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Strength Evaluation of Flexible Securing Systems for Ship's Deck-Stowed Containers

by

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Abstract

The seaway forces acting on ship's on-deck containers, the elements of strength of containers and their securing gear and the equations characterizing the behavior of flexible securing systems are discussed. An algorithm that generates points for a container stack weight diagram, for use by ship deck officers, is presented.

Introduction

In the early years of containerized shipping, there were numerous instances of damage to or loss of cargo containers stowed on ship's decks (1), (2). The passage of time has seen improvements in securing systems. There still are, however, very recent cases of loss or damage. As late as last year, a foreign-flag ship bound for the U.S. West Coast lost two boxes to a stormy sea. A local containership operator has recently experienced the buckling of corner posts of containers and the tearing of "D-rings" from hatch covers. These rings, which are welded onto hatch cover top plates, serve as anchor points for the lashings securing the containers.

The need for the provision of an adequate securing system cannot be overstated, involving as it does cargo safety. Some ship classification societies, in response to this need, now require approved securing arrangements as a condition for classification. In those instances where there is no such requirement, it would still be advisable for a shipping company to supply its deck officers with a stowage manual, showing, among other items, the allowable container weight combinations in any stack at any location on board.

The structural design of hatch covers, upon which most of the deck-stowed containers rest, is based in part on the maximum possible weight of a stack. For this purpose, a 20-ft. container is normally assumed to have a weight equal to the maximum gross weight of 20 tonnes, the usual rating of the container. The corresponding value for 40 footers is 30 tonnes. It is often the case that the strength of the securing system is more restrictive than the strength of the hatch cover. Therefore, hatch cover ratings are not a sufficient basis for ship deck officers to determine allowable container weight combinations in a stack.

An operator may easily find himself in a situation where the hatch cover ratings are in the ship's specifications and where the ratings of the individual pieces of securing gear may readily be known but where the overall strength of the secu-

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ring system is not specified. For the particular trade that he is engaged in, he may want to know whether a given securing system is adequate or not.

This paper presents a computer-aided method by which the allowable combinations of container weights in a stack can be determined based on the strength of the securing arrangement. It can be used by a designer as well when he tries to put together not only an adequate but also an efficient securing system.

Forces on Containers at Sea

The forces acting on deck-stowed containers at sea are a combination of dynamic (motion) loads, static (gravity) load and wind load.

Ship Motions. There are six degrees of freedom of ship motion: roll, pitch, yaw, sway, heave and surge. (See Fig. 1.) The first three are rotational and the last three are translational.

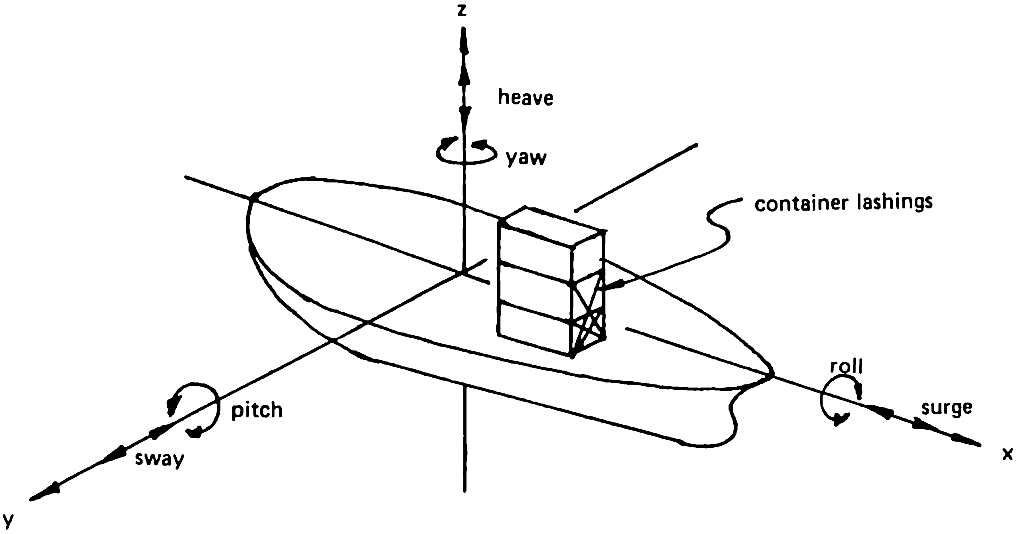

Figure 1. Ship Motions

Surge is neglected here since it does not have a component in the transverse (yz) plane, on which the securing hardware transmits all loads. (See Fig. 1.) The combined accelerations associated with the other motions give rise to dynamic loading on the containers, lashings and inter-box connecting fittings.

For the prediction of the magnitudes of ship motions and accelerations, reference 3 is used. The formulae below give extreme values with a probability level of 10^{-8}. Roll radial acceleration and pitch radial acceleration are considered negligible.

The basic parameters are:

L = ship's length between perpendiculars (m)
B = molded breadth (m)
D = molded depth (m)
T = molded draft (m)
C_b = block coefficient
V = ship speed (knots)

GM = metacentric height (m)

C_w = wave coefficient

$= 0.0792L$ for $L \leqslant 100$ m

$= 10.75 - [(300 - L)/100]^{3/2}$ for $100 \text{ m} < L \leqslant 300$ m

$= 10.75$ for $300 \text{ m} < L \leqslant 350$ m

$= 10.75 - [(L - 350)/150]^{3/2}$ for $L > 350$ m

$C_v = \sqrt{L}/50$, maximum of 0.2

a_o = common acceleration parameter

$$= \frac{3C_w}{L} + \frac{C_v V}{\sqrt{L}}$$

The motions and accelerations are:

Roll:

K_r = roll radius of gyration (m)

$\cong 0.39B$

T_r = period of roll (sec)

$$= \frac{2\ K_r}{\sqrt{GM}}$$

ϕ = roll angle, single-amplitude

$$= \frac{50C}{B + 75}$$

where $C = 1.1$ for ship without bilge keels when $T_r < 20$ sec

$= 1.0$ for ships with bilge keels when $T_r < 20$ sec

$= 0.8$ for ships with active roll-damping devices when $T_r < 20$ sec

$= 0.5$, in general, when $T_r > 30$ sec

For $20 < T_r < 30$, C may be varied lineraly.

z = roll axis of rotation as height above ship's baseline

= the smaller of $\left[\frac{D}{4} + \frac{T}{2}\right]$ or $\frac{D}{2}$

R_r = distance from the center of mass to the roll axis

a_r = tangential roll acceleration

$$= \phi \left[\frac{2\pi}{T_r}\right]^2 R_r \quad (\text{m/s}^2)$$

a_{ry} = across-the-deck component of a_r

a_{rz} = normal-to-deck component of a_r

Pitch:

T_p = pitch period

$= 1.8\sqrt{\frac{L}{g_o}}$ where $g_o = 9.80665 \text{ m/s}^2$

θ = pitch angle

$$= 0.2\,\frac{a_o}{C_b}$$

The axis of rotation may be taken as 0.45L from the after perpendicular and z meters above the baseline.

R_p = distance from the center of mass to the pitch axis
a_p = tangential pitch acceleration

$$= \theta \left[\frac{2\pi}{T_p}\right]^2 R_p \ (\mathrm{m/s^2})$$

Combined yaw-sway:

a_y = combined yaw-sway acceleration
= $0.8\ g_o a_o$ ($\mathrm{m/s^2}$) within 0.7L from the after perpendicular
= $1.0\ g_o a_o$ ($\mathrm{m/s^2}$) forward of the forward perpendicular

Heave:

a_z = heave acceleration

$$= \frac{0.7\ g_o a_o}{\sqrt{C_b}}$$

For purposes of container securing system evaluation, the maximum transverse (across-the-deck), maximum vertical (normal-to-deck) and minimum vertical accelerations are of interest. The above acceleration components will then have to be combined vectorially to yield resultants in the transverse and vertical directions.

Combined accelerations. It is assumed here that the peak loads on containers and lashing gear occur at maximum roll amplitude. Reference 4 shows that maximum across-the-deck forces occur at maximum roll angle while normal-to-deck forces exhibit only a small decrease as roll angle increases.

Outside of roll acceleration itself, the peak values given in the foregoing formulae do not occur at maximum roll amplitude. Taking into account phase angles as well as wave encounter angles, the following are the magnitudes of the acceleration components at maximum roll amplitude (5), (6):

$$(a_p)_\phi = 0.16\ a_p$$

$$(a_z)_\phi = 0.45 a_z$$

$$(a_y)_\phi = 0.17\ a_y$$

Heave motion is taken to act in the direction of gravity and pitch to act in the plane of the ship's centerline (1).

Figure 2a shows the combination of acceleration vectors (gravity not included) to give maximum across-the-deck acceleration (a_t), maximum normal-to-deck acceleration $(a_n)_{max}$ and minimum normal-to-deck acceleration $(a_n)_{min}$.

Figure 2b shows the combination of motion and gravity. The lower container (tier #2), through the connecting corner fittings or stackers, imparts the force necessary to accelerate as well as support the weight of the upper container (tier #3). If broken down into transverse and vertical components, the forces involved as shown as F_t and F_n are assumed to act through the center of the upper container.

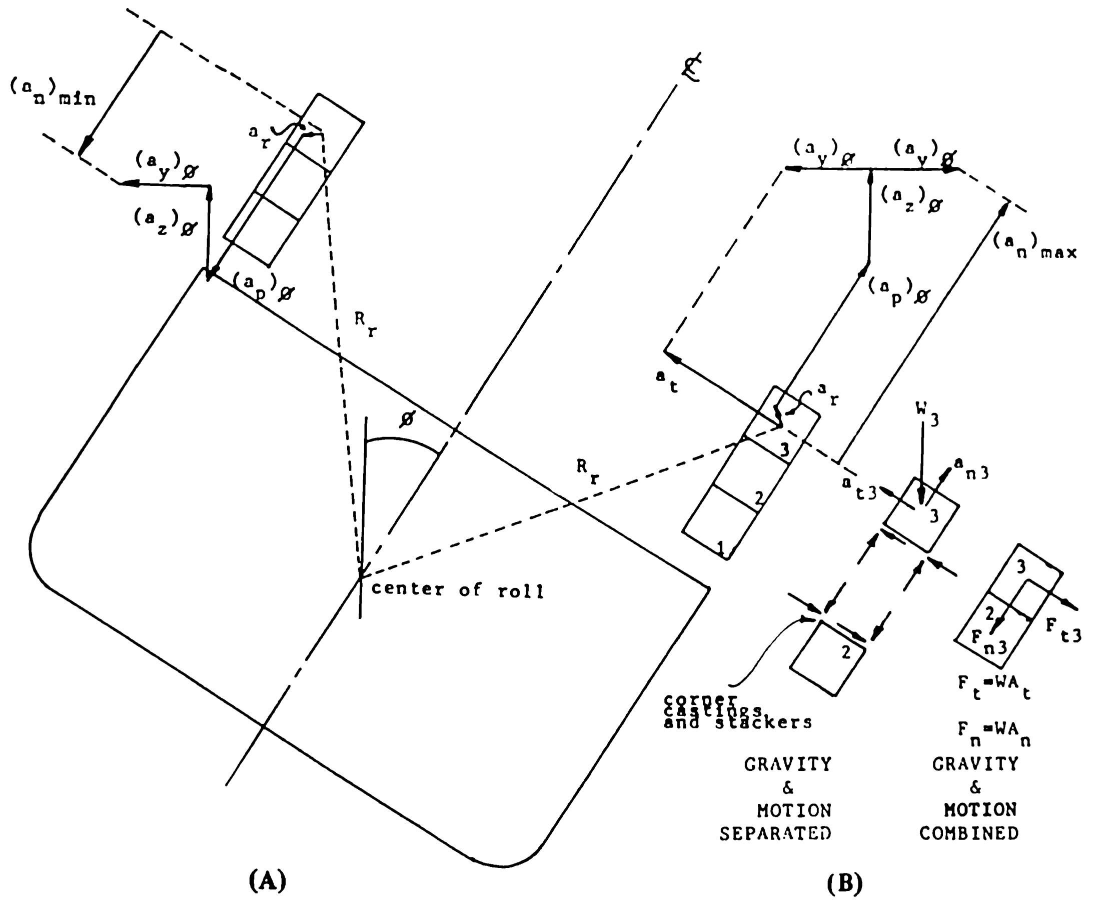

Figure 2. Acceleration Components and Resultants.

The expression for the forces are (6):

$$F_t = W\sin\phi + \frac{W}{g}(a_{ry}) + \frac{W}{g}(a_y)_\phi\cos\phi + \frac{W}{g}(a_z)_\phi\sin\phi$$

$$(F_n)_{max} = W\cos\phi + \frac{W}{g}(a_{rz}) + \frac{W}{g}(a_y)_\phi\sin\phi + \frac{W}{g}(a_z)_\phi\cos\phi + \frac{W}{g}(a_p)_\phi$$

$$(F_n)_{min} = W\cos\phi - \frac{W}{g}(a_{rz}) - \frac{W}{g}(a_y)_\phi\sin\phi + \frac{W}{g}(a_z)_\phi\cos\phi - \frac{W}{g}(a_p)_\phi$$

The appendix gives sample values. The combined acceleration vectors A_t, $(A_n)_{max}$ and $(A_n)_{min}$ include the gravity component.

Thus:

$$F_t = WA_t$$

$$(F_n)_{max} = W(A_n)_{max}$$

$$(F_n)_{min} = W(A_n)_{min}$$

Wind Load. For outboard stacks and inboard stacks exposed to the wind for part of the voyage, wind load is to be added. Beaufort 10 velocity, corresponding to 7.5 psf stagnation pressure, is assumed (6). At an assumed 30-degree roll angle and a 50-degree wind encounter angle, corresponding to seas off the stern quarter for which maximum roll amplitude may be expected, the transverse component of wind load is:

$$\begin{aligned} P_w &= \text{across-the-deck wind load (lb)} \\ &= 7.5(\cos 30^\circ)(\sin 50^\circ) A_c \\ &= 5.0\, A_c \end{aligned}$$

where A_c = length X height of one container (ft^2)

For a standard 40 ft container:

$$P_w = 5.0(8.5)(40) = 1700 \text{ lb} = 7.56 \text{ KN}$$

Reference 7 gives the following much higher values:

$$\begin{aligned} P_w &= 35.0 \text{ KN for 40 ft containers} \\ &= 17.5 \text{ KN for 20 ft containers} \end{aligned}$$

Elements of Container Strength

Due to seaway loads, a stack of containers and its securing system may fail in various ways: 1) racking of containers: 2) buckling of container corner posts; 3) excessive tension in corner posts or in the twistlock connecting the lowest container to the base sockets; and 4) failure of the lashing assembly or its points of attachment.

Table 1 gives ISO container strength ratings.

Reference 6 recommends higher ratings for corner post tension: 20 L.T. for 20 ft containers and 25 L.T. for 40 ft containers. These values are based on the use of twistlock type inter-box connectors, which allow the lifting of more than one container at a time.

Table 1. ISO Container Strength Ratings

Ref. 8

	Rating in KN (long tons in parentheses)	
	20′ containers	40′ containers
Stacking weight on corner post (corner post compression)	448.38 (45)	627.57 (67.5)
Top lifting vertically by corner post (corner post tension)	99.64 (10)	149.46 (15)
Lashing loads in corner castings; top or bottom		
– horizontally	149.46 (15)	149.46 (15)
– vertically	298.92 (30)	298.92 (30)
Transverse racking		
– door end	149.46 (15)	149.46 (15)
– front end	149.46 (15)	149.46 (15)

Racking stiffness. An important parameter in the sharing of load between containers and securing gear is the stiffness of container ends against racking forces. Table 2 shows some recommended values for use in analysis and design:

Table 2. Values for Racking Stiffness (KN/mm)

	Ref. 6	Ref. 7	Ref. 9
Front end	7.00 (= 40 kips/in)	10.00	17.68
Door end	2.63 (= 15 kips/in)	3.33	3.64

Strength of Securing Hardware

For balanced design, the strength of securing hardware should match container strength as far as practicable.

Fixed gear (D-rings, base sockets) and loose gear (twistlocks, stackers, bridge fittings) are to be governed by the strength ratings of containers. For example, a twistlock should be just about as strong as a corner post in tension and a stacker should be just as resistant in shear as a container is in racking.

The strength of securing gear is usually specified as a minimum breaking strength (MBS). The recommended design load is 60 percent of MBS for tension and compression and 45 percent of MBS for shear (4).

Wire ropes used as lashing come in the form of pendant assemblies with end fittings to attach to the corner casting of a container at one end and to a D-ring at the other. A turnbuckle takes up slack. Any looseness is killed off prior to use by applying a 50 percent MBS load. Design load is usually limited to 65 percent of MBS (4).

Just like container stiffness, the spring constant of a wire rope assembly affects the amount of load that will be transferred to the lashing. Table 3 gives values of stiffness constant (S), the product of cross-sectional area of wire rope (A) and modulus of elasticity (E).

The spring constant (K) can be computed from $K = AE/l$, where l is the length of the wire rope.

Rigid rods are sometimes used in place of wire ropes. Since their stiffness is very high, they take up a very high share of the racking load on a container stack.

Table 3. Wire Rope Assembly Stiffness
Ref. 7

Steel Wire Rope Diameter in mm	Stiffness (S) KN
12.5	8,000
16	15,000
19	21,000
22	28,000

Lashing Analysis

Racking equations

Let m = no. of tiers

n = tier no. under consideration

W_n = weight of container at tier n

R_n = transverse racking load at top of tier n (KN)

$(Kc)_{max}$ = container front end stiffness (KN/mm)

$(Kc)_{min}$ = container door end stiffness (KN/mm)

δ_o = distance the lowest container shifts on the base sockets (mm)

δ_n = horizontal deflection of the top of container at tier n

$L_{(n)}$ = tension in lashing assembly connected to the top of tier n or bottom of tier (n+1)

$L_{t(n)}$ = transverse component of $L_{(n)}$

Kn = spring constant of lashing assembly connected to top of tier n or bottom of tier (n+1)

θn = angle between the transverse direction and the lashing connected to the top of tier n or bottom of tier (n+1)

F_t, $(F_n)_{max}$ and $(F_n)_{min}$ are assumed to be distributed equally into either end of the container.

Based on Fig. 3, the expression for R_n is:

$$(1)\quad R_n = \frac{1}{4}F_{t(n)} + \frac{1}{2}F_{t(n+1)} + \ldots + \frac{1}{2}F_{t(m)} - L_{t(n)} - L_{t(n+1)} - \ldots - L_{t(m)}$$

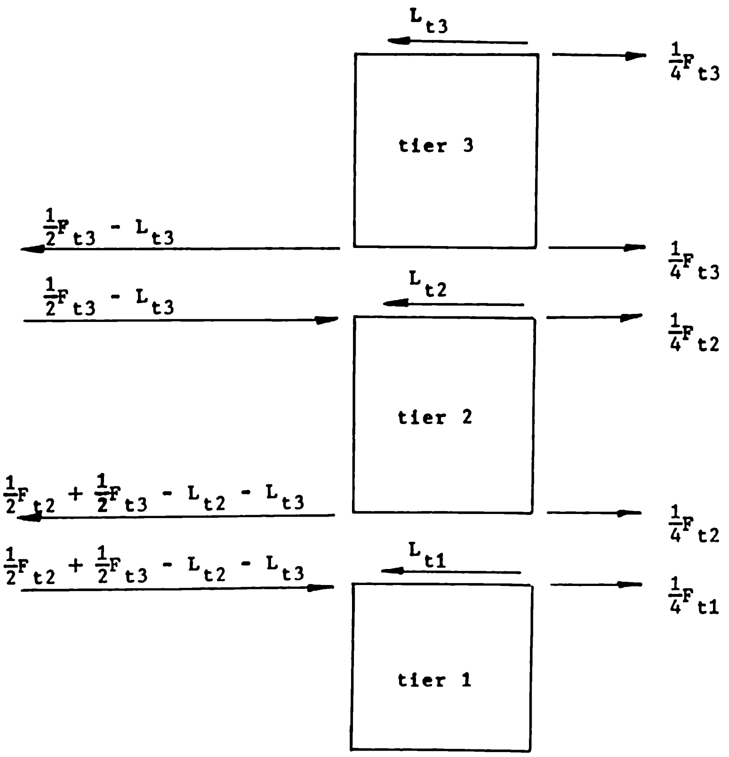

Figure 3. Racking Loads

This assumes that for each container end the transverse load $\frac{1}{2}F_t$ is distributed equally to the top and the bottom (4). Ref. 7 assumes that only $\frac{1}{8}F_t$ is acting on the top.

Based on Fig. 4, the lashing tension can be expressed as:

$$(2)\quad L_{(n)} = Kn\,(\delta_n \cos\theta n)$$

Its transverse component can be expressed as:

$$(3)\quad L_{t(n)} = \delta_n Kn \cos^2\theta n$$

The transverse deflection of the top of a container at tier n is:

$$(4)\quad \delta_n = \frac{R_n}{Kc} + \delta_{(n-1)} + \delta_o$$

where Kc can take on its maximum or minimum value depending upon which container end is being studied.

Substituting (3) into (1) and then the resulting expression into (4), a system of equations is developed. For simplicity, three tiers shall be considered in the illustration. Recalling that $F_t = WA_t$,

$$\text{tier 1:}\quad \left[1 + \frac{K_1\cos^2\theta_1}{Kc}\right]\delta_1 + \frac{K_2\cos^2\theta_2}{Kc}\delta_2 + \frac{K_3\cos^2\theta_3}{Kc}\delta_3 =$$

$$\left[\frac{1}{4}W_1A_{t1} + \frac{1}{2}W_2A_{t2} + \frac{1}{2}W_3A_{t3} + \delta_o\right]\frac{1}{Kc}$$

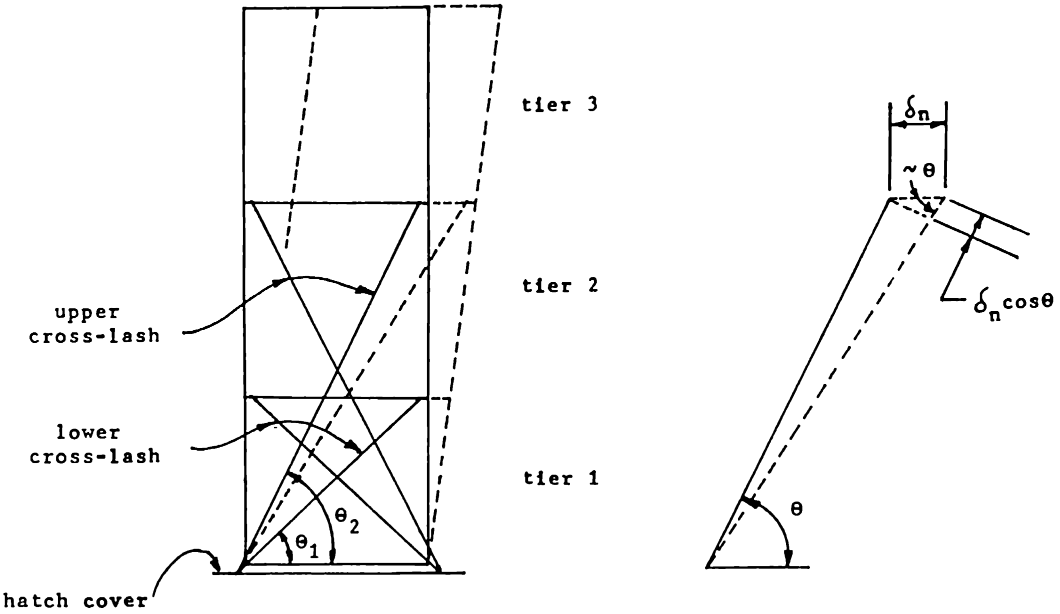

Figure 4. Lashing Deflection

$$\text{tier 2: } -\delta_1 + \left[1 + \frac{K_2\cos^2\theta_2}{Kc}\right]\delta_2 + \frac{K_3\cos^2\theta_3}{Kc}\delta_3 = \left[\frac{1}{4}W_2A_{t2} + \frac{1}{2}W_3A_{t3}\right]\frac{1}{Kc}$$

$$\text{tier 3: } -\delta_2 + \left[1 + \frac{K_3\cos^2\theta_3}{Kc}\right]\delta_3 = \left[\frac{1}{4}W_3A_{t3}\right]\frac{1}{Kc}$$

In matrix form,

$$\begin{bmatrix} 1 + \dfrac{K_1\cos^2\theta_1}{Kc} & \dfrac{K_2\cos^2\theta_2}{Kc} & \dfrac{K_3\cos^2\theta_3}{Kc} \\ -1 & 1 + \dfrac{K_2\cos^2\theta_2}{Kc} & \dfrac{K_3\cos^2\theta_3}{Kc} \\ 0 & -1 & 1 + \dfrac{K_3\cos^2\theta_3}{Kc} \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} = \begin{bmatrix} \dfrac{A_{t1}}{4Kc}W_1 + \dfrac{A_{t2}}{2Kc}W_2 + \dfrac{A_{t3}}{2Kc}W_3 + \delta_o \\ 0 + \dfrac{A_{t2}}{4Kc}W_2 + \dfrac{A_{t3}}{2Kc}W_3 + 0 \\ 0 + 0 + \dfrac{A_{t3}}{4Kc}W_3 + 0 \end{bmatrix}$$

The right hand side is a vector of constants. If the problem involves the determination of allowable combinations of W_1, W_2 and W_3, then the vector of constants has to be handled in a way that will enable W_1, W_2 and W_3 to be considered as unknowns. The system of equations has to be solved, using a computer routine, to yield $\delta_n = \delta_n(W_1, W_2, W_3)$. The δ_n's can then be set to their allowable maximums and all possible combinations of container weights satisfying the equations determined. To follow this procedure, the vector of constants has to be set up as an array shown below, where each of the first three columns represents multipliers of container weights. It must be noted here that rewriting the matrix equation so that W_1, W_2 and W_3 are the unknowns will not serve the purpose of determining allowable container weight combinations. If this is done and the δ_n's are set to their allowable values, only one set on W's will result, representing the case when the allowable values of container deflection at all tiers occur simultaneously.

$$\begin{array}{cccc} \text{multipliers of } W_1 & \text{multipliers of } W_2 & \text{multipliers of } W_3 & \\ \left[\dfrac{A_{t1}}{4Kc}\right. & \dfrac{A_{t2}}{2Kc} & \dfrac{A_{t3}}{2Kc} & \left.\delta_o\right. \\ 0 & \dfrac{A_{t2}}{4Kc} & \dfrac{A_{t3}}{2Kc} & 0 \\ \left.0\right. & 0 & \dfrac{A_{t3}}{4Kc} & \left.0\right] \end{array}$$

After setting up the matrix of coefficients and the "vector" of constants, substituting a value of KN = 0 where there is no lashing, the Gauss-Jordan method of solving simultaneous equations is applied, resulting in the matrix "equation" shown below:

multipliers of W_1
multipliers of W_2
multipliers of W_3

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \end{bmatrix}$$

The "vector" of constants after Gauss-Jordan

This is to be written in long-form as:

$$\delta_1 = a_{11} W_1 + a_{12} W_2 + a_{13} W_3 + a_{14}$$

$$\delta_2 = a_{21} W_1 + a_{22} W_2 + a_{23} W_3 + a_{24}$$

$$\delta_3 = a_{31} W_1 + a_{32} W_2 + a_{33} W_3 + a_{34}$$

It may be shown that the handling of the "vector" of constants in this manner does not violate any algebraic rule on the simultaneous solution of a set of equations.

The allowable values of δ_n may now be substituted. If $(R_n)_{all}$ is the allowable racking load, then:

$$(\delta_1)_{all} = \frac{(R_n)_{all}}{Kc} = g_1(W_1, W_2, W_3)$$

$$(\delta_2)_{all} = \frac{(R_n)_{all}}{Kc} + \delta_1 = g_2(W_1, W_2, W_3)$$

$$(\delta_3)_{all} = \frac{(R_n)_{all}}{Kc} + \delta_1 + \delta_2 = g_3(W_1, W_2, W_3)$$

These are the container weight limitation equations based on racking. The most severe racking may be expected with $(Kc)_{max}$ and $\delta_o = 0$.

Lashing assembly in tension. Given equations (1), (3) and (4), L_t can be considered as the unknown. The following matrix "equation" results, with the "vector" of constants handled in the same fashion as before:

$$\left[\begin{array}{c|c|c} 1+\dfrac{Kc}{K_1\cos^2\theta_1} & 1 & 1 \\ -\dfrac{Kc}{K_1\cos^2\theta_1} & 1+\dfrac{Kc}{K_2\cos^2\theta_2} & 1 \\ 0 & -\dfrac{Kc}{K_2\cos^2\theta_2} & 1+\dfrac{Kc}{K_3\cos^2\theta_3} \end{array}\right] \begin{bmatrix} L_{t1} \\ L_{t2} \\ L_{t3} \end{bmatrix} = \begin{bmatrix} \dfrac{A_{t1}}{4} & \dfrac{A_{t2}}{2} & \dfrac{A_{t3}}{2} & \delta_o \\ 0 & \dfrac{A_{t2}}{4} & \dfrac{A_{t3}}{2} & 0 \\ 0 & 0 & \dfrac{A_{t3}}{4} & 0 \end{bmatrix}$$

If the number of lashings is less than the number of tiers, as is usually the case, then the number of equations is equal, quite naturally, to the number of lashings.

By using the Gauss-Jordan elimination method, expressions of the L_t's in terms of W_1, W_2 and W_3 may be determined. By substituting allowable values of L_t, the container weight limitation equations based on lashing tension can be arrived at.

The use of $(Kc)_{min}$ transfers more of the racking load to the lashings. The effect of the lowest container slipping over the base sockets is uncertain. Therefore, both slipping and nonslipping have to be investigated.

Corner post compression. By summing moments about "0" in Fig. 5; by using the expressions for L_{t1}, L_{t2} and L_{t3} in terms of W_1, W_2 and W_3 as previously derived; and by equating the force C in Fig. 5 to the maximum allowable compressive load on the corner post, the container weight limitation equations based on corner post compression can be determined.

The following cases are to be studied: $(Kc)_{min}$ with and without slip and $(Kc)_{max}$ without slip (4).

Corner post tension. Maximum corner post tension generally occurs when F_n is minimum. However, corner post tension should also be investigated when F_n is maximum. The latter may govern for 4-hi or 5-hi stacks (4).

By summing moments about "0′" in Fig. 5; by using the expressions for L_{t1}, L_{t2} and L_{t3} as previously determined; and by equating the force T in Fig. 5 to the maximum allowable tensile load on corner posts, the container weight limitation equations based on corner post tension can be determined. Corner post tension is highest with $(Kc)_{max}$ and $\delta_o = 0$.

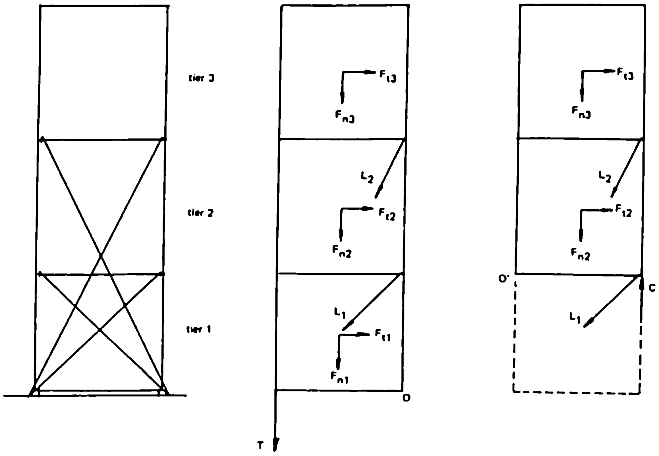

Figure 5. Corner Post Tension and Compression

Governing case. The container weight limitation equations based on all possible modes of failure may now be assembled. By a systematic variation of W_1 and W_2, the allowable value of W_3 may be determined from each of these equations. The equation which gives the lowest value of W_3 then defines the governing case for a particular set of W_1 and W_2 values.

Example

The appendix gives sample values for a 190 m containership with 3-hi container stowage on deck. Four cases are worked out to show the effect of wind, double lashing and slipping over base sockets.

Based on the results for case 1, a stack weight diagram has been generated as shown in Fig. 6. A diagram such as this can be incorporated into a container stowage manual as a means to rapidly check whether a contemplated combination of containers in one stack is allowable or not. Released from the drudgery of computations by the use of a computer, separate diagrams may be made for different locations on board since motions in some locations may not be as severe as at some other locations on board. Alternatively, a small computer on board may be made to give this kind of information.

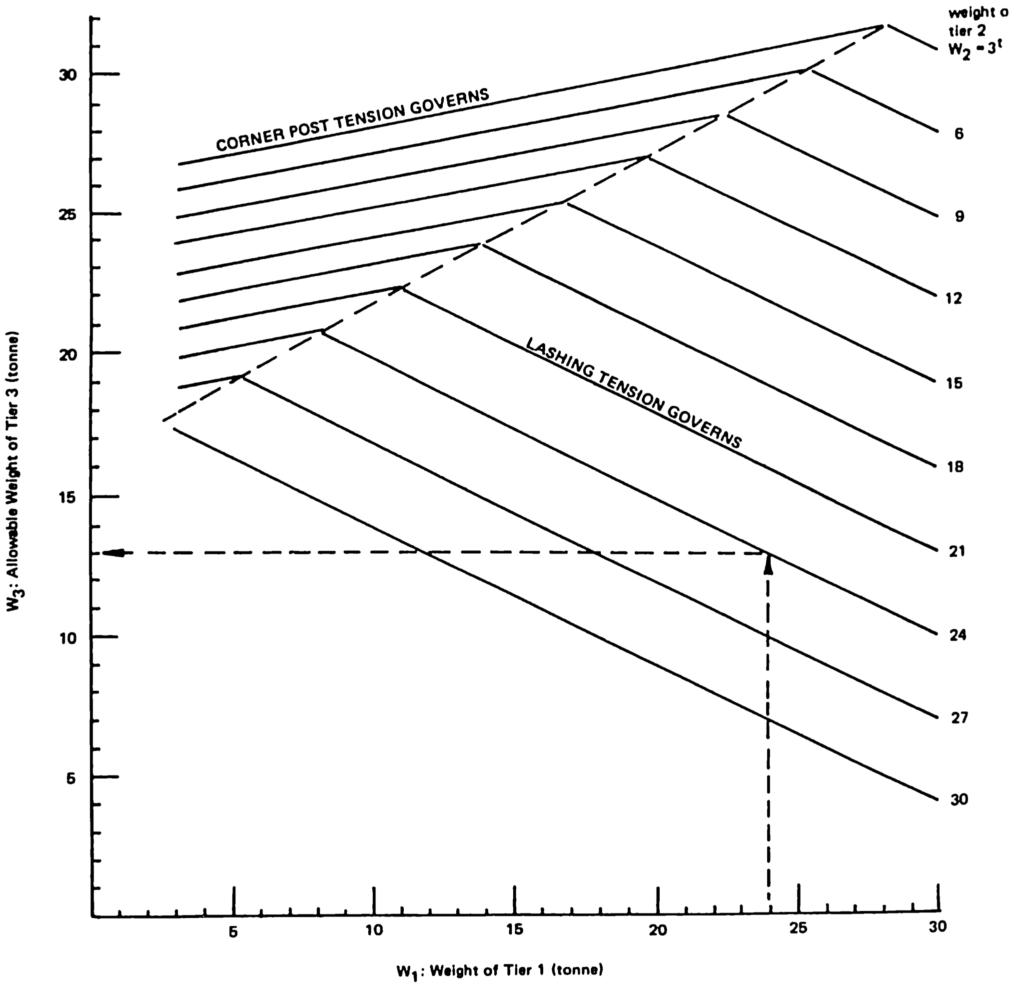

Figure 6. Sample Stack Weight Diagram

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APPENDIX

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                 190 m CONTAINERSHIP

                     PARTICULARS:
                     ------------

              Lbp          190.50 m
              Beam          27.43 m
              Depth         16.15 m
              Draft         10.06 m
              GMt            1.22 m
              Cb              .58
              Speed         23.00 Knots

             LOWEST CONTAINER LOCATION
             -------------------------

         Vcg    19.51  m  (Abv baseline)
         Lcg    83.21  m  (Aft amidships)
         Tcg    12.49  m  (From centerline)

                     CRITERIA:
                     ---------
                 (with  bilge keel)

             Roll angle  = 30.8 degrees
             Roll period = 19.4 seconds

             ACCELERATION COMPONENTS
             -----------------------

     Ay   (yaw-sway)                          .388g
     Az   (heave)                             .447g
     Ary  (across-dk roll; lowest cont)       .066g
     Arz  (normal-to-deck roll)               .072g
     Ap   (pitch)                             .794g

           COMBINED ACCELERATION VECTORS
           -----------------------------

              An (maximum)     1.339g
              An (minimum)      .874g
              At (1st tier)     .781g
              At (2nd tier)     .796g
              At (3rd tier)     .811g


    An = normal-to-deck acceleration component
    At = across-deck acceleration component

                     WIND LOAD
                     ---------
                 (based on 5 psf)

           Pwind (1st tier)     7.56 KN
           Pwind (2nd tier)     7.56 KN
           Pwind (3rd tier)     7.56 KN
```

CASE 1 : SINGLE LASH ; WITH WIND

```
TRANSVERSE ACCELERATION VECTORS          MAX NORMAL ACCELERATION VECTORS
-------------------------------          -------------------------------
   Tier No. 1           .78g                All tiers          1.34g
   Tier No. 2           .80g
   Tier No. 3           .81g             MIN NORMAL ACCELERATION VECTOR
                                         ---------------------------------
                                            All tiers           .87g

--------------------TRANSVERSE WIND LOAD OF 5 PSF ASSUMED-- -------------- --
------------ASSUMES LOWEST CONTAINER DOES NOT SLIDE ON BASE SOCKET-----------

CONTAINER STRENGTH/STIFFNESS             STACK DESCRIPTION
----------------------------             ------ ----------

Racking              149.5  KN             3 tiers per stack
C.P. compression     672.6  KN             8.5 ft high containers
C.P. tension         199.3  KN            40 ft long containers
Min spring const       2.6  KN/mm          1 - number of cross_lashings
Max spring const       7.0  KN/mm

                             LASH DESCRIPTION
                             ----------------

                    Cross lash to bottom of tier No. 2
                    21 mm diameter wire rope
                    311 KN    MBS
                    SWL assumed 65% of MBS
                    Lash spring constant =    9.54 KN/mm

                CONTAINER WEIGHT LIMITATION EQUATIONS (KN)
                ------------------------------------------
         RACKING:
                   1st tier:        .1191 W1 +  .2420 W2 +   .2473 W3 =  143.70
                   2nd tier:       0.0000 W1 +  .1990 W2 +   .4055 W3 =  143.79

      LASH TENSION:
                                    .1231 W1 +  .2509 W2 +   .2557 W3 =  122.00

C.P. COMPRESSION:
                   C_min;slip:      .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4795.86
                   C_min;no-slip:   .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4878.77
                   C_max;no-slip:   .6006 W1 + 5.4157 W2 +  8.9340 W3 = 4896.67

      C.P. TENSION:
                   min force:      -.9745 W1 +  .9804 W2 +  3.7786 W3 = 1364.93
                   max force:     -1.0430 W1 + 1.7124 W2 +  5.2464 W3 = 1396.28
```

CASE 1 : SINGLE LASH ; WITH WIND

TABLE OF ALLOWABLE CONTAINER WEIGHTS

(All container weights in tonnes)

```
                           T   I   E   R    N o.  1

               3      6      9     12     15     18     21     24     27     30

       3     26.8   27.4   28.0   28.6   29.2   29.8   30.4   31.0   31.6   31.0
               T      T      T      T      T      T      T      T      T      L

T      6     25.8   26.4   27.0   27.6   28.2   28.8   29.4   30.0   29.5   28.0
               T      T      T      T      T      T      T      T      L      L

I      9     24.8   25.4   26.0   26.6   27.2   27.8   28.4   28.0   26.5   25.0
               T      T      T      T      T      T      T      L      L      L

E     12     23.8   24.4   25.0   25.6   26.2   26.8   26.5   25.0   23.5   22.1
               T      T      T      T      T      T      L      L      L      L

R     15     22.8   23.4   24.0   24.6   25.2   24.9   23.5   22.0   20.5   19.1
               T      T      T      T      T      L      L      L      L      L

      18     21.8   22.4   23.0   23.6   23.4   21.9   20.5   19.0   17.5   16.1
               T      T      T      T      L      L      L      L      L      L

N     21     20.8   21.4   22.0   21.9   20.4   18.9   17.5   16.0   14.5   13.1
               T      T      T      L      L      L      L      L      L      L

o     24     19.8   20.4   20.4   18.9   17.4   16.0   14.5   13.0   11.6   10.1
               T      T      L      L      L      L      L      L      L      L

      27     18.8   18.8   17.4   15.9   14.4   13.0   11.5   10.0    8.6    7.1
               T      L      L      L      L      L      L      L      L      L

2     30     17.3   15.8   14.4   12.9   11.4   10.0    8.5    7.0    5.6    4.1
               L      L      L      L      L      L      L      L      L      L


   LEGEND FOR GOVERNING CASE:  R = racking         C = c.p. compression
                               L = lashing         T = c.p. tension

IF APPLICABLE, 4th tier and fifth tier containers assumed to weigh
5 L.T. if 40 footers or 3 L.T. if 20 footers
```

CASE 2 : SINGLE LASH ; WITHOUT WIND

```
TRANSVERSE ACCELERATION VECTORS          MAX NORMAL ACCELERATION VECTORS
-------------------------------          -------------------------------
   Tier No. 1           .78g                All tiers          1.34g
   Tier No. 2           .80g
   Tier No. 3           .81g             MIN NORMAL ACCELERATION VECTOR
                                         ---------------------------------
                                            All tiers           .87g

------------------------------WIND LOAD NEGLECTED----------------------------
------------ASSUMES LOWEST CONTAINER DOES NOT SLIDE ON BASE SOCKET-----------
```

```
CONTAINER STRENGTH/STIFFNESS              STACK DESCRIPTION
----------------------------              -----------------

Racking              149.5  KN               3 tiers per stack
C.P. compression     672.6  KN               8.5 ft high containers
C.P. tension         199.3  KN              40 ft long containers
Min spring const       2.6  KN/mm            1 - number of cross_lashings
Max spring const       7.0  KN/mm

                          LASH DESCRIPTION
                          ----------------

                    Cross lash to bottom of tier No. 2
                    21 mm diameter wire rope
                    311 KN    MBS
                    SWL assumed 65% of MBS
                    Lash spring constant =    9.54 KN/mm

               CONTAINER WEIGHT LIMITATION EQUATIONS (KN)
               ----------------------------------------
       RACKING:
               1st tier:          .1191 W1 +  .2428 W2 +   .2473 W3 =  149.46
               2nd tier:         0.0000 W1 +  .1990 W2 +   .4055 W3 =  149.46

    LASH TENSION:
                                  .1231 W1 +  .2509 W2 +   .2557 W3 =  128.04

C.P. COMPRESSION:
               C_min;slip:        .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4907.56
               C_min;no-slip:     .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4990.47
               C_max;no-slip:     .6006 W1 + 5.4157 W2 +  8.9340 W3 = 4990.47

    C.P. TENSION:
               min force:        -.9745 W1 +  .9804 W2 +  3.7786 W3 = 1478.66
               max force:       -1.0430 W1 + 1.7124 W2 +  5.2464 W3 = 1478.66
```

CASE 2 : SINGLE LASH ; WITHOUT WIND

TABLE OF ALLOWABLE CONTAINER WEIGHTS

(All container weights in tonnes)

```
                          T   I   E   R    N o.  1

             3      6      9     12     15     18     21     24     27     30

     3     28.4   29.0   29.6   30.2   30.8   31.4   32.0   32.6   33.2   33.4
             T      T      T      T      T      T      T      T      T      L

T    6     27.4   28.0   28.6   29.2   29.8   30.4   31.0   31.6   31.9   30.4
             T      T      T      T      T      T      T      T      L      L

I    9     26.4   27.0   27.6   28.2   28.8   29.4   30.0   30.4   28.9   27.4
             T      T      T      T      T      T      T      L      L      L

E   12     25.4   26.0   26.6   27.2   27.8   28.4   28.8   27.4   25.9   24.4
             T      T      T      T      T      T      L      L      L      L

R   15     24.4   25.0   25.6   26.2   26.8   27.3   25.8   24.4   22.9   21.4
             T      T      T      T      T      L      L      L      L      L

    18     23.4   24.0   24.6   25.2   25.8   24.3   22.9   21.4   19.9   18.4
             T      T      T      T      L      L      L      L      L      L

N   21     22.4   23.0   23.6   24.2   22.8   21.3   19.9   18.4   16.9   15.5
             T      T      T      T      L      L      L      L      L      L

o   24     21.4   22.0   22.6   21.3   19.8   18.3   16.9   15.4   13.9   12.5
             T      T      T      L      L      L      L      L      L      L

    27     20.4   21.0   19.7   18.3   16.8   15.3   13.9   12.4   10.9    9.5
             T      T      L      L      L      L      L      L      L      L

2   30     19.4   18.2   16.8   15.3   13.8   12.3   10.9    9.4    7.9    6.5
             T      L      L      L      L      L      L      L      L      L

    LEGEND FOR GOVERNING CASE:  R = racking        C = c.p. compression
                                L = lashing        T = c.p. tension

IF APPLICABLE, 4th tier and fifth tier containers assumed to weigh
5 L.T. if 40 footers or 3 L.T. if 20 footers
```

CASE 3 : DOUBLE LASH ; WITH WIND

```
TRANSVERSE ACCELERATION VECTORS          MAX NORMAL ACCELERATION VECTORS
-------------------------------          -------------------------------
   Tier No. 1            .78g                All tiers          1.34g
   Tier No. 2            .80g
   Tier No. 3            .81g            MIN NORMAL ACCELERATION VECTOR
                                         ---------------------------------
                                             All tiers           .87g

--------------------TRANSVERSE WIND LOAD OF 5 PSF ASSUMED--------------------
-------------ASSUMES LOWEST CONTAINER DOES NOT SLIDE ON BASE SOCKET-----------

CONTAINER STRENGTH/STIFFNESS             STACK DESCRIPTION
----------------------------             -----------------

Racking              149.5  KN              3 tiers per stack
C.P. compression     672.6  KN              8.5 ft high containers
C.P. tension         199.3  KN             40 ft long containers
Min spring const       2.6  KN/mm           2 - number of cross_lashings
Max spring const       7.0  KN/mm

LOWER LASH DESCRIPTION                   UPPER LASH DESCRIPTION
----------------------                   ----------------------
Cross-lash to bottom of tier no. 2       Cross-lash to bottom of tier no.3
21 mm diameter wire rope                 19 mm diameter wire rope
311 KN    MBS                            231 KN    MBS
SWL assumed 65% of MBS                   SWL assumed 65% of MBS
Lash spring constant =  9.54 KN/mm       Lash spring constant =  4.13 KN/mm
```

```
                 CONTAINER WEIGHT LIMITATION EQUATIONS (KN)
                 ------------------------------------------
       RACKING:
              1st tier:         .1125 W1 +  .2102 W2 +   .2110 W3 =  144.33
              2nd tier:        -.0109 W1 +  .1507 W2 +   .3460 W3 =  144.83

   LASH TENSION:
              1st lash:         .1130 W1 +  .2062 W2 +   .1039 W3 =  123.27
              2nd lash:         .0148 W1 +  .0710 W2 +   .1139 W3 =   62.14

C.P. COMPRESSION:
              C_min;slip:      1.0045 W1 + 6.3320 W2 +  9.9630 W3 = 4780.64
              C_min;no-slip:   1.0045 W1 + 6.3320 W2 +  9.9630 W3 = 4874.45
              C_max;no-slip:    .6461 W1 + 5.5046 W2 +  9.1036 W3 = 4892.30

   C.P. TENSION:
              min force:      -1.0700 W1 +  .5977 W2 +  3.1731 W3 = 1361.40
              max force:      -1.1923 W1 + 1.1585 W2 +  4.4279 W3 = 1309.36
```

CASE 3 : DOUBLE LASH ; WITH WIND

TABLE OF ALLOWABLE CONTAINER WEIGHTS

(All container weights in tonnes)

		TIER No. 1									
		3	6	9	12	15	18	21	24	27	30
	3	32.0 T	32.8 T	33.7 T	34.5 T	35.3 T	36.1 T	37.0 T	37.8 T	38.6 T	39.4 T
T	6	31.2 T	32.1 T	32.9 T	33.7 T	34.5 T	35.3 T	36.2 T	37.0 T	37.8 T	38.6 T
I	9	30.4 T	31.3 T	32.1 T	32.9 T	33.7 T	34.5 T	35.4 T	36.2 T	37.0 T	37.8 T
E	12	29.6 T	30.5 T	31.3 T	32.1 T	32.9 T	33.7 T	34.6 T	35.4 T	36.2 T	35.8 L
R	15	28.8 T	29.7 T	30.5 T	31.3 T	32.1 T	32.9 T	33.8 T	34.6 T	34.3 L	32.4 L
	18	28.0 T	28.9 T	29.7 T	30.5 T	31.3 T	32.1 T	33.0 T	32.8 L	30.9 L	29.0 L
N	21	27.2 T	28.1 T	28.9 T	29.7 T	30.5 T	31.3 T	31.2 L	29.3 L	27.5 L	25.6 L
o	24	26.4 T	27.3 T	28.1 T	28.9 T	29.7 T	29.7 L	27.8 L	25.9 L	24.0 L	22.2 L
	27	25.6 T	26.5 T	27.3 T	28.1 T	28.2 L	26.3 L	24.4 L	22.5 L	20.6 L	18.7 L
2	30	24.8 T	25.7 T	26.5 T	26.6 L	24.8 L	22.9 L	21.0 L	19.1 L	17.2 L	15.3 L

```
    LEGEND FOR GOVERNING CASE:  R = racking        C = c.p. compression
                                L = lashing        T = c.p. tension

IF APPLICABLE, 4th tier and fifth tier containers assumed to weigh
5 L.T. if 40 footers or 3 L.T. if 20 footers
```

CASE 4 : SINGLE LASH ; WITH WIND ; SLIP

```
TRANSVERSE ACCELERATION VECTORS           MAX NORMAL ACCELERATION VECTORS
-------------------------------           -------------------------------
   Tier No. 1            .78g                All tiers           1.34g
   Tier No. 2            .80g
   Tier No. 3            .81g             MIN NORMAL ACCELERATION VECTOR
                                          ----------------------------------
                                             All tiers            .87g

--------------------TRANSVERSE WIND LOAD OF 5 PSF ASSUMED--------------------
----------------ASSUMES LOWEST CONTAINER SLIDES ON BASE SOCKET---------------

CONTAINER STRENGTH/STIFFNESS              STACK DESCRIPTION
----------------------------              -----------------

Racking              149.5  KN              3 tiers per stack
C.P. compression     672.6  KN              8.5 ft high containers
C.P. tension         199.3  KN             40 ft long containers
Min spring const       2.6  KN/mm           1 - number of cross_lashings
Max spring const       7.0  KN/mm

                             LASH DESCRIPTION
                             ----------------

                    Cross lash to bottom of tier No. 2
                    21 mm diameter wire rope
                    311 KN    MBS
                    SWL assumed 65% of MBS
                    Lash spring constant =   9.54 KN/mm

                CONTAINER WEIGHT LIMITATION EQUATIONS (KN)
                ------------------------------------------
       RACKING:
              1st tier:          .1191 W1 +  .2428 W2 +   .2473 W3 =  143.70
              2nd tier:         0.0000 W1 +  .1990 W2 +   .4055 W3 =  143.79

   LASH TENSION:
                                 .1231 W1 +  .2509 W2 +   .2557 W3 =  111.57

C.P. COMPRESSION:
              C_min;slip:        .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4795.86
              C_min;no-slip:     .9705 W1 + 6.1697 W2 +  9.7023 W3 = 4878.77
              C_max;no-slip:     .6006 W1 + 5.4157 W2 +  8.9340 W3 = 4896.67

   C.P. TENSION:
              min force:        -.9745 W1 +  .9804 W2 +  3.7786 W3 = 1364.93
              max force:       -1.0430 W1 + 1.7124 W2 +  5.2464 W3 = 1396.28
```

CASE 4 : SINGLE LASH ; WITH WIND ; SLIP

TABLE OF ALLOWABLE CONTAINER WEIGHTS

(All container weights in tonnes)

		T I E R No. 1									
		3	6	9	12	15	18	21	24	27	30
	3	26.8 T	27.4 T	28.0 T	28.6 T	29.2 T	29.8 T	30.4 T	29.8 L	28.3 L	26.8 L
T	6	25.8 T	26.4 T	27.0 T	27.6 T	28.2 T	28.8 T	28.2 L	26.8 L	25.3 L	23.8 L
I	9	24.8 T	25.4 T	26.0 T	26.6 T	27.2 T	26.7 L	25.3 L	23.8 L	22.3 L	20.9 L
E	12	23.8 T	24.4 T	25.0 T	25.6 T	25.2 L	23.7 L	22.3 L	20.8 L	19.3 L	17.9 L
R	15	22.8 T	23.4 T	24.0 T	23.7 L	22.2 L	20.7 L	19.3 L	17.8 L	16.3 L	14.9 L
	18	21.8 T	22.4 T	22.2 L	20.7 L	19.2 L	17.7 L	16.3 L	14.8 L	13.3 L	11.9 L
N	21	20.8 T	20.6 L	19.2 L	17.7 L	16.2 L	14.8 L	13.3 L	11.8 L	10.3 L	8.9 L
o	24	19.1 L	17.6 L	16.2 L	14.7 L	13.2 L	11.8 L	10.3 L	8.8 L	7.4 L	5.9 L
	27	16.1 L	14.6 L	13.2 L	11.7 L	10.2 L	8.8 L	7.3 L	5.8 L	4.4 L	2.9 L
2	30	13.1 L	11.6 L	10.2 L	8.7 L	7.2 L	5.8 L	4.3 L	2.8 L	1.4 L	-.1 L

LEGEND FOR GOVERNING CASE: R = racking C = c.p. compression
L = lashing T = c.p. tension

IF APPLICABLE, 4th tier and fifth tier containers assumed to weigh
5 L.T. if 40 footers or 3 L.T. if 20 footers