (3545 Ft-Tons/rad). Detail design may show they are not required.

## 5. LOWER MOMENT CONNECTORS

The lower connector is similar in concept to the upper one, but modified to suit remote activation from the deck. Two remote rod systems are required: one to spring-bias the connector in either the engaged or disengaged position, and one to tension (loosen) the connector push rod. The design incorporates the same shock relief (belleville washers) as the upper connectors.

Max Hull girder bending moment (240-ft barge)	5,000 Ft-tons, = 11,201 Ft-Kip
Moment arm 'tween deck & lower connector:	7.6 Ft
Force in 4 connectors:	1469.0 Kip
Force / Connector =	367.2 Kip
Connector section is 3" square, Titanium. Stress area =	9.0 In <sup>2</sup>
Stress =	40.8 Ksi
Allowable =	66.0 Ksi, OK
Head bearing area =	8.3 In
Bearing stress =	44.5 Ksi, OK
Head shear: Area =	13.5 In <sup>2</sup>
Head avg shear stress =	27.2 Ksi
Allowable shear stress =	44.0 Ksi, OK
Pin Shear: Diameter =	2.5 In
Shear Area =	9.8 In
Shear stress =	37.4 Ksi
K-Monel allowable =	40.0 Ksi, OK
Since rocker arm ratio is 1:1, remote rod OK by inspection.	
Rocker pin: $F = \text{Pin force} * 2^{.5} =$	519.4 Kip
Pin Diameter =	3.0 In
Shear Area =	14.1 In <sup>2</sup>
Shear stress =	36.7 Ksi, OK
Bearing stresses at 160% allowable tensile are OK by inspection.	

## 6. LOWER CONNECTOR ENGAGEMENT ROD

Each side of the piston is bounded by two century #866 springs pre-compressed to 50% length. The resultant spring rate is about 15 lb/in, or about 60 pounds at full travel. This force is sufficient to bias the connecting pin to engage or disengage.

Max design rod force =	100.0 Lb
Radius of gyration	0.4 In
KL/R =	194.8
Allowable AISC stress for 36 KSI yield =	6.3 Ksi
Area (1" Sch 40) =	0.5 In <sup>2</sup>
Activation stress =	0.2 Ksi, OK

## 7. FENDERS

In general, two fenders will engage for maximum speed head-on barge impacts. Corner hits will typically result in barge rotation and lower forces until they are squared to each other. However, we will design the fenders so that one will absorb the full impact at maximum compression.

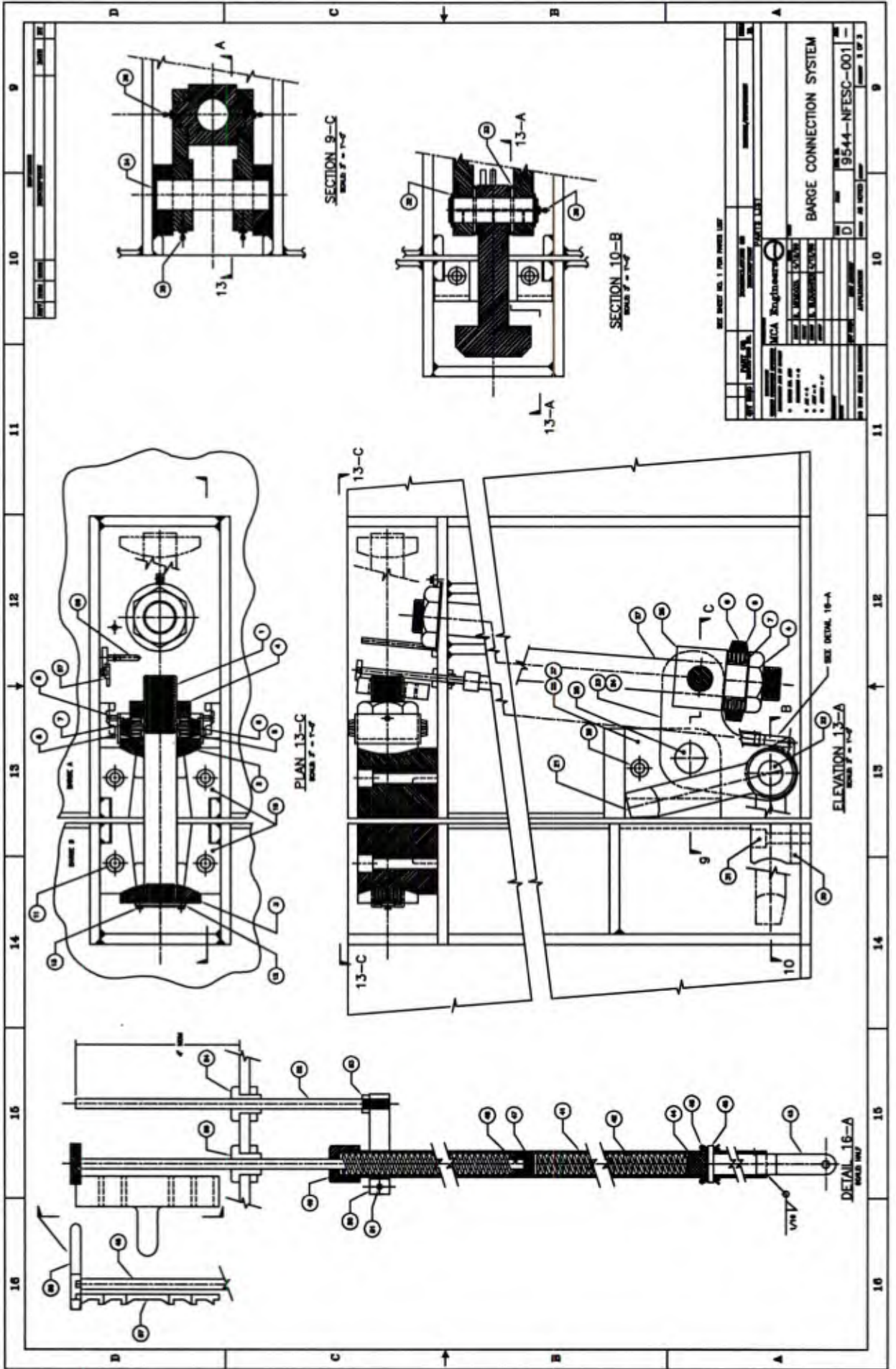
From the dynamic analysis, we have a maximum relative velocity of 10.9 Ft/sec  
Since the fender is located between the two barges, force imparted to one equals the force (and energy) imparted to the other. Ignoring added mass, we have:

Barge Weight =	32.9 Ltons
Barge Mass = W/G =	2289.7 Slug
Half relative velocity =	5.5 Ft/sec
Energy = $1/2 MV^2$ =	34,005 Ft-lb, =
	<b>4.7 Ton-Meter</b>

This is within the capacity of 2 meters of Sumitomo (2.5 T-M/M at 200 mm deflection).  
Therefore use Type D 400H200.

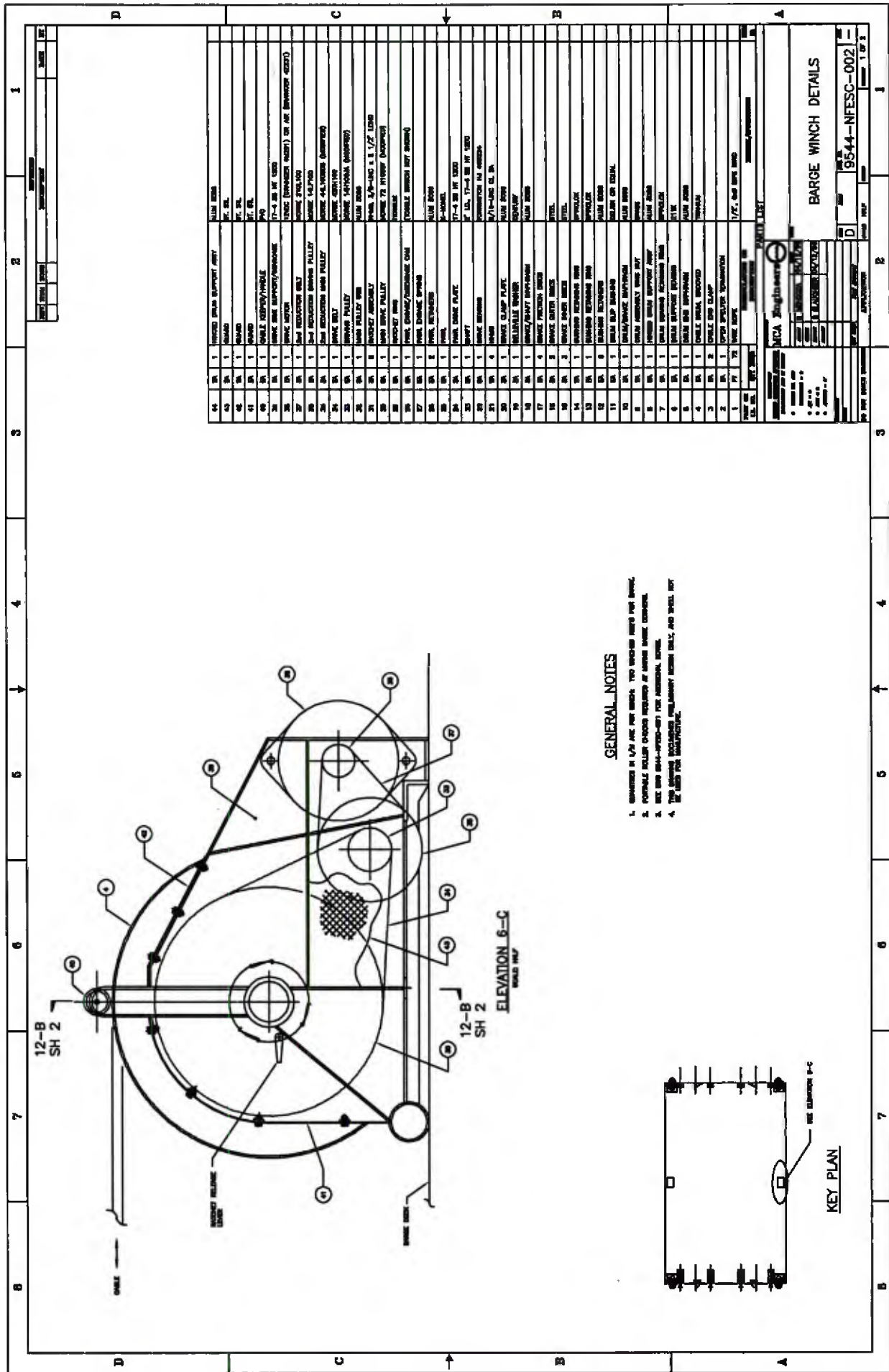
**Appendix C.**  
**Design Drawings**





SEE SHEET NO. 1 FOR PANEL LAYOUT	
PROJECT NO.	9544-NFESC-001
DATE	
SCALE	
DESIGNED BY	
CHECKED BY	
APPROVED BY	
<b>BARGE CONNECTION SYSTEM</b>	
MCA Engineering	
1000 UNIVERSITY DRIVE ANN ARBOR, MI 48106-1500 TEL: 313.763.1000 FAX: 313.763.1001	





**GENERAL NOTES**

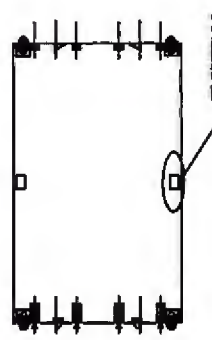
1. DIMENSIONS IN 1/8" ARE PER UNLESS TWO DECIMALS ARE NOT SHOWN.
2. FURNISH ALL BOLTS AND NUTS REQUIRED AT LEAST 3/8" DIA. UNLESS OTHERWISE NOTED.
3. SEE END VIEW FOR DIMENSIONS AND MATERIALS.
4. THIS DRAWING INCLUDES DIMENSIONS FOR BOLT HEADS AND NUTS BUT NOT FOR THE MATERIALS.

NO.	DESCRIPTION	QTY.	UNIT	REMARKS
14	1/2" DIA. BALL BEARING	1	EA.	
15	1/2" DIA. BALL BEARING	1	EA.	
16	1/2" DIA. BALL BEARING	1	EA.	
17	1/2" DIA. BALL BEARING	1	EA.	
18	1/2" DIA. BALL BEARING	1	EA.	
19	1/2" DIA. BALL BEARING	1	EA.	
20	1/2" DIA. BALL BEARING	1	EA.	
21	1/2" DIA. BALL BEARING	1	EA.	
22	1/2" DIA. BALL BEARING	1	EA.	
23	1/2" DIA. BALL BEARING	1	EA.	
24	1/2" DIA. BALL BEARING	1	EA.	
25	1/2" DIA. BALL BEARING	1	EA.	
26	1/2" DIA. BALL BEARING	1	EA.	
27	1/2" DIA. BALL BEARING	1	EA.	
28	1/2" DIA. BALL BEARING	1	EA.	
29	1/2" DIA. BALL BEARING	1	EA.	
30	1/2" DIA. BALL BEARING	1	EA.	
31	1/2" DIA. BALL BEARING	1	EA.	
32	1/2" DIA. BALL BEARING	1	EA.	
33	1/2" DIA. BALL BEARING	1	EA.	
34	1/2" DIA. BALL BEARING	1	EA.	
35	1/2" DIA. BALL BEARING	1	EA.	
36	1/2" DIA. BALL BEARING	1	EA.	
37	1/2" DIA. BALL BEARING	1	EA.	
38	1/2" DIA. BALL BEARING	1	EA.	
39	1/2" DIA. BALL BEARING	1	EA.	
40	1/2" DIA. BALL BEARING	1	EA.	
41	1/2" DIA. BALL BEARING	1	EA.	
42	1/2" DIA. BALL BEARING	1	EA.	
43	1/2" DIA. BALL BEARING	1	EA.	
44	1/2" DIA. BALL BEARING	1	EA.	

BARGE WINCH DETAILS

9544-NFESC-002

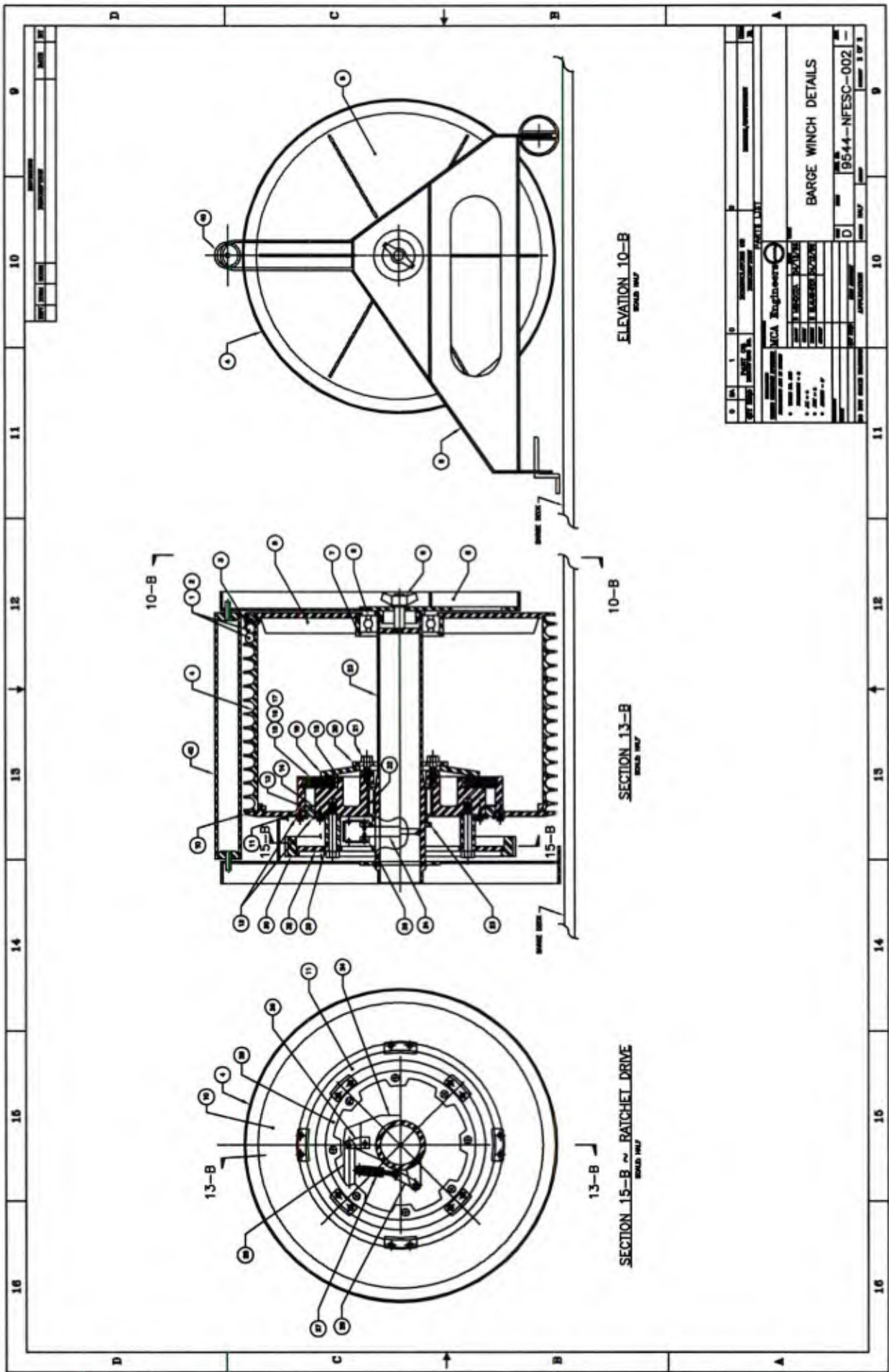
KEY PLAN



ELEVATION 6-C  
WIND UP

12-B  
SH 2

12-B  
SH 2



ELEVATION 10-B  
SCALE 1/4" = 1'-0"

SECTION 13-B  
SCALE 1/4" = 1'-0"

SECTION 15-B - RATCHET DRIVE  
SCALE 1/4" = 1'-0"

REVISIONS		DATE		BY		CHECKED	
1	AS SHOWN						
PROJECT: BARGE WINCH DETAILS DRAWING NO: 9544-NFESC-002 SHEET NO: 1 OF 1							
CONTRACTOR: ENGINEER: ARCHITECT: MANUFACTURER:				APPROVED: DATE:			



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