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DECEMBER 1992

**TRANSPORTABILITY
ENGINEERING ANALYSIS**

LOAD FACTORS FOR CARGO RESTRAINT DURING MARINE TRANSPORT

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Prepared by:
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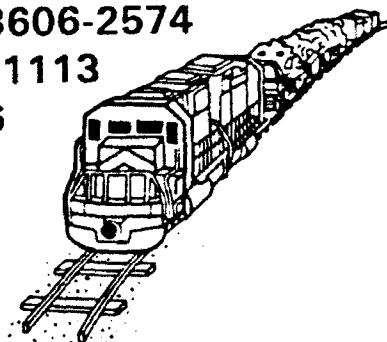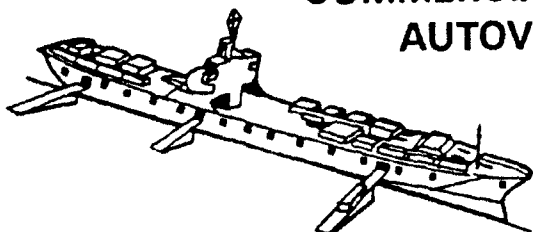
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I. EXECUTIVE SUMMARY

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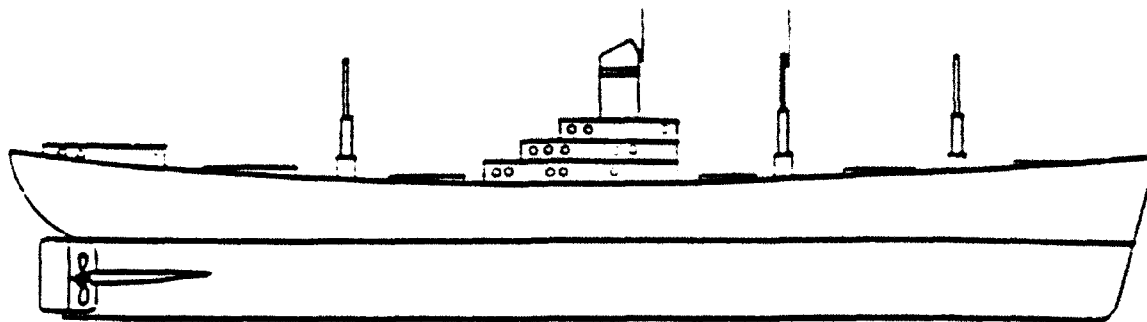
"...cargo and its restraining system should be capable of sustaining an environment occasioned by a seaway-induced loading on a transport ship consequent to twenty days of Beaufort sea state condition 12." [2]

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.

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[1] American National Standard, *Requirements for Closed Van Cargo Containers*, ANSI MH5.1.1M - 1979.
[2] Army Technical Bulletin 55-100, *Transportability Criteria: Shock and Vibration*, 17 April 1964.

SCHEMATIC (C-2 CLASS)

FREQUENCY (cps)
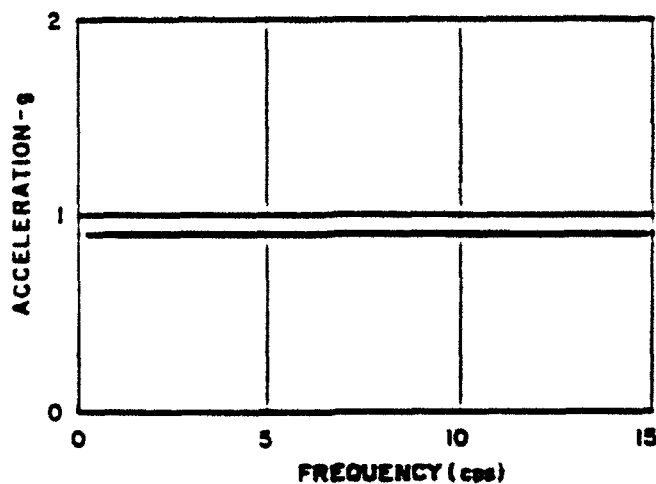
— VIBRATION, VERTICAL & LATERAL —

CURVE	PULSE TIME (sec)	MAX. AMP (g)	DIRECTION
A	.044	1.5	VERT. & LAT.

TIME IN SECONDS

— SHOCK —
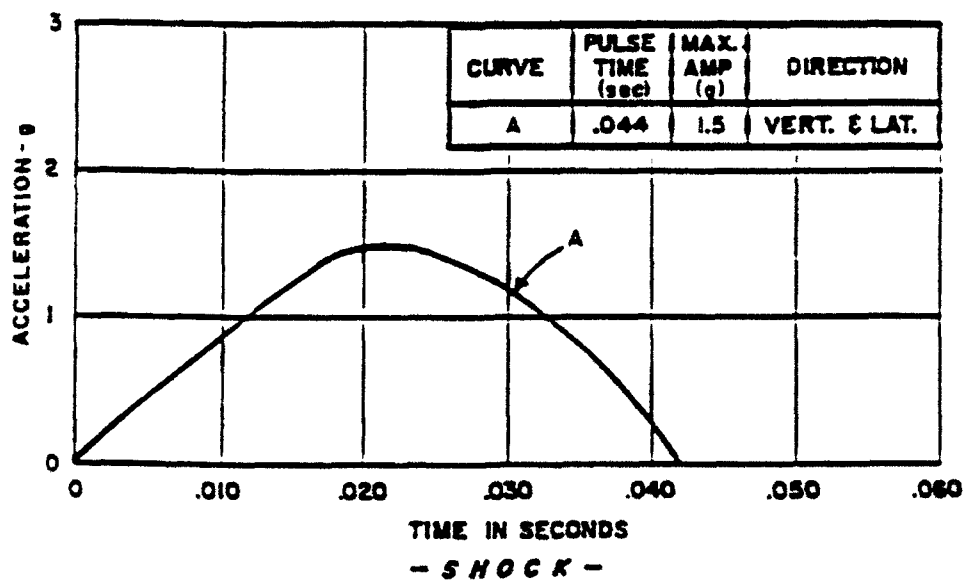
CARGO ENVIRONMENTS FOR SEA TRANSPORT

TAGO 5746-A

Figure 1. Load factor data from TB 55-100.

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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. [1] MSC's response to our request (app A) recommended that we use DOD-STD-1399 [2] 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 architechture; 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. [2]

1. $A_x = g\sin\Theta + s + k_1\Theta X + k_1 Z$

2. $A_y = g\sin\Phi + \tfrac{1}{2}k_1 X + k_2\Phi Y + k_2 Z$

3. $A_z = g \pm [h + k_1 X + k_2 Y]$ ("+" is up, "-" is down)

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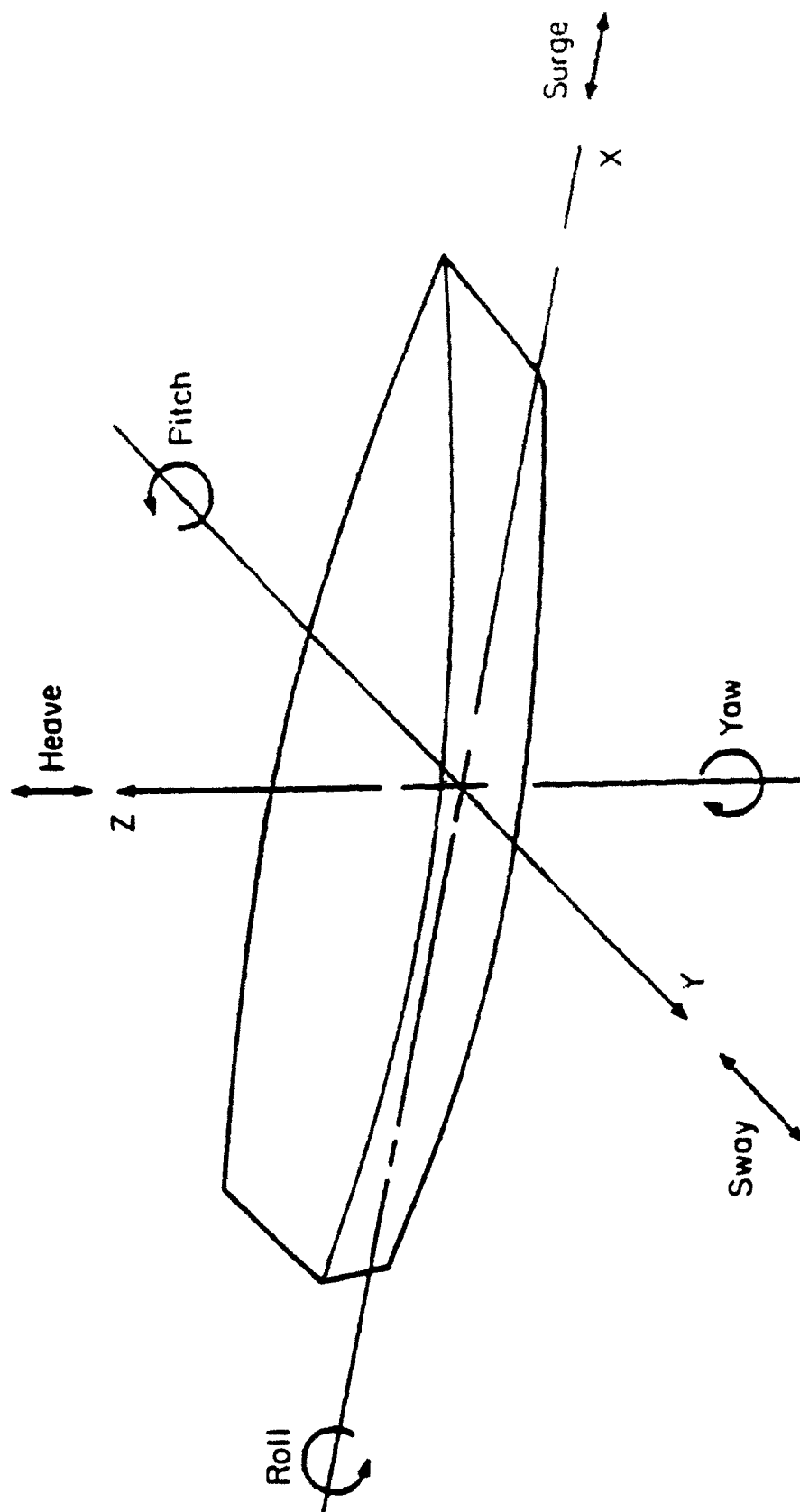
Figure 2. Conventional ship coordinate axes and ship motions.

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Where,

4.　　$k_1 = 4\pi^2\Theta/T_r^2$　　$(T_r = (CB)/\sqrt{GM})$

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

Θ　=　maximum pitch angle (rad)

Φ　=　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 ($s/\sqrt{ft}$)

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.

$\overline{WL}$ = initial waterline

$\overline{W_1L_1}$ = waterline after

rolling ϕ degrees

G = center of gravity

M = metacenter

GM = metacentric height

B = center of buoyancy
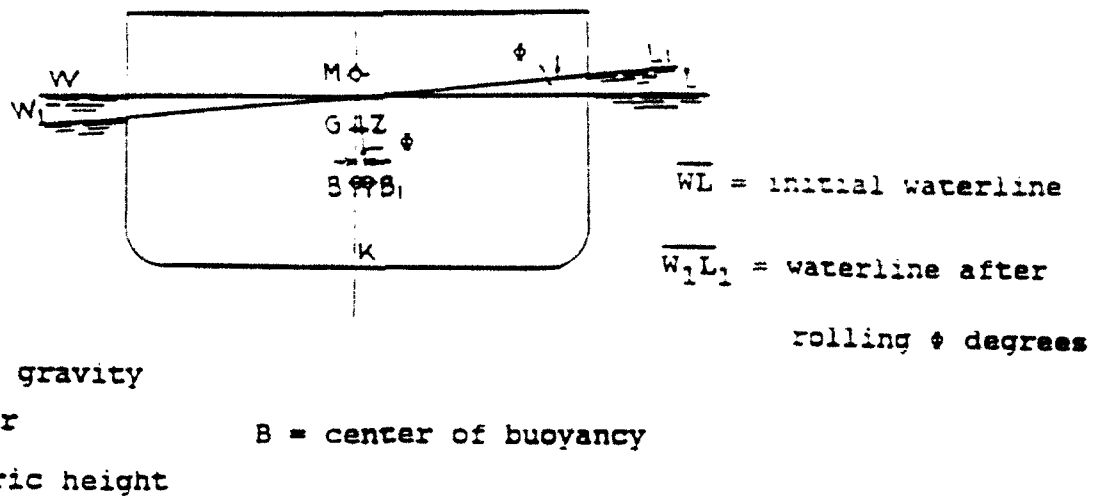
Figure 3. End view of a vessel upright and after rolling ϕ degrees.

$\overline{WL}$ = initial waterline

$\overline{W_1L_1}$ = waterline after

pitching θ degrees

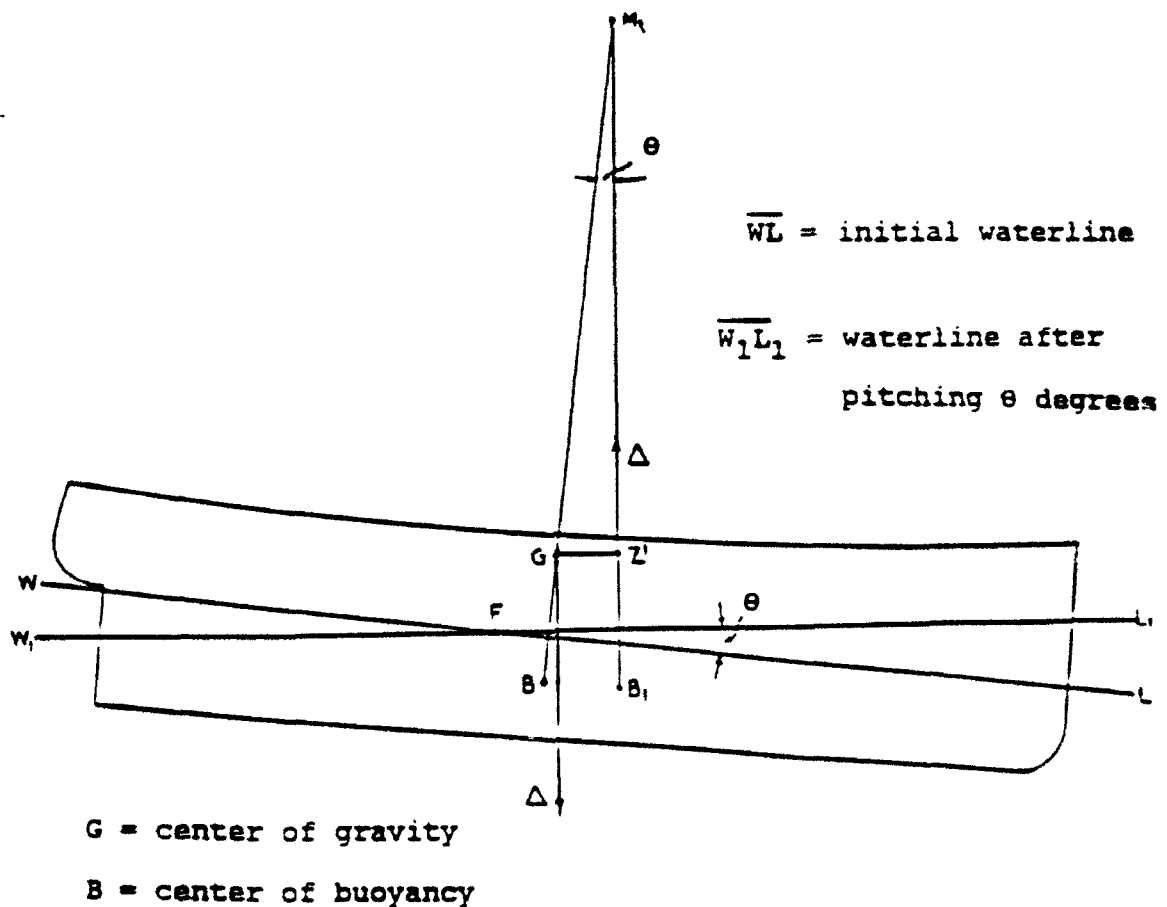G = center of gravity

B = center of buoyancy

Figure 4. Side view of a vessel upright and after pitching θ degrees.

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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. $L_{fx} = A_x/g$ longitudinal load factor

2. $L_{fy} = A_y/g$ transverse load factor

3. $L_{fz} = A_z/g$ 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 1
Sea States and Corresponding Wave Heights

Sea State Number	Significant Wave Height	
	Meters	Feet
0-1	0.00 - 0.10	0.00 - 0.30
2	0.10 - 0.50	0.30 - 1.60
3	0.50 - 1.25	1.60 - 4.10
4	1.25 - 2.50	4.10 - 8.20
5	2.50 - 4.00	8.20 - 13.10
6	4.00 - 6.00	13.10 - 19.70
7	6.00 - 9.00	19.70 - 29.50
8	9.00 - 14.00	29.50 - 45.50
>8	>14.00	>45.50

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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/√ft 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
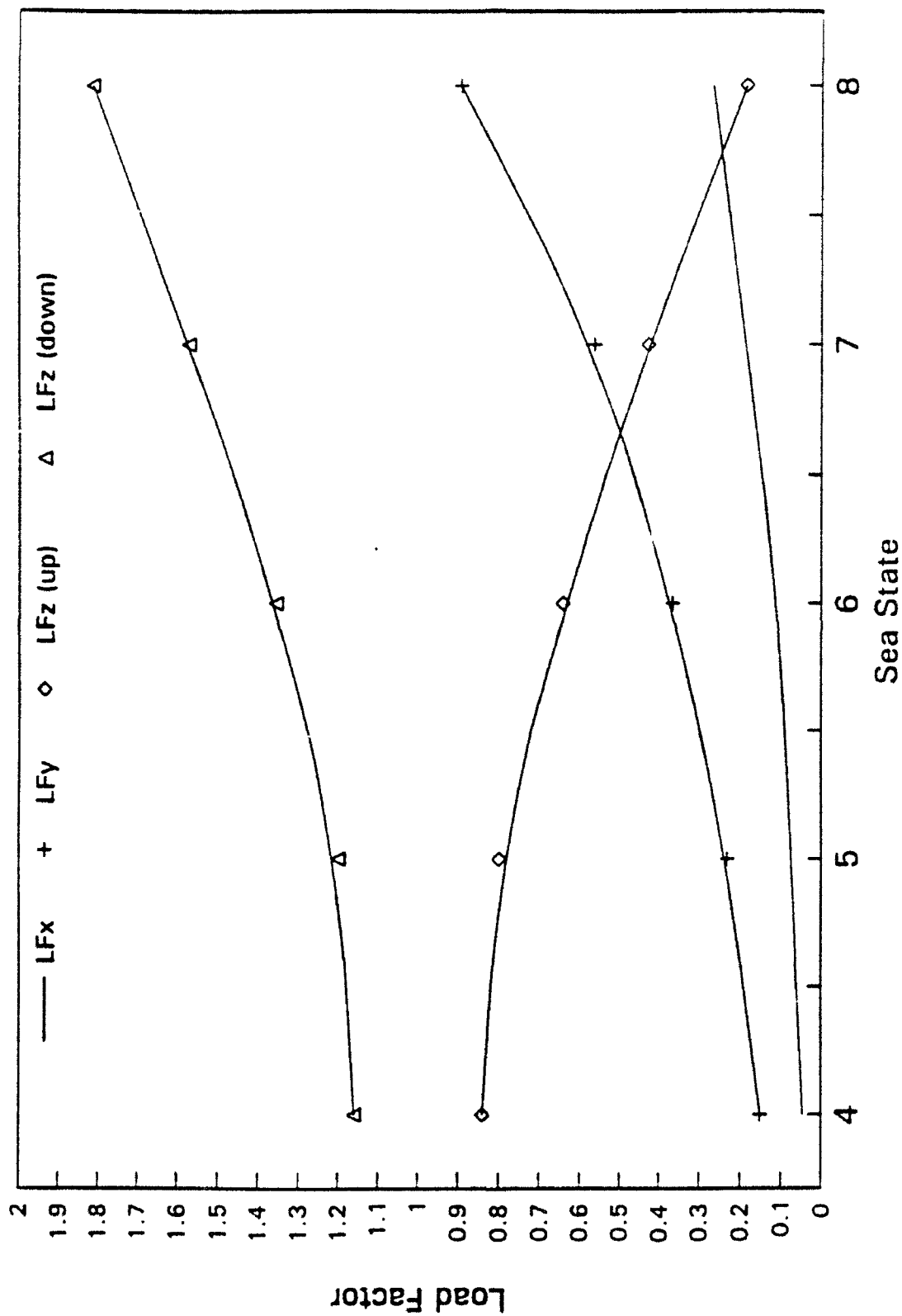
FIGURE 5
LOAD FACTORS VERSUS SEA STATE
FOR THE FAST SEALIFT SHIP

TABLE 2

Data and Results for the Ships Analyzed

DATA CATEGORY	DATA SUMMARY					
Ship Name	Fast Sealift Ship	PFC Eugene A. Obregon	USNS Comet	USNS Southern Cross	Aide	USNS Mercury
Ship Type	RORO	MPS Waterman	RORO	Breakbulk	Container Breakbulk	RORO
MA #	n/a	C7-S-133a	C3-ST-14a	C3-S-33a	C3-S-38a	C7-S-95a
Length Between Perpendiculars, LBP (ft)	840.5	766.0	465.0	458.0	470.0	640.0
Beam, B (ft)	105.5	105.5	78.0	68.0	73.0	102.0
Metacentric Height, GM (ft)	8.41	7.30	4.01	4.43	3.40	7.06
Max. Longitudinal Distance from Ship's CG, X (ft)	317.0	380.0	175.5	172.0	189.0	315.0
Max. Vertical Distance from Ship's CG, Z (ft)	21.45	30.52	37.80	32.00	44.00	49.00
Max. Horizontal Distance from Ship's CG, Y (ft)	26.4	26.38	19.50	26.00	30.00	25.50
Roll Constant, C (sec/$\sqrt{ft}$)	0.40	0.40	0.40	0.40	0.40	0.40
Roll Angle, ϕ (rad)	0.54	0.54	0.593	0.646	0.646	0.593
Pitch Angle, Θ (rad)	0.087	0.087	0.122	0.122	0.122	0.1047
Roll Period, T_r (sec)	14.55	15.62	15.58	12.92	15.836	15.355
Pitch Period, T_p (sec)	8	8	6	6	6	7
Heave Acceleration, h (ft/sec^2)	6.43	6.43	16.075	16.075	16.075	12.860
Surge Acceleration, s (ft/sec^2)	3.215	3.215	8.0375	8.0375	8.0375	8.0375
Transv. Acceleration, A_y (ft/sec^2)	28.696	30.71	34.5	38.322	38.45	37.64
Long. Acceleration, A_x (ft/sec^2)	8.66	9.445	19.893	19.06	20.94	18.315
Vert. Acceleration (up), A_z (ft/sec^2)	5.992	2.955	-9.32	-10.94	-12.3	-9.805
Vert. Acceleration (down), A_z (ft/sec^2)	58.307	61.34	73.62	75.24	76.6	74.12
Transv. Load Factor, L_{fy}	0.89	0.955	1.07	1.19	1.196	1.17
Long. Load Factor, L_{fx}	0.269	0.294	0.619	0.593	0.651	0.57
Vert. Load Factor (up), L_{fz}	0.186	0.092	-0.29	-0.34	-0.382	-0.305

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. [5] MSC concurred with our results, stating that "These factors are considered conservative and satisfactory for ship cargo loadings." [6]

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, apppropriate 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:

Ship	Transverse Load Factor	Longitudinal Load Factor	Vertical Load Factor
FSS	0.9	0.3	0.0
Other	1.2	0.7	0.4

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.

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[5] Memorandum, MTMCTEA (MTTE-TRS), 04 Feb 91, subject: Revised Load factors for Restraint During Marine Transport.
[6] Letter, MSC (4700 ser N741/000987), 26 Feb 91, subject: Revised Load Factors for Restraint During Marine Transport.

TABLE 3
Actual Load Factor Reduction

SHIP	DIRECTION	CURRENT LOAD FACTOR	REDUCED LOAD FACTOR	PERCENT REDUCTION
FSS	TRANSVERSE	1.5	0.9	40
	LONGITUDINAL	1.0	0.3	70
	VERTICAL *	1.5	0.0	100
OTHER	TRANSVERSE	1.5	1.2	20
	LONGITUDINAL	1.0	0.7	30
	VERTICAL	1.5	0.4	73

*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   ＴＥＣ 6 |990
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
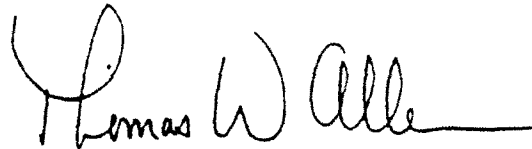issues and questions of reference (a).

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

A-2

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.

T.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/$\sqrt{ft}$;
X = 189 ft;   Y = 30 ft;   Z = 44 ft

T_r = (B)(C)/GM$^{\frac{1}{4}}$ = 15.8 sec

Φ = 37°(π/180°) = 37π/180 rad

Θ = 7°(π/180°) = 7π/180 rad

T_p = 6 sec

h = (0.50)(32.15 ft/sec^2) = 16.1 ft/sec^2

s = (0.25)(32.15 ft/sec^2) = 8.04 ft/sec^2

Using equation 2 in paragraph III A,

A_y = (32.15)sin(37π/180) + ½ [(4π^2/36)(7π/180)(189)] +
    ((4π^2/(15.8)^2)(37π/180)^2(30) + (4π^2/(15.8)^2)(37π/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,

$$A_z \text{ (up)} = -12.30 \text{ ft/sec}^2$$

$$L_{fz} \text{ (up)} = -0.382$$

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.

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