TRANSPORTABILITY ENGINEERING ANALYSIS

LOAD FACTORS FOR CARGO RESTRAINT DURING MARINE TRANSPORT

Prepared by:
MR. JOHN T.H. GERMANOS

MILITARY TRAFFIC MANAGEMENT COMMAND
TRANSPORTATION ENGINEERING AGENCY
720 THIMBLE SHOALS BLVD, SUITE 130
NEWPORT NEWS, VIRGINIA 23606-2574
COMMERCIAL (804) 599-1113
AUTOVON 927-4646

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>EXECUTIVE SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>II.</td>
<td>BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>III.</td>
<td>ANALYSIS</td>
<td>3</td>
</tr>
<tr>
<td>A.</td>
<td>Acceleration Equations</td>
<td>3</td>
</tr>
<tr>
<td>B.</td>
<td>Load Factor Equations</td>
<td>6</td>
</tr>
<tr>
<td>C.</td>
<td>Assumptions and Rationale</td>
<td>6</td>
</tr>
<tr>
<td>D.</td>
<td>Findings</td>
<td>8</td>
</tr>
<tr>
<td>IV.</td>
<td>CONCLUSION</td>
<td>10</td>
</tr>
<tr>
<td>V.</td>
<td>RECOMMENDATIONS</td>
<td>12</td>
</tr>
<tr>
<td>APPENDIXES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.</td>
<td>MSC Memorandum on Effects of G-Forces During Marine Transport</td>
<td>A-1</td>
</tr>
<tr>
<td>B.</td>
<td>Load Factor Example Calculation</td>
<td>B-1</td>
</tr>
<tr>
<td>GLOSSARY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTION</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

St #A, Auth MIMC/TEA
(Ms. Napiecek - DSN 927-4646)
Telecon, 12 Apr 93 - CB
I. EXECUTIVE SUMMARY

This analysis establishes up-to-date load factors for use in establishing tiedown procedures for military equipment during marine transport. These load factors apply to all ships currently listed on the Computerized Deployment System (CODES) database.

II. BACKGROUND

Prior to this study, load factors specifically for use in determining marine tiedown procedures had never been documented. The American National Standards Institute (ANSI) lists load factors imposed on containers during marine transport as follows:

"It is assumed that the combined effect of a vessel's motions and gravity results in an equivalent 1.8 times gravity vertical acceleration, an equivalent 0.6 times gravity transverse acceleration and an equivalent 0.4 times gravity longitudinal acceleration." 1

However, these factors are primarily used to influence the design of containers. They are not supported by any rationale, such as sea conditions and/or ship design. As a result, Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) had always based marine tiedown procedures on the acceleration data in Army Technical Bulletin (TB) 55-100, which states:

"...cargo and its restraining system should be capable of sustaining an environment occasioned by a seaway-induced loading on a transport ship consequent to twenty days of Beaufort sea state condition 12." 2

The data from TB 55-100 used to establish the guidance for sustaining the above environment is shown by figure 1. These data are a plot of an envelope of the maximum values of vibrations in the frequency range of 0 to 15 cycles per second. Figure 1 also shows a time history envelope of the maximum shock environment measured. It indicates that the maximum accelerations for a C-2 general cargo ship would be 1.5g in the vertical and lateral directions. Longitudinal accelerations are not addressed, so we typically used 1.0g as a "rule of thumb." Experience gained from Operation Desert Shield/Storm indicates that these data are outdated and inappropriate for today's fleet of larger roll-on/roll-off (RORO) and breakbulk ships that were used to deploy Army equipment to Southwest Asia (SWA). In addition, inconsistent and often excessive tiedown procedures were required by ship's officers because we did not have any published restraint criteria to use for guidance. This resulted in wasted time, money, materials, and manpower hours, especially when lashing gangs were forced to break down and redo lashings to satisfy varying "gut instincts" of ship officers. For example, at the port of Jacksonville, we witnessed one lashing gang being directed by ship officers to tie down 5-ton trucks three different ways on three successive vessels. This led to frustration and wasted valuable time.

Figure 1. Load factor data from TB 55-100.
Recognizing the need for reliable marine tiedown guidance, the Commander, MTMC requested that we establish tiedown criteria that would be adequately conservative, yet enable us to reduce the time and cost of deployment. To initiate this effort, we had to establish some realistic load factors that could serve as the common reference for tiedown criteria and procedures. Initially, we requested that the Military Sealift Command (MSC) provide us with these load factors. MSC's response to our request (app A) recommended that we use DOD-STD-1399 to calculate the load factors. The following analysis accomplishes this task and provides the foundation for the development of a consolidated marine lifting and tiedown handbook that will effectively standardize sealift procedures.

III. ANALYSIS

The load factors presented herein are dimensionless numbers that account for the component accelerations imposed on military equipment by ship motion and attitude during storm sea conditions. When multiplied by the equipment's weight, these load factors give design loads that the equipment tiedown assembly must be able to withstand in the longitudinal (X), transverse (Y), and vertical (Z) directions. We do not intend this study to be a primer in naval architecture; however, the following equations and assumptions must be addressed, since they provide the foundation for our analysis.

A. Acceleration Equations

The motion of a floating object has six degrees of freedom, as shown by figure 2. To determine the accelerations imposed on cargo by ship motion and attitude, we must consider static and dynamic contributions. Static contributions are dictated by the ship attitude and include list, heel, and trim. Dynamic contributions, shown in figure 2, include angular (roll, pitch, and yaw) and linear (surge, sway, and heave) motions. When combined with the components of the gravitational acceleration on the equipment, the terms for these static and dynamic motions are summed to determine the net accelerations in the X, Y, and Z directions as described by the following formulas.

1. \[ A_x = g \sin \Theta + s + k_1 \Theta X + k_2 \]
2. \[ A_y = g \sin \Phi + \frac{1}{2} k_1 X + k_2 \Phi Y + k_2 Z \]
3. \[ A_z = g \pm [h + k_1 X + k_2 Y] \quad ("+" \text{ is up, "-" is down}) \]

\[ ^1 \text{ Memorandum, MTMCTEA, ATTN: MTTE-TRV, 6 Nov 90, subject: G-Forces Encountered During Marine Transport.} \]
\[ ^2 \text{ DOD-STD-1399 (Navy), Interface Standard for Shipboard Systems, Section 301A, Ship Motion and Attitude, 21 July 1986.} \]
Figure 2. Conventional ship coordinate axes and ship motions.
Where,

4. \( k_1 = 4\pi^2\Theta / T_r^2 \) \( (T_r = (CB)/GM) \)

and,

5. \( k_2 = 4\pi^2\Phi / T_p^2 \)

The variables and symbols used in the above equations are defined as follows:

\( A_x \) = component acceleration in the longitudinal direction
\( A_y \) = component acceleration in the transverse direction
\( A_z \) = component acceleration in the vertical direction
\( \Theta \) = maximum pitch angle (rad)
\( \Phi \) = maximum roll angle (rad)
\( s \) = surge acceleration (m/s\(^2\) or ft/s\(^2\))
\( h \) = heave acceleration (m/s\(^2\) or ft/s\(^2\))
\( g \) = acceleration caused by gravity (m/s\(^2\) or ft/s\(^2\))
\( T_p \) = pitch period (sec)
\( T_r \) = roll period (sec)
\( GM \) = maximum metacentric height (m or ft)
\( B \) = maximum beam at or below the waterline (m or ft)
\( C \) = roll constant (s/ft)
\( X \) = longitudinal distance from CG (m or ft)
\( Y \) = transverse distance from CG (m or ft)
\( Z \) = vertical distance above CG (m or ft)

Note: \( X \), \( Y \), and \( Z \) define the stowage location farthest from the ship's center of gravity (CG).

Many of the above symbols and/or terms appear in the Glossary. In addition, figures 3 and 4 illustrate the two most significant dynamic motions (rolling and pitching) along with some appropriate symbols.
Figure 3. End view of a vessel upright and after rolling \( \Phi \) degrees.

\( G = \) center of gravity
\( M = \) metacenter
\( B = \) center of buoyancy
\( \text{GM} = \) metacentric height

\( \overline{WL} = \) initial waterline
\( \overline{W_1L_1} = \) waterline after pitching \( \Theta \) degrees

Figure 4. Side view of a vessel upright and after pitching \( \Theta \) degrees.

\( G = \) center of gravity
\( B = \) center of buoyancy
B. Load Factor Equations

Once the component accelerations have been calculated as shown above, determination of the load factors is relatively simple. The following equations define these load factors.

1. \( L_{tx} = \frac{A_x}{g} \) longitudinal load factor
2. \( L_{ty} = \frac{A_y}{g} \) transverse load factor
3. \( L_{tz} = \frac{A_z}{g} \) vertical load factor

C. Assumptions and Rationale

To conduct our analysis for a "worst case" scenario, we made the following assumptions. Rationale is included where appropriate.

1. The vessel is on a transoceanic voyage under storm sea conditions equivalent to sea state 8 (up to 45-foot wave height). Sea state 8 is the worst case presented in DOD-STD-1399, section 301A, and it is used here to represent a "winter North Atlantic" environment. Therefore, we are considering maximum sea-induced accelerations in our load factor equations. Interviews with ship officers returning from SWA during Desert Shield/Storm revealed that the worst sea encountered was sea state 4. This implies we have been adequately conservative in assuming sea state 8. Table 1 relates sea state to significant wave height.

<table>
<thead>
<tr>
<th>Sea State Number</th>
<th>Significant Wave Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meters</td>
</tr>
<tr>
<td>0-1</td>
<td>0.00 - 0.10</td>
</tr>
<tr>
<td>2</td>
<td>0.10 - 0.50</td>
</tr>
<tr>
<td>3</td>
<td>0.50 - 1.25</td>
</tr>
<tr>
<td>4</td>
<td>1.25 - 2.50</td>
</tr>
<tr>
<td>5</td>
<td>2.50 - 4.00</td>
</tr>
<tr>
<td>6</td>
<td>4.00 - 6.00</td>
</tr>
<tr>
<td>7</td>
<td>6.00 - 9.00</td>
</tr>
<tr>
<td>8</td>
<td>9.00 - 14.00</td>
</tr>
<tr>
<td>&gt;8</td>
<td>&gt;14.00</td>
</tr>
</tbody>
</table>
2. Greatest initial emphasis must be placed on the transverse load factor. It is typically the largest factor and contributes the most to overall restraint requirements. This is because that ships have a greater tendency to rotate about their longitudinal axis (roll). Figure 5 illustrates how load factors vary with increasing sea state for the Fast Sealift Ship (FSS). The transverse load factor is always the highest for cargo restraint/tiedown considerations. Note that only negative vertical load factor values (up or down) contribute to restraint requirements. The positive values shown in figure 5 are actually load factors for determining the “g-load” on the deck, not a “g-load” that must be accounted for by the cargo tiedown assembly.

3. The load being restrained is at the stowage location farthest from the ship’s CG. Since the acceleration induced by ship motion is proportional to the distance from the ship’s CG, the load will experience the greatest accelerations and corresponding load factors at the farthest location from the CG.

4. Ships analyzed were partially loaded to create a notional worst case metacentric height (GM). An ideal GM usually corresponds to a fully loaded vessel riding relatively low in the water, since this condition is less inclined to promote rolling. As the load lightens, the vessel rides proportionally higher in the water, and the GM increases. As it rides higher in the water, the vessel tends to “bob” and is more inclined to roll; hence, a worst case is introduced.

5. A roll constant (C) of 0.4 s/rt was used to represent the ships in this study. The roll constant is based on experimental results from similar vessels. Per DOD-STD-1399, C varies from 0.38 to 0.49. Lower values of C reflect a worst case; however, varying C over the full range of possible values yields a maximum transverse load factor change of 0.05, or about 3 percent. This variation is relatively insignificant and supports our contention that C = 0.4 is adequately conservative. The transverse load factor is the most sensitive to variations in C.

6. The ships used in our calculations represent an acceptable sample of vessels in the CODES database for use in determining a generic set of load factors. We wrote a computer program that varied all components of the load factor equations for the FSS to see which tended to have the most detrimental effect on the transverse load factor. We compared these results with the CODES ship database and files to produce a list of smaller RORO and breakbulk ships with characteristics that would result in the highest load factors (worst case).

7. Generally, a correlation exists between overall ship size and load factors. Larger vessels tend to be more stable in rough seas; therefore, their corresponding load factors tend to be less than that of smaller vessels.

D. Findings

Based on these equations and assumptions and the ship data provided by MSC and Maritime Administration, we calculated load factors for each ship. Table 2 compiles the data and results for the ships analyzed. As expected, the load factors for the FSS because of its relative size and stability, are significantly less than for the “other ships” analyzed. Therefore, we have chosen to treat the FSS as a special case, independent of smaller RORO and breakbulk ships in the CODES database. From table 2, the highest load factors correlate to the smallest vessels, with the container/breakbulk being the notional worst case. This observation lends credence to our sixth and seventh assumptions. In all cases, our calculated load factors
FIGURE 5
LOAD FACTORS VERSUS SEA STATE
FOR THE FAST SEALIFT SHIP
# TABLE 2

Data and Results for the Ships Analyzed

<table>
<thead>
<tr>
<th>DATA CATEGORY</th>
<th>DATA SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ship Name</strong></td>
<td>Fast Scalift Ship</td>
</tr>
<tr>
<td><strong>Ship Type</strong></td>
<td>RORO</td>
</tr>
<tr>
<td><strong>MA #</strong></td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Length Between Perpendiculars, LBP (ft)</strong></td>
<td>840.5</td>
</tr>
<tr>
<td><strong>Beam, B (ft)</strong></td>
<td>105.5</td>
</tr>
<tr>
<td><strong>Metacentric Height, GM (ft)</strong></td>
<td>8.41</td>
</tr>
<tr>
<td><strong>Max. Longitudinal Distance from Ship's CG, X (ft)</strong></td>
<td>317.0</td>
</tr>
<tr>
<td><strong>Max. Vertical Distance from Ship's CG, Z (ft)</strong></td>
<td>21.45</td>
</tr>
<tr>
<td><strong>Max. Horizontal Distance from Ship's CG, Y (ft)</strong></td>
<td>26.4</td>
</tr>
<tr>
<td><strong>Roll Constant, C (sec*ft)</strong></td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Roll Angle, φ (rad)</strong></td>
<td>0.54</td>
</tr>
<tr>
<td><strong>Pitch Angle, θ (rad)</strong></td>
<td>0.087</td>
</tr>
<tr>
<td><strong>Roll Period, T_r (sec)</strong></td>
<td>14.55</td>
</tr>
<tr>
<td><strong>Pitch Period, T_p (sec)</strong></td>
<td>8</td>
</tr>
<tr>
<td><strong>Heave Acceleration, h (ft/sec^2)</strong></td>
<td>6.43</td>
</tr>
<tr>
<td><strong>Surge Acceleration, s (ft/sec^2)</strong></td>
<td>3.215</td>
</tr>
<tr>
<td><strong>Transv. Acceleration, A_y (ft/sec^2)</strong></td>
<td>28.696</td>
</tr>
<tr>
<td><strong>Vert. Acceleration (up), A_z (ft/sec^2)</strong></td>
<td>5.992</td>
</tr>
<tr>
<td><strong>Vert. Acceleration (down), A_z (ft/sec^2)</strong></td>
<td>58.307</td>
</tr>
<tr>
<td><strong>Transv. Load Factor, L_y</strong></td>
<td>0.89</td>
</tr>
<tr>
<td><strong>Long. Load Factor, L_x</strong></td>
<td>0.269</td>
</tr>
<tr>
<td><strong>Vert. Load Factor (up), L_z</strong></td>
<td>0.186</td>
</tr>
</tbody>
</table>
were significantly less than those historically used by MTMC for planning marine restraint/tiedown procedures. Table 3 compares our results with the load factors previously used and shows the percent reduction resulting from our study. Appendix B contains an example calculation for the vessel, Aide, since it presented the worst case load factors. Similar calculations were done for each vessel analyzed by using the equations in paragraphs III A and B. Our calculations and results were sent to MSC for approval in February 1991. MSC concurred with our results, stating that “These factors are considered conservative and satisfactory for ship cargo loadings.”

These load factors provide the common base required for developing general tiedown procedures for marine transport. Once developed, these procedures will be incorporated into MTMCTEA Pamphlet 55-22, Marine Terminal Lifting and Tiedown Guidance. We published similar pamphlets for rail tiedown (MTMCTEA Pam 55-19) and marine lifting (MTMCTEA Pam 56-1). These pamphlets were used extensively during Desert Shield/Storm operations. MTMCTEA Pam 55-22 will consolidate the revision of MTMCTEA Pam 56-1 (lifting manual) with the newly developed tiedown guidance, to produce a comprehensive marine terminal reference that military and commercial shippers did not have in the past. The net result will be more efficient loading operations at the ports.

**IV. CONCLUSION**

Prior to this study, appropriate load factors for determining marine restraint criteria did not exist. Marine tiedown procedures typically varied for different vessels, subject to the discretion of the individual inspecting the load. This often led to excessive lashing and wasted time, money, and manpower hours, particularly when lashing gangs were required to breakdown and redo tiedowns to satisfy a particular individual. This study provides the baseline for establishing uniform tiedown procedures on all ships in the CODES database. The load factors we established are adequately conservative and have been approved by MSC. The following summarizes these load factors for the FSS and all “other ships” in the CODES database:

<table>
<thead>
<tr>
<th>Ship</th>
<th>Transverse Load Factor</th>
<th>Longitudinal Load Factor</th>
<th>Vertical Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSS</td>
<td>0.9</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Other</td>
<td>1.2</td>
<td>0.7</td>
<td>0.4</td>
</tr>
</tbody>
</table>

We will use these load factors to develop general marine tiedown guidance that will be consolidated into the new MTMCTEA Pam 55-22, Marine Terminal Lifting and Tiedown Guidance. This pamphlet will promote uniform lifting and tiedown procedures, to ensure commercial and military shippers share a common reference during future deployment.

---

**Note:**


TABLE 3
Actual Load Factor Reductions:

<table>
<thead>
<tr>
<th>SHIP</th>
<th>DIRECTION</th>
<th>CURRENT LOAD FACTOR</th>
<th>REDUCED LOAD FACTOR</th>
<th>PERCENT REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSS</td>
<td>TRANSVERSE</td>
<td>1.5</td>
<td>0.9</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>LONGITUDINAL</td>
<td>1.0</td>
<td>0.3</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>VERTICAL</td>
<td>1.5</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>OTHER</td>
<td>TRANSVERSE</td>
<td>1.5</td>
<td>1.2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>LONGITUDINAL</td>
<td>1.0</td>
<td>0.7</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>VERTICAL</td>
<td>1.5</td>
<td>0.4</td>
<td>73</td>
</tr>
</tbody>
</table>

*Only the absolute value of negative vertical load factors contributes to the restraint requirements. Since the FSS does not induce negative “g’s” on its cargo at sea state 8, a vertical load factor is not necessary. In reality, however, the geometry of the tiedown assembly will always provide a minimum of 0.2 g’s in the vertical (up) direction.

V. RECOMMENDATIONS

MTMCTEA should:

A. Proceed with the development of marine tiedown guidance based on the load factors presented herein.

B. Assess the feasibility of establishing optional, less conservative load factors and subsequent tiedown requirements for:

1. Different ship classes, that is, Cape D's, Cape H's, and so forth.

2. Varying sea states, that is, sea states 4 through 8, versus sea state 8 exclusively, to give the captain an option when he expects the ship to encounter sea state 8 or less (as was the case during Desert Shield/Storm).

3. Stowage locations closer to the ship’s CG since locations closest to the CG will require little or no restraint.
C. Coordinate all future related progress and findings extensively throughout DOD and the commercial shipping industry.

**Note:** For ships not in the CODES database, ships with unusual ship loading configurations, and/or ship's with extraordinary dimensions, load factors should be calculated on a case-by-case basis to ensure they are less than or equal to those presented in this analysis. MTMCTEA will be happy to assist and/or perform these calculations on a request basis.

In addition, questions and/or suggestions pertaining to this study should be addressed to:

Director, MTMCTEA
ATTN: MTTE-TRV (Mr. John Germanos)
720 Thimble Shoals Blvd - Suite 130
Newport News, VA 23606-2574
APPENDIX A

MSC Memorandum on Effects of G-Forces During Marine Transport
From: Commander, Military Sealift Command  
To: Commander, Military Traffic Management Command  
Transportation Engineering Agency  

Subj: EFFECTS OF G-FORCES DURING MARINE TRANSPORT  

Ref:  
(a) MTMCTEA ltr Ser MTTE-TRV (70-47a) of 6 Nov 90  
(b) Phonecon J. Cassidy (MTMC)/A. Attermeyer (N741) of 9 Nov 90  
(c) Army Technical Bulletin 55-100, "Transportability Criteria: Shock and Vibration", 18 Apr 64  

Encl:  
(1) MIL-STD-1399 Sect. 301A, "Ship Motion and Attitude", July 86  

1. References (a) and (b) requested that Military Sealift Command (MSC) provide the g-forces Army equipment can experience during Marine transport. Reference (a) also indicated that reference (c) is presently used to determine the cargo restraining system. The restraint criteria of reference (c), i.e., a minimum of 1.5g in lateral and vertical directions, is considered by MTMC to be excessive, time consuming and costly. The comments below address specific issues and questions of reference (a).  

2. Reference (c) addresses the required tie-down procedures of equipment to resist shock and vibration loads while in transit (rail, sea, or air). Although these loads are important variables in the design of equipment and tie-down procedure, they are separate issues from seakeeping forces induced by ship motions.  

3. Reference (a) requests restraint criteria (g-forces) for different ship size or type, cargo location on board the ship, and sea states in transit. All of these concerns are addressed in enclosure (1) which is provided for your use. Enclosure (1) is the Navy's manual for determining general ship motions and provides appropriate equations for forces (called "load factors") in both moderate and storm seas. It is recommended that enclosure (1) be utilized for tie-down designs to resist ship motion forces as described in the document.  

4. References (a) and (b) expressed the desire to reduce tie-down restraints due to the use of larger ships on shorter (Mediterranean) voyages. Ship motions, while generally lower on larger ships, are a complex combination of sea conditions and ship characteristics and are not a strict linear function of overall ship size. Also, high accelerations can still occur at the extreme distances of cargo on larger ships from the centers of rolling and pitching. Therefore, a reduction in tie-down restraint cannot be provided due to ship size alone. Concerning shorter voyages, although sea states are generally lower in the Mediterranean Sea, wave heights can reach up to 30 feet during the month of January, corresponding to sea state 7. Enclosure (1) may also be
Subj: EFFECTS OF G-FORCES DURING MARINE TRANSPORT

utilized to determine appropriate loading forces in the Mediterranean on a case-by-case basis. However, any voyage originating on the East Coast (U.S.) but transiting through the Mediterranean should have cargo restraint for an ocean voyage.

Thomas W. Allen
By Direction
APPENDIX B

Load Factor Example Calculation

Ship Name: Aide  Type: Container/Breakbulk  MA#: C3-S-38a

Physical Characteristics:

LBP = 470 ft;  GM = 3.40 ft;  B = 73 ft;  C = 0.40 sec/√ft;
X = 189 ft;  Y = 30 ft;  Z = 44 ft

T = (B)(C)/GM² = 15.8 sec

Φ = 37°(π/180°) = 37π/180 rad

Θ = 7°(π/180°) = 7π/180 rad

Tₚ = 6 sec

h = (0.50)(32.15 ft/sec²) = 16.1 ft/sec²

s = (0.25)(32.15 ft/sec²) = 8.04 ft/sec²

Using equation 2 in paragraph III A,

\[ A_y = (32.15)\sin(37\pi/180) + \frac{1}{2} [(4\pi²/36)(7\pi/180)(189)] + ((4\pi²/(15.8)²)(37\pi/180)(30) + (4\pi²/(15.8)²)(37\pi/180)(44) \]

Therefore,

\[ A_y = 38.45 \text{ ft/sec}² \]

And, using equation 2 in paragraph III B,

\[ L_{fY} = 38.45/32.15 = 1.196 \]

Substituting similar of values in equations 1, 3, and 6 of paragraph III A and equation 3 of paragraph III B yields the following:

\[ A_x = 20.94 \text{ ft/sec}² \]

\[ L_{fx} = 0.651 \]

And,

\[ A_z (up) = -12.30 \text{ ft/sec}² \]

\[ L_{fz} (up) = -0.382 \]
GLOSSARY

1. Angular motions - the oscillatory motions of roll, pitch, and yaw.
2. Attitude, ship's - defined by a ship's list, trim, and heel; the net inclination of a ship in the water.
3. Beam - the extreme width of a ship at or below the waterline.
4. Design load - the force applied to cargo at a given location in the ship, determined by multiplying the cargo mass by the load factor(s). This is the load the tiedown assembly must be capable of restraining.
5. "g-load" or "g-force" - acceleration caused by gravity (9.807 m/sec\(^2\) or 32.15 ft/sec\(^2\)).
6. Heave - the up and down motion of a ship along the vertical (Z) axis.
7. Heel - the nonoscillating angular displacement of a ship about the longitudinal (X) axis caused by steady externally imposed loads (that is wind, control surface, and so forth).
8. Length between perpendiculars - the length of a ship measured from the forward perpendicular to the after perpendicular.
9. Linear motions - motions contributed by heave, surge and sway along the respective axes.
10. List, also called “heel”- the inclination of a ship about the longitudinal (X) axis caused by either lateral separation between the center of gravity and the center of buoyancy or by steady externally imposed loads (that is wind or control surface).
11. Load factor - a calculated number in terms of gravitational and dynamic acceleration, which, when multiplied by the mass of cargo, determines the design load that the cargo tiedown assembly must restrain in the longitudinal, transverse, and vertical directions as a result of the accelerations of gravity and ship motions.
12. Metacentric height - distance from the ship's center of gravity to the metacenter; a measure of the vessel’s stability in the upright or nearly upright condition.
13. Pitch - the oscillatory motion of a ship about the transverse (Y) axis.
14. Roll - the oscillatory motion of a ship about the longitudinal (X) axis.
15. Sea state - a measure of the severity of the sea conditions, to include wave height, period, energy distribution with wave frequency, and direction.
16. Ship’s motion - the motions defined by the six degrees of freedom of a floating vessel (roll, pitch, yaw, surge, sway, and heave).
17. Surge - fore and aft motion of a ship along the longitudinal (X) axis.

18. Sway - the lateral motion of a ship along the transverse (Y) axis.

19. Tiedown assembly - all components of the restraint system that must secure the cargo to the design load requirements dictated by the respective load factors; includes cargo tiedown provisions, chains, load binders, shackles, deck tiedowns, and so forth.

20. Trim - the inclination of a ship about the transverse (Y) axis caused by longitudinal separation of the center of gravity and the center of buoyancy.

21. Yaw - the oscillatory motion of a ship about the vertical (Y) axis.
DISTRIBUTION:
Deputy Chief of Staff for Logistics, ATTN: DALO-TSM, DALO-SMS, Washington, DC 20310
Deputy Director, Joint Strategic Deployment Training Center, ATTN: ATSP-TJ, Bldg 630, Fort Eustis, VA 23604-5363
Commander, Defense Logistics Agency, ATTN: DLA-AT, Cameron Station, Alexandria, VA 22304-6100
US Army Library, ATTN: Army Studies Section, ANRAL Room 1A51A, Pentagon, Washington, DC 20310
Commander, FSS Sqdn, 4400 Dauphine St, New Orleans, LA 70146-6700
Commander, Military Sealift Command, ATTN: P-3TI, EOC, Oakland, CA 94625-5010
Commander, Military Sealift Command, ATTN: Plans and Operations, M-4E1, EOC, Washington, DC 20390-5100
Commander, MSC, ATTN: Code N7/N74/N74tC/N311a Bldg 210, Washington Navy Yard, Washington, DC 20398-5100
Commander, MSC Atlantic Fleet, ATTN: L32, EOC, MOTBA, Bayonne, NJ 07002-5302
Commandant, U.S. Coast Guard, ATTN: G-MVI-2, 2100 Second St, S.W., Washington, DC 20593-0001
MARAD, Office of Ship Operations, EOC, 400 Seventh St SW, Washington, DC 20590
U.S. Merchant Marine Academy, Dept of Marine Transportation, Kings Point, NY 11024-1699
Commandant, US Army Transportation School, ATTN: ATSP-TDD-W, Fort Eustis, VA 23604-5408
Commander, USA CASCOM & Fort Lee, ATTN: DOIM Publications, Bldg 7120, Fort Lee, VA 23801-5240
Commander, 7th Transportation Group, ATTN: S3/AFG-C-PL, Fort Eustis, VA 23604-5484
Commander, USMC Combat Engineer Instruction Company, Marine Corps Engineer School, Marine Corps Base, Camp Lejeune, NC 28542-5040
Commander, USTRANSCOM, ATTN: TCJ3/4-LLD, TCJ5-D, TCJ5-S, TCJ3/4-ODE, TCDA J5 J3/4, EOC, Scott AFB, IL 62225-7001
Commandant, USADACS, ATTN: SMCC-DAT, Savannah, IL 61074-9639
Commander, TRADOC, ATTN: ATDD-S, ATLD-S, ATCD-DC, ATCD-E, Fort Monroe, VA 23651
Commander, Combat Systems Test Activity, ATTN: STECS-AE-SM, APG, MD 21005-5059
Commander, Natick Research, Development and Engineering Center, ATTN: STRNC-UAS, STRNC-UB, STRNC-UST, Natick, MA 01760-5017
Commander, Operational Test and Evaluation Command, ATTN: CSTE, Park Center IV, 4505 Ford Ave, Alexandria, VA 22302-1458
Commander, Belvoir Research, Development and Engineering Center, ATTN: SATBE-D, Fort Belvoir, VA 22060-5606
Commander, U.S. Army Forces Command, ATTN: AFLG-TRU, Fort McPherson, GA 30330
Commander, U.S. Army Waterways Experiment Station, ATTN: WESZA, PO Box 631, Vicksburg, MS 39180
Commander, 4th Transportation Command, ATTN: AEUTR-MOV, APO NY 09451
Commandant, U.S. Army Logistic Management Center, Fort Lee, VA 23801
Commandant, U.S. Army War College, Carlisle Barracks, PA 17013
Commandant, Defense Systems Management College, Fort Belvoir, VA 22060
Administrator, Defense Technical Information Center, ATTN: PPA, Cameron Station, Alexandria, VA 22314
Superintendent, U.S. Military Academy, West Point, NY 10996
Deputy Commanding General, Marine Corps Research, Development and Acquisition Command, T&E Sect, Code: PSG-T&E, Quantico, VA 22134
Commander, MTMC Terminal, Yokohama, PSC 471, ATTN: MTPAC-YOO, FPO AP 96347-2900
Commander, MTMC Terminal, Okinawa, APO AP 96376-0508
Commander, HQMTMC, ATTN: MTTT-M, MT-PL, MT-RC, EOC, 5611 Columbia Pike, Falls Church, VA 22041-5050
Commander, MTMCCEA, ATTN: C/S, MTE-ITM, MTE-PL, EOC, Bayonne, NJ 07002-5302
Commander, MTMC Military Ocean Terminal, Bay Area, ATTN: MTWA-O-C, Oakland Army Base, Oakland, CA 94626-5005
Commander, MTMCEA, ATTN: C/S, MTW-IMP, MTW-IT, MTW-PL, EOC, Oakland Army Base, Oakland, CA 94626-5000
Commander, TTCPE, ATTN: MTMC-IM, APO AE 09715-5110
Commander, MTMC Europe, ATTN: MTEUR-TOPS-OPSP, Box 3, APO AE NY 09715-5110
Commander, TTCPE, APO AE 96205-0441
Commander, MTMC Field Office Europe, HQ, USEUCOM, J4/7-MTMC, APO AE 09128-4209
Commander, MTMC Pacific Northwest Outport, ATTN: MTW-S-OP, 4735 East Marginal Way South, Seattle, WA 98134-2391
Commander, MTMC Southern California Outport, ATTN: MTW-L-O, 1620 S. Wilmington Ave, Compton, CA 90220-5115
Commander, MTMC Terminal Pusan, APO AP 96259-0258
Commander, MTMC Transportation Brigade (Terminal), Bayonne, NJ 07002-5301
Commander, MTMC Transportation Brigade (Terminal) Sunny Point, Southport, NC 28461-5000
Commander, MTMC Trans BDE (TML) Bremerhaven, ATTN: MTEUR-BH-ODCO, Unit # 2419, APO AE 09069
Commander, MTMC Transportation Battalion (Terminal) Dundalk Marine Terminal, Baltimore, MD 21222-4197
Commander, MTMC Transportation Battalion (Terminal), Azores, APO AE 09406-5000
Commander, MTMC TTU Greece, APO AE 09841
Commander, MTMC TTU Turkey, APO AE 09821
Commander, MTMC TTU Spain, PO Box 5696, North Charleston, SC 29406-0696
Commander, MTMC Transporlation Battalion (Terminal), Panama, APO AA 34004-5000
Commander, MTMC Gulf Outport, New Orleans, LA 70146
Chief, MTMC Beaumont Det, PO Box 4043, Beaumont, TX 77704
Commander, MTMC Legborn Tml, ATTN: Plans and Operations, APO NY 09613
Commander, 1169th TTU, 1170th TTU, 1172d TTU, 1173d TTU, Barnes Bldg, 495 Summer St., Boston, MA 02210-2109
Commander, 1174th TTU, 1187th TTU, Fort Totten, USARC, Flushing, NY 11359-1016
Commander, 1175th TTU Pedricktown Support Facility, Bldg 171, Rt 130 South, Pedricktown, NJ 08067-5000
Commander, 1176th TTU, Brandt KUSARC, 700 Ordnance Road, Baltimore, MD 21226-1790
Commander, 1179th DCU, Fort Hamilton, USARC, Fort Hamilton, NY 11252-7445
Commander, 1181st TTU, 5701 Old Hwy 80 West, Meridian, MS 39305-6106
Commander, 1182d TTU, USAR Center #2, PO Box 9188, Charleston, SC 29410-0188
Commander, 1184th TTU, Wright USARC, 1900 Hurtel Street, Mobile, AL 36605-2396
Commander, 1185th TTU, USAR Cr, 1135 Ranck Mill Road, Lancaster, PA 17602-2594
Commander, 1186th TTU, Lovejoy USARC, 4815 N. Hubert Ave, Tampa, FL 33614-6493
Commander, 1188th MOT, East Point USARC, 2523 Dauphine St, East Point, GA 30344-2502
Commander, 1189th TTU, Martin USARC, 9 Chisholm St, Charleston, SC 29401-1831
Commander, 1191st TTU, 1192d TTU, Naval Support Acty, 4400 Dauphine St, New Orleans, LA 70146-7600
Commander, 1205th RSU, USAR Center, Mile Lane, Middletown, CT 06457-1809
Commander, 1302d PSD, USAR Center, 123 Rty 303, Orangeburg, NY 10962-2209
Commander, 2145th PLU, Martin USARC, 9 Chisholm St., Charleston, SC 29401-1834
Commander, 4249d PSD, USAR Center, Rural Rt 1, Pocahontas, IA 50574-5000
Commander, MTMC-NR 202, Naval Reserve Ctr, Fort Wadsworth, Bldg 356, Staten Island, NY 10305-5098
Commander, MTMC-NR 320, Naval & Marine Corps Reserve Ctr, 144 Clement Ave, Alameda, CA 94501
Commander, 91st Trans Det (CDD), Hampton USAR Ctr, Marcella Rd, Hampton, VA 23666-1599
Commander, 143d, Transportation Command, ATTN: Movements Section, 2800 Dowden Rd, Orlando, FL 32827-5299
Commander, 145th Trans Det (CDD), Butler Farm USAR Center, Airborne Rd, Hampton, VA 23666-1599
Commander, 159th Transportation Detachment, ATTN: AFGR-I-159, Fort Story, VA 23459
Commander, 1395th TTU, 1397th TTU, Harvey Hall USARDC, 4505 36th Ave West, Fort Lawton, Seattle, WA 98199-5099
Commander, 6632d PSD, AFRC, Bldg 200, Los Alamitos, CA 90720-5001
Commander, COA (-DET 1) 560th ENGR BN (e) GA ARNG, P.O. Box 8, Dawson, GA 31742-0008
Commander, 7th Trans Gp, ATTN: EOC, 10th Trans Bn, 6th Trans Bn, 24th Trans Bn, Fort Eustis, VA 23604
Commander, 11th Trans Bn, Fort Story, VA 23459
SEA-LAND Service, Inc., P.O. Box 800, Iselin, NJ 08830
ABS America, 16855 N. Chase Dr, Houston, TX 77060-6008
ABS America, Government Service Unit, 2011 Crystal Dr., Suite 903, Arlington, VA 22202
ABS, America (Mr. Soper Pres & CEO), 45 Eisenhower Dr., Paramus, NJ 07652
Director, Trade Relations, Port of Oakland, P.O. Box 2064, 66 Jack London Square, Oakland, CA 94604
American Maritime Congress, 444 North Capitol Street, N.W., Suite 80, Washington, DC 20001
American Overseas Marine Corporation, 116 East Harvard Street, Quincy, MA 02169
American Overseas Marine Corporation, 1600 Pennsylvania Avenue, Washington, DC 20006
American President Lines, Ltd., 1320 Harrison St., Oakland, CA 94612
Central Gulf Lines, Inc., 1700 Paydars Center, 650 Paydars St., P.O. Box 3366, New Orleans, LA 70153-3366
Consolidated Freightways, Inc., 175 Linfield Dr, Menlo Park, CA 94025-3799
Crawley Maritime Corporation, 101 California St., San Francisco, CA 94111-5875
International Longshoreman's Association, AFL-CIO, 17 Battery Place, New York, NY 10004
Waterman Steamship Corporation, 1 White Hall St., New York, NY 10004