Container Lashing Assessment

November 2017

Guidance Note
NI 648 DT R00 E

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MARINE & OFFSHORE - GENERAL CONDITIONS

1. INDEPENDENCY OF THE SOCIETY AND APPLICABLE TERMS

1.1. The Society shall remain at all times an independent contractor and neither the Society nor any of its officers, employees, servants, agents or subcontractors shall be or act as an employee, servant or agent of any other party hereto in the performance of the Services.

1.2. The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not, in any circumstances, involve monitoring or exhaustive verification.

1.3. The Society acts as a services provider. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty. The Society is not and may not be considered as an underwriter, broker in Unit's sale or chartering, expert in Unit's valuation, consulting engineer, controller, naval architect, manufacturer, shipbuilder, repair or conversion yard, charterer or shipowner; none of them above listed being relieved of any of their expressed or implied obligations as a result of the interventions of the Society.

1.4. The Services are carried out by the Society according to the applicable Rules and to the Bureau Veritas' Code of Ethics. The Society only is qualified to apply and interpret its Rules.

1.5. The Client acknowledges the latest versions of the Conditions and of the applicable Rules applying to the Services' performance.

1.6. Unless an express written agreement is made between the Parties on the applicable Rules, the applicable Rules shall be the rules applicable at the time of the Services' performance and con tract's execution.

1.7. The Services' performance is solely based on the Conditions. No other terms shall apply whether express or implied.

2. DEFINITIONS

2.1. "**Certificate(s)**" means class certificates, attestations and reports following the Society's intervention. The Certificates are an appraisement given by the Society to the Client, at a certain date, following surveys by its surveyors on the level of compliance of the Unit to the Society's Rules or to the documents of reference for the Services provided. They cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

2.2. "**Certification**" means the activity of certification in application of national and international regulations or standards, in particular by delegation from different governments that can result in the issuance of a certificate.

2.3. "**Classification**" means the classification of a Unit that can result or not in the issuance of a class certificate with reference to the Rules.

2.4. "**Client**" means the Party and/or its representative requesting the Services.

2.5. "**Conditions**" means the terms and conditions set out in the present document.

2.6. "**Industry Practice**" means International Maritime and/or Offshore industry practices.

2.7. "**Intellectual Property**" means all patents, rights to inventions, utility models, copyright and related rights, trade marks, logos, service marks, trade dress, business and domain names, rights in trade dress or get-up, rights in goodwill or to sue for passing off, unfair competition rights, rights in designs, rights in computer software, database rights, topography rights, moral rights, rights in confidential information (including know-how and trade secrets), methods and proto cols for Services, and any other intellectual property rights, in each case whether capable of registration, registered or unregistered and including all applications for and renewals, reversions or extensions of such rights, and all similar or equivalent rights or forms of protection in any part of the world.

2.8. "**Parties**" means the Society and Client together.

2.9. "**Party**" means the Society or the Client.

2.10. "**Register**" means the register published annually by the Society.

2.11. "**Rules**" means the Society's classification rules, guidance notes and other documents. The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical minimum requirements but are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.

2.12. "**Services**" means the services set out in clauses 2.2 and 2.3 but also other services related to Classification and Certification such as, but not limited to: ship and company safety management certification, ship and port security certification, training activities, all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

2.13. "**Society**" means the classification society '**Bureau Veritas Marine & Offshore SAS**', a company organized and existing under the laws of France, registered in Nanterre under the number 821 131 844, or any other legal entity of Bureau Veritas Group as may be specified in the relevant contract, and whose main activities are Classification and Certification of ships or offshore units.

2.14. "**Unit**" means any ship or vessel or offshore unit or structure of any type or part of it or system whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

3. SCOPE AND PERFORMANCE

3.1. The Society shall perform the Services according to the applicable national and international standards and Industry Practice and always on the assumption that the Client is aware of such standards and Industry Practice.

3.2. Subject to the Services performance and always by reference to the Rules, the Society shall:

- review the construction arrangements of the Unit as shown on the documents provided by the Client;
- conduct the Unit surveys at the place of the Unit construction;
- class the Unit and enters the Unit's class in the Society's Register;
- survey the Unit periodically in service to note that the requirements for the maintenance of class are met. The Client shall inform the Society without delay of any circumstances which may cause any changes on the conducted surveys or Services.

The Society will not:

- declare the acceptance or commissioning of a Unit, nor its construction in conformity with its design, such activities remaining under the exclusive responsibility of the Unit's owner or builder;
- engage in any work relating to the design, construction, production or repair checks, neither in the operation of the Unit or the Unit's trade, neither in any advisory services, and cannot be held liable on those accounts.

4. RESERVATION CLAUSE

4.1. The Client shall always: (i) maintain the Unit in good condition after surveys; (ii) present the Unit after surveys; (iii) present the Unit for surveys; and (iv) inform the Society in due course of any circumstances that may affect the given appraisement of the Unit or cause to modify the scope of the Services.

4.2. Certificates referring to the Society's Rules are only valid if issued by the Society.

4.3. The Society has entire control over the Certificates issued and may at any time withdraw a Certificate at its entire discretion including, but not limited to, in the following situations: where the Client fails to comply in due time with instructions of the Society or where the Client fails to pay in accordance with clause 6.2 hereunder.

5. ACCESS AND SAFETY

5.1. The Client shall give to the Society all access and information necessary for the efficient performance of the requested Services. The Client shall be the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out. Any information, drawings, etc. required for the performance of the Services must be made available in due time.

5.2. The Client shall notify the Society of any relevant safety issue and shall take all necessary safety-related measures to ensure a safe work environment for the Society or any of its officers, employees, servants, agents or subcontractors and shall comply with all applicable safety regulations.

6. PAYMENT OF INVOICES

6.1. The provision of the Services by the Society, whether complete or not, involve, for the part carried out, the payment of fees thirty (30) days upon issuance of the invoice.

6.2. Without prejudice to any other rights hereunder, in case of Client's payment default, the Society shall be entitled to charge, in addition to the amount not properly paid, interests equal to twelve (12) months LIBOR plus two (2) per cent as of due date calculated on the number of days such payment is delinquent. The Society shall also have the right to withhold certificates and other documents and/or to suspend or revoke the validity of certificates.

6.3. In case of dispute on the invoice amount, the undisputed portion of the invoice shall be paid and an explanation on the dispute shall accompany payment so that action can be taken to solve the dispute.

7. 7. LIABILITY

7.1. The Society bears no liability for consequential loss. For the purpose of this clause consequential loss shall include, without limitation:

- Indirect or consequential loss;
- Any loss and/or deferral of production, loss of product, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case whether direct or indirect.

The Client shall save, indemnify, defend and hold harmless the Society from the Client's own consequential loss regardless of cause.

7.2. In any case, the Society's maximum liability towards the Client is limited to one hundred and fifty per-cents (150%) of the price paid by the Client to the Society for the performance of the Services. This limit applies regardless of fault by the Society, including breach of contract, breach of warranty, tort, strict liability, breach of statute.

7.3. All claims shall be presented to the Society in writing within three (3) months of the Services' performance or (if later) the date when the events which are relied on were first discovered by the Client. Any claim not so presented as defined above shall be deemed waived and absolutely time barred.

8. INDEMNITY CLAUSE

8.1. The Client agrees to release, indemnify and hold harmless the Society from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, for harm or loss to persons and/or property tangible, intangible or otherwise which may be brought against the Society, incidental to, arising out of or in connection with the performance of the Services except for those claims caused solely and completely by the negligence of the Society, its officers, employees, servants, agents or subcontractors.

9. TERMINATION

9.1. The Parties shall have the right to terminate the Services (and the relevant contract) for convenience after giving the other Party thirty (30) days' written notice, and without prejudice to clause 6 above.

9.2. In such a case, the class granted to the concerned Unit and the previously issued certificates shall remain valid until the date of effect of the termination notice issued, subject to compliance with clause 4.1 and 6 above.

10. FORCE MAJEURE

10.1. Neither Party shall be responsible for any failure to fulfil any term or provision of the Conditions if and to the extent that fulfilment has been delayed or temporarily prevented by a force majeure occurrence without the fault or negligence of the Party affected and which, by the exercise of reasonable diligence, the said Party is unable to provide against.

10.2. For the purpose of this clause, force majeure shall mean any circumstance not being within a Party's reasonable control including, but not limited to: acts of God, natural disasters, epidemics or pandemics, wars, terrorist attacks, riots, sabotages, impositions of sanctions, embargoes, nuclear, chemical or biological contaminations, laws or action taken by a government or public authority, quotas or prohibition, expropriations, destructions of the worksite, explosions, fires, accidents, any labour or trade disputes, strikes or lockouts

11. CONFIDENTIALITY

11.1. The documents and data provided to or prepared by the Society in performing the Services, and the information made available to the Society, are treated as confidential except where the information:

- is already known by the receiving Party from another source and is properly and lawfully in the possession of the receiving Party prior to the date that it is disclosed;
- is already in possession of the public or has entered the public domain, otherwise than through a breach of this obligation;
- is acquired independently from a third party that has the right to disseminate such information;
- is required to be disclosed under applicable law or by a governmental order, decree, regulation or rule or by a stock exchange authority (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure.

11.2. The Society and the Client shall use the confidential information exclusively within the framework of their activity underlying these Conditions.

11.3. Confidential information shall only be provided to third parties with the prior written consent of the other Party. However, such prior consent shall not be required when the Society provides the confidential information to a subsidiary.

11.4. The Society shall have the right to disclose the confidential information if required to do so under regulations of the International Association of Classifications Societies (IACS) or any statutory obligations.

12. INTELLECTUAL PROPERTY

12.1. Each Party exclusively owns all rights to its Intellectual Property created before or after the commencement date of the Conditions and whether or not associated with any contract between the Parties.

12.2. The Intellectual Property developed for the performance of the Services including, but not limited to drawings, calculations, and reports shall remain exclusive property of the Society.

13. ASSIGNMENT

13.1. The contract resulting from to these Conditions cannot be assigned or transferred by any means by a Party to a third party without the prior written consent of the other Party.

13.2. The Society shall however have the right to assign or transfer by any means the said contract to a subsidiary of the Bureau Veritas Group.

14. SEVERABILITY

14.1. Invalidity of one or more provisions does not affect the remaining provisions.

14.2. Definitions herein take precedence over other definitions which may appear in other documents issued by the Society.

14.3. In case of doubt as to the interpretation of the Conditions, the English text shall prevail.

15. GOVERNING LAW AND DISPUTE RESOLUTION

15.1. The Conditions shall be construed and governed by the laws of England and Wales.

15.2. The Society and the Client shall make every effort to settle any dispute amicably and in good faith by way of negotiation within thirty (30) days from the date of receipt by either one of the Parties of a written notice of such a dispute.

15.3. Failing that, the dispute shall finally be settled by arbitration under the LCIA rules, which rules are deemed to be incorporated by reference into this clause. The number of arbitrators shall be three (3). The place of arbitration shall be London (UK).

16. PROFESSIONNAL ETHICS

16.1. Each Party shall conduct all activities in compliance with all laws, statutes, rules, and regulations applicable to such Party including but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption. Each of the Parties warrants that neither it, nor its affiliates, has made or will make, with respect to the matters provided for hereunder, any offer, payment, gift or authorization of the payment of any money directly or indirectly, to or for the use or benefit of any official or employee of the government, political party, official, or candidate.

16.2. In addition, the Client shall act consistently with the Society's Code of Ethics of Bureau Veritas. http://www.bureauveritas.com/home/about-us/ethics+and+compliance/

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Container Lashing Assessment

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Section 1 Container Lashing Assessment

Appendix 1 Sample Calculation without Gap

SECTION 1 CONTAINER LASHING ASSESSMENT

Symbols

For symbols not defined in this Section, refer to NR625 Structural Rules for Container Ships.

H_i : Height, in m, of the container located at tier "i"

B : Breadth, in m, of the container

$K_{r,i}$: Racking stiffness of container located at tier "i", in kN/mm, values for door end and wall end are to be taken as defined in [2.3.5]

K_ℓ : Total stiffness of the lashing device, in kN/mm, to be taken as defined in [2.3.1]

$K_{\ell,HH}$: Horizontal stiffness of the lashing device, in kN/mm, to be taken as defined in [2.3.2]

$K_{\ell,VV}$: Vertical stiffness of the lashing device, in kN/mm, to be taken as defined in [2.3.3]

$K_{\ell,VH}$: Combined stiffness of the lashing device, in kN/mm, to be taken as defined in [2.3.4]

ℓ : Total length of the lashing device, including tensioning devices, in m

$$\ell = \sqrt{\delta x^2 + \delta y^2 + \delta z^2}$$

δx : Longitudinal distance (with sign), in m, from the anchoring point to the container corner where the lashing device is connected

δy : Transverse distance (with sign), in m, from the anchoring point to the container corner where the lashing device is connected

δz : Vertical distance (with sign), in m, from the anchoring point to the container corner where the lashing device is connected

d_{2i}, d_{2i-1} : Horizontal displacement, in mm, at the top or the bottom of the container located at "tier i", as defined in [3.1.4]

s_{2i}, s_{2i-1} : Vertical displacement on left side, in mm, at the top and bottom corners of the container, as defined in [3.2.3]

d_{LB} : Horizontal displacement of the lashing bridge at the anchoring point, in mm, to be taken equal to zero when there is no lashing bridge.

Typical values are:

- 10 mm for 1st tier lashing bridge
- 25 mm for 2nd tier lashing bridge
- 35 mm for 3rd tier and higher lashing bridge.

G_h : Maximum horizontal gap between twistlock and corner fitting, in mm (see Fig 2).

Typical value is 5 mm. Other values may be considered by the designer.

G_v : Maximum vertical gap between twistlock and corner fitting, in mm (see Fig 2).

Typical values are between 12 mm to 20 mm. Other values may be considered by the designer.

1 General

1.1 Application

1.1.1 This Guidance Note gives guidelines for the calculation of reactions in the lashing equipment due to the loads applied to one stack of containers, according to NR625 Structural Rules for Container Ships:

- Sec 1 describes the methodology for the lashing assessment
- App 1 gives a numerical application of the methodology.

1.2 Definition

1.2.1 Reference coordinate system

The loads and motions are defined with respect to the following right-hand coordinate system:

- X axis: Longitudinal axis, positive forwards
- Y axis: Transverse axis, positive towards portside
- Z axis: Vertical axis, positive upwards.

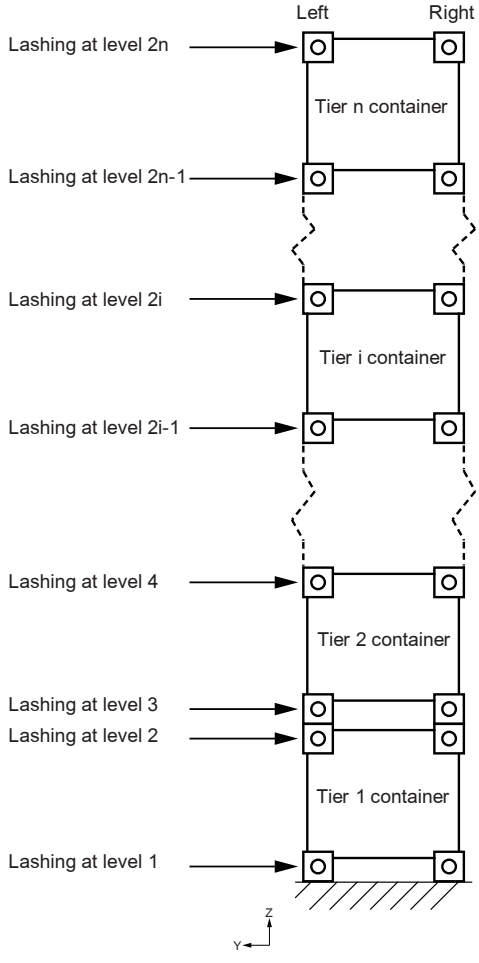
1.2.2 Stack of containers

A stack of containers consists of "n" containers connected vertically by securing devices.

Within a stack as indicated in Fig 1, two lashing levels are defined for the container located at the tier "i":

- level "2i" corresponds to the lashing at the top corners of the container
- level "2i – 1" corresponds to the lashing at the bottom corners of the container.

Figure 1 : Container tiers and lashing levels in a stack



2 Modelisation

2.1 Hypothesis

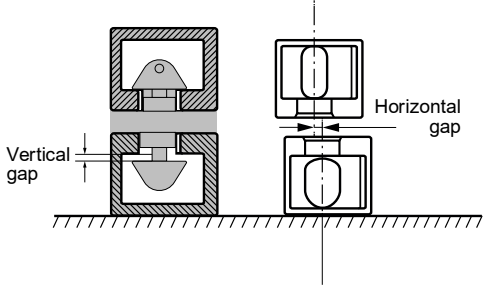
2.1.1 Interaction between wall and door

The interaction between wall end and door end frames of the container is not taken into account. Consequently, the wall end and door end are considered independently in this guidance note.

2.1.2 Horizontal and vertical gaps

The horizontal and vertical gaps due to a clearance between twistlocks and corner fitting (see Fig 2) are considered to be equal for both ends, wall end and door end.

Figure 2 : Horizontal and vertical gaps



2.2 Loads

2.2.1 Distribution

Forces are applied on the four corners of both container ends, wall end and door end.

In this guidance note, the methodology is detailed for one typical case only, with the following convention:

- the forces are given for one end only (wall end or door end)
- the transverse forces are applied from the left to the right (negative values), inducing a vertical displacement on the left side.

2.2.2 Transverse forces at corners

For the container located at tier "i", the transverse forces:

- $F_{Y, 2i}$
- $F_{Y, 2i-1}$

applied at the top and bottom corners respectively, are given by:

- for the top corner:
  $F_{Y, 2i} = F_{W, Y, 2i} + F_{Y, wind, 2i}$
- for the bottom corner:
  $F_{Y, 2i-1} = F_{W, Y, 2i-1} + F_{Y, wind, 2i-1}$

where:

- $F_{W, Y, 2i} = 0$
- $F_{W, Y, 2i-1} = 0,5\ F_{W, Y, i}$
  with $F_{W, Y, i}$ as defined in NR625, Ch 14, Sec 1, [4]
- $F_{Y, wind, 2i} = F_{Y, wind, 2i-1} = 0,25\ F_{Y, wind, i}$
  with $F_{Y, wind, i}$ as defined in NR625, Ch 4, Sec 5, [5].

Note 1: in the above formula, the wind force $F_{Y, wind, i}$ is equally distributed on the four corners of the exposed side (left or right) of the container.

2.2.3 Vertical forces at corners

For the container located at tier "i", the vertical forces:

- $F_{Z, 2i, L}$
- $F_{Z, 2i, R}$
- $F_{Z, 2i-1, L}$
- $F_{Z, 2i-1, R}$

applied at the top and bottom corners, on left and right sides respectively, are given by:

- for the top corner, left and right sides:
  $F_{Z, 2i, L} = F_{Z, 2i, R} = F_{S, 2i} + F_{W, Z, 2i}$
- for the bottom corner, left side:
  $F_{Z, 2i-1, L} = F_{S, 2i-1} + F_{W, Z, 2i-1} - R_{W, Z, i}$
- for the bottom corner, right side:
  $F_{Z, 2i-1, R} = F_{S, 2i-1} + F_{W, Z, 2i-1} + R_{W, Z, i}$

where:

- $F_{S, 2i}$ and $F_{S, 2i-1}$ are the still water forces, as detailed in a)
- $F_{W, Z, 2i}$ and $F_{W, Z, 2i-1}$ are the inertial forces, as detailed in b)
- $R_{W, Z, i}$ is the reaction due to inertial transverse force, as detailed in c).

a) Still water forces

The vertical still water forces $F_{S,\,i}$ calculated according to NR625, Ch 14, Sec 1, [4], are equally distributed on the four corners at bottom of the container:

- for the top corner:

  $F_{S,\,2i} = 0$

- for the bottom corner:

  $F_{S,\,2i-1} = 0{,}25\ F_{S,\,i}$

b) Inertial forces

The vertical inertial forces $F_{W,\,Z,\,i}$ calculated according to NR625, Ch 14, Sec 1, [4], are equally distributed on the four corners at bottom of the container:

- for the top corner:

  $F_{W,\,Z,\,2i} = 0$

- for the bottom corner:

  $F_{W,\,Z,\,2i-1} = 0{,}25\ F_{W,\,Z,\,i}$

c) Reaction forces due to inertial transverse force

A couple of vertical reactions (see $R_{W,\,Z,\,i}$ in Fig 3) are applied at the bottom of the container due to the moment induced by the inertial transverse force acting on the cargo within the container.

The moment induced by the inertial transverse force for one end (wall end or door end), assuming a centre of gravity for the cargo equal to 0,45 H_i , is given by:

$M_F = M = 0{,}45\ H_i\ F_{W,\,Y,\,i} / 2$

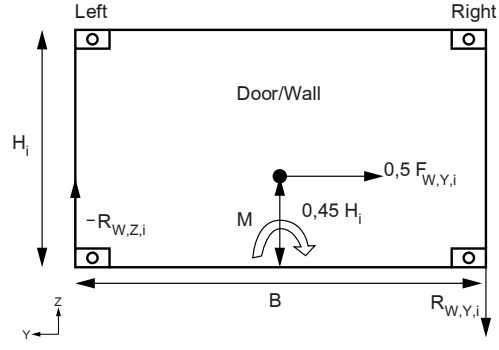
The moment induced by the reactions at the bottom of the container, is given by:

$M_R = M = 2 \cdot B/2 \cdot R_{W,\,Z,\,i} = B \cdot R_{W,\,Z,\,i}$

Reactions due to the moment induced by the inertial transverse force, are given by:

$R_{W,\,Z,\,i} = 0{,}45\ H_i\ F_{W,\,Y,\,i} / (2B)$

Figure 3 : Reaction forces due to the moment induced by the inertial transverse force



2.3 Stiffness

2.3.1 Total lashing stiffness

The total stiffness of a lashing device is to be obtained, in kN/mm, from the following formula:

$$K_\ell = \frac{A_\ell E_a}{\ell} 10^{-4}$$

where:

A_ℓ : Cross-section of the lashing device, in cm^2

E_a : Modulus of elasticity of the lashing device, in N/mm^2, which may be obtained from NR625, Ch 14, Sec 1, Tab 9, in the absence of data on the actual value.

2.3.2 Pure horizontal lashing stiffness

The horizontal stiffness of a lashing device is to be obtained, in kN/mm, from the following formula:

$$K_{\ell,\,HH} = \left(\frac{\delta y}{\ell}\right)^2 K_\ell$$

Note 1: When multiple lashing devices are connected at the same lashing level, the horizontal lashing stiffnesses ($K_{\ell,HH}$) are to be cumulated.

2.3.3 Pure vertical lashing stiffness

The vertical stiffness of a lashing device is to be obtained, in kN/mm, from the following formula:

$$K_{\ell,\,VV} = \left(\frac{\delta z}{\ell}\right)^2 K_\ell$$

Note 1: When multiple lashing devices are connected at the same lashing level, the vertical lashing stiffnesses ($K_{\ell,VV}$) are to be cumulated.

2.3.4 Combined vertical and horizontal lashing stiffness

The combined vertical and horizontal stiffness of a lashing device is to be obtained, in kN/mm, from the following formula:

$$K_{\ell,\,VH} = K_{\ell,\,HV} = \left(\frac{\delta y \delta z}{\ell^2}\right) K_\ell$$

Note 1: When multiple lashing devices are connected at the same lashing level, the combined lashing stiffnesses ($K_{\ell,VH}$ and $K_{\ell,HV}$) are to be cumulated.

2.3.5 Racking stiffness

For the purpose of the calculation, in the absence of data on the actual values, the racking stiffness of containers K_r may be obtained, in kN/mm, from NR625, Ch 14, Sec 1, Tab 10.

3 Reactions and displacements

3.1 Horizontal

3.1.1 Lashing reaction

The horizontal reaction R_{2i} in the corner, due to the lashing device, at the top of the container located at tier "i" is given by the following formula:

$$R_{2i} = -\left(K_{\ell,HH,2i}\,(d_{2i} - d_{LB}) + K_{\ell,HV,2i}\,s_{2i}\right)$$

3.1.2 Container reaction

The racking force T_{2i} corresponding to the reaction to the horizontal displacement in the container located at tier "i" is given by the following formula:

$$T_{2i} = -K_{r,i}\,\Delta d_i = -K_{r,i}\,(d_{2i} - d_{2i-1})$$

3.1.3 Twistlock reaction

The shear force T_{2i-1} corresponding to the reaction in the twistlock between the container located at tier "i – 1" and the container located at tier "i" is given by the following formula:

$$T_{2i-1} = T_{2i} - (F_{Y,2i-1} + R_{2i-1})$$

3.1.4 Horizontal displacements

The horizontal displacements on left and right sides at top or at bottom of the container are assumed to be identical (see Fig 4).

The horizontal displacement d_{2i-1} at the bottom of the container located at tier "i" is given by the following formula:

$$d_{2i-1} = d_{2(i-1)} + g_{2i-1}$$

where:

g_{2i-1} : Horizontal sliding, in mm, between the bottom of the container located at tier "i" and the top of the container located at tier "i – 1" (see Fig 5), to be limited in both directions by the horizontal gap G_h.

Figure 4 : Horizontal displacements (negative)

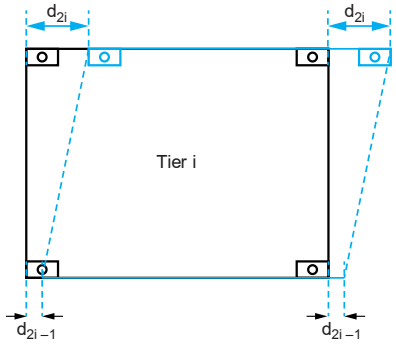
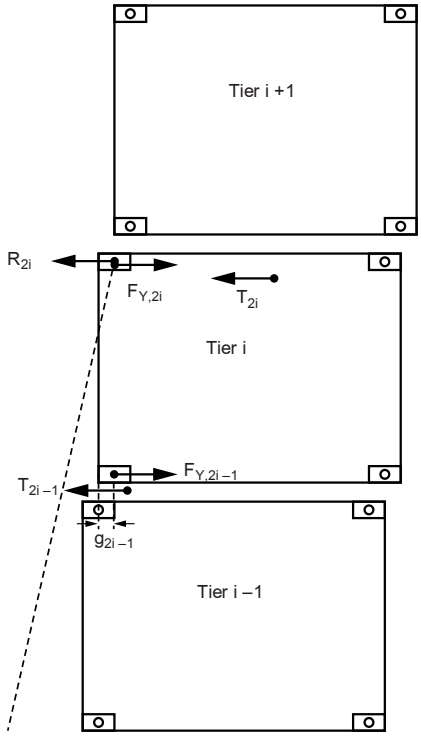


Figure 5 : Horizontal reactions and forces



3.2 Vertical

3.2.1 Lashing reaction

The vertical reaction V_{2i} in the corner, due to the lashing device at the top of the container located at tier "i" is given by the following formula:

$$V_{2i} = -(K_{\ell,VV,2i}\, s_{2i} + K_{\ell,VH,2i}\,(d_{2i} - d_{LB}))$$

3.2.2 Forces at container's corner

The vertical forces at the top corner of the container located at tier "i" are given by the following formula (see Fig 6):

$$P_{2i,L} = P_{2i+1,L} + tc_{2i}\, V_{2i}$$

$$P_{2i,R} = P_{2i+1,R} + (1 - tc_{2i})\, V_{2i}$$

where:

tc_{2i} : Factor of efficiency (tilt code with value 0 or 1) to restrain the vertical displacement of the left side according to the position of the lashing device at lashing level 2i (see Fig 7).

The vertical forces at the bottom corner of the container located at tier "i", taking into account the reactions due to the moment induced by the horizontal forces applied at the top of the container - and corresponding to the opposite of the racking force - are given by the following formula:

$$P_{2i-1,L} = P_{2i,L} + tc_{2i-1}\, V_{2i-1} + F_{Z,2i-1,L} + T_{2i}\, H_i / B$$

$$P_{2i-1,R} = P_{2i,R} + (1 - tc_{2i-1})\, V_{2i-1} + F_{Z,2i-1,R} - T_{2i}\, H_i / B$$

3.2.3 Vertical displacements

The vertical displacements, on left side, at bottom corner (s_{2i-1}) and at top corner (s_{2i}) are assumed to be identical (see Fig 8):

$$s_{2i} = s_{2i-1}$$

Figure 6 : Vertical reactions and forces

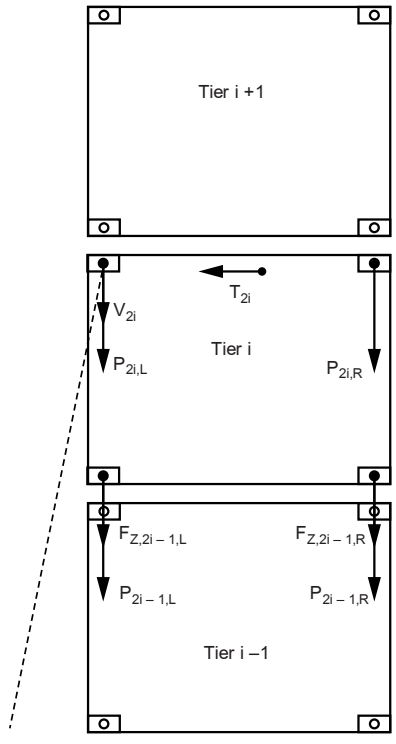


Figure 7 : Tilt code

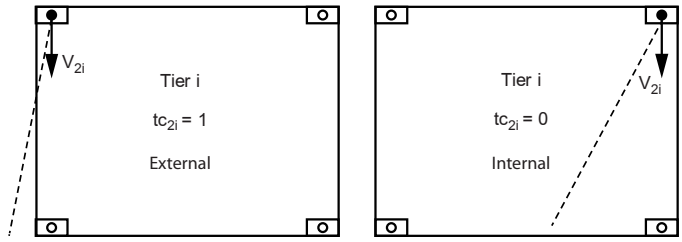
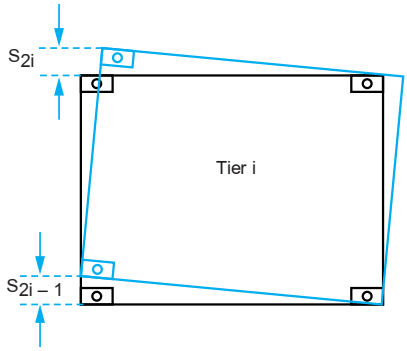


Figure 8 : Vertical displacements (positive)



3.3 Total lashing reaction

3.3.1 The total lashing reaction in the corner L_{2i} , due to the lashing device at the top of the container located at tier "i" is given by the following formula:

$$L_{2i} = R_{2i}\left(\frac{\delta y}{\ell}\right) + V_{2i}\left(\frac{\delta z}{\ell}\right)$$

When the lashing device is in tension, the total lashing reaction in the corner is negative.

When the lashing device is in compression, the total lashing reaction in the corner is positive.

4 Calculations

4.1 Method of resolution

4.1.1 Principles

The goal is to determine at each lashing level the horizontal and vertical displacements and to derive the corresponding reactions in lashing devices and containers.

The horizontal displacements (d_j) are obtained by the resolution of a system of equations, assuming the vertical displacements are known. Then the lashing reactions are derived.

4.1.2 Determination of horizontal reactions

The same relation is applied for each level, from the top of the first tier "1" to the top of the last tier "n":

- for j = 2, between tier "1" and tier "2":
  $T_3 - T_2 = F_{Y,2} + R_2$
  ...
- for j = 2i, between tier "i" and tier "i + 1":
  $T_{j+1} - T_j = F_{Y,j} + R_j$
- for j = 2i + 1, between tier "i + 1" and tier "i + 2":
  $T_{j+2} - T_{j+1} = F_{Y,j+1} + R_{j+1}$
  ...
- for j = 2n, between tier "n" and above:
  $T_{2n+1} - T_{2n} = F_{Y,2n} + R_{2n}$

We assume the shear force above tier "n" is zero ($T_{2n+1} = 0$), and we derive the horizontal reaction at level j as follows:

$$T_j = T_{j+1} - (F_{Y,j} + R_j) = T_{j+2} - (F_{Y,j+1} + R_{j+1}) - (F_{Y,j} + R_j)$$

Finally, each horizontal reactions are calculated with the following formula (level j = 2n .. 1):

$$T_j = -\sum_{k=j}^{2n}(F_{Y,k} + R_k)$$

4.1.3 Calculation of horizontal displacements

The calculation is based on the resolution of a system of 2n equations.

Equation for the bottom (level j = 2i – 1):

$$d_j - d_{j-1} = g_j$$

Equation for the top (level j = 2i):

$$K_{r,i}\, d_j - K_{r,i}\, d_{j-1} = -T_j$$

Using the relation in [3.1.1],the equation for the top can be also written as follows:

$$K_{r,i}d_j - K_{r,i}d_{j-1} + \sum_{k=j}^{2n} K_{\ell,HH,k}d_k = \sum_{k=j}^{2n}(F_{Y,k} - K_{\ell,HV,k}s_k)$$

Starting from the lower tier "1", and assuming the displacement below the lower tier at the deck level is zero ($d_0 = 0$), the expression of the displacement at the bottom of the tier "1" (d_1), is given by:

$$d_1 - d_0 = d_1 = g_0$$

where:

g_0 : The horizontal sliding, in mm, between the deck and the bottom of the container located at tier "1".

4.1.4 Calculation of vertical forces

Starting from the upper tier "n", and assuming the forces at level 2n + 1 are zero ($P_{2n+1,L} = P_{2n+1,R} = 0$), for each sub-level, from level 2n to deck level 1, the vertical forces on left and right sides are calculated with the following formula (level j = 2n .. 1):

- for the top (level j = 2i):
  $P_{j,L} = P_{j+1,L} + tc_j V_j$
  $P_{j,R} = P_{j+1,R} + (1 - tc_j) V_j$
- for the bottom (level j = 2i – 1):
  $P_{j,L} = P_{j+1,L} + tc_j V_j + F_{Z,j,L} + T_{j+1} H_i / B$
  $P_{j,R} = P_{j+1,R} + (1 - tc_j) V_j + F_{Z,j,R} - T_{j+1} H_i / B$

APPENDIX 1 SAMPLE CALCULATION WITHOUT GAP

1 Lashing assessment for one stack

1.1 Model description

1.1.1 Stack definition

This example is given for the door end of one stack of three tiers with two types of lashing devices as illustrated in Fig 1.

1.1.2 Container properties

All the containers have the same characteristics given in Tab 1.

Table 1 : Container's properties

Property	Value	Unit
Length	20	feet
Height	2,438 (8)	m (feet)
Breadth	2,438 (8)	m (feet)
Racking stiffness	4	kN/mm

1.1.3 Lashing properties

On the left side, at the lashing level 3, the properties of the lashing device (lashing 1 - steel chain) are given in Tab 2.

On the right side, at the lashing level 3, the properties of the lashing device (lashing 1 - steel chain) are given in Tab 2.

On the left side, at the lashing level 5, the properties of the lashing device (lashing 2 - steel wire rope) are given in Tab 3.

On the right side, at the lashing level 5, the properties of the lashing device (lashing 2 - steel wire rope) are given in Tab 3.

Figure 1 : Stack definition

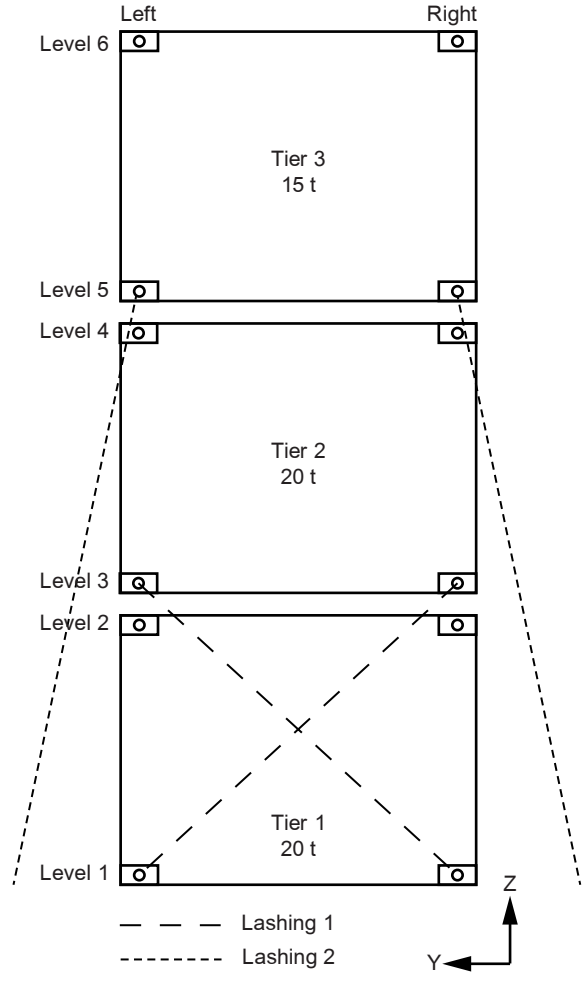


Table 2 : Lashing 1 properties (left side & right side)

Property	Value on left side	Value on right side	Unit
Area	2,65	2,65	cm^2
Distance δx	0	0	m
Distance δy	2,44	–2,44	m
Distance δz	2,44	2,44	m
Length ℓ	3,45	3,45	m
Modulus of elasticity E_a	4000	4000	N/mm^2
Total stiffness K_l	0,307	0,307	kN/mm
Horizontal stiffness $K_{l,HH}$	0,154	0,154	kN/mm
Vertical stiffness $K_{l,VV}$	0,154	0,154	kN/mm
Combined stiffness $K_{l,VH}$	0,154	–0,154	kN/mm

Table 3 : Lashing 2 properties (left side & right side)

Property	Value on left side	Value on right side	Unit
Area	2,26	2,26	cm^2
Distance δx	0,61	0,61	m
Distance δy	–1,65	1,65	m
Distance δz	4,88	4,88	m
Length ℓ	5,19	5,19	m
Modulus of elasticity E_a	20 000	20 000	N/mm^2
Total stiffness K_l	0,871	0,871	kN/mm
Horizontal stiffness $K_{l,HH}$	0,088	0,088	kN/mm
Vertical stiffness $K_{l,VV}$	0,771	0,771	kN/mm
Combined stiffness $K_{l,VH}$	–0,261	0,261	kN/mm

Table 4 : Loads definition

Tier i	Lashing level j	Transverse (kN)		Vertical (kN)			
		$F_{W,Y,i}$	$F_{Y,j}$	$F_{W,Z,j}$	$R_{W,Z,i}$	$F_{z,j,L}$	$F_{z,j,R}$
1	1	–73,03	–36,52	–173	–16,43	–26,81	–59,67
	2	0	0	0	0	0	0
2	3	–73,03	–36,52	–173	–16,43	–26,81	–59,67
	4	0	0	0	0	0	0
3	5	–54,77	–27,39	–129,7	–12,32	–20,11	–44,75
	6	0	0	0	0	0	0
Total (kN)		–200,83	–100,43	–475,7	–45,78	–73,73	–164,06

1.1.4 Twistlock properties

In this example, the twislock devices are assumed not having horizontal or vertical gaps ($G_h = G_v = 0$ mm).

1.1.5 Loads

Transverse forces are applied to each tier from left to right (negative values) and vertical forces are applied from top to bottom (negative values).

The effect of wind is not considered.

The loads are based on the load case LC2 Min from NR625 and are given in Tab 4.

1.2 Calculations

1.2.1 Horizontal displacements

Taking into account the sign of the total transverse forces, the following assumptions are considered:

- the lashing devices which are assumed to be in tension are the lashing on left side at level 5 and on the right side at level 3. Other lashing devices are disabled
- all horizontal slidings are initialised to 0 (no horizontal gap).

The horizontal displacements are derived from the system of equations written in the matrix format and considering the vertical displacements are zero (no vertical gap):

$A\,d = B$

where:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -4 & 4 & 0,154 & 0 & 0,088 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & -4 & 4 & 0,088 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & -4 & 4 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ -63,90 \\ 0 \\ -27,39 \\ 0 \\ 0 \end{bmatrix}$$

Then the matrix A is inverted to derive the displacements:

$d = A^{-1}\,B$

where:

$$A^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0,943 & -0,236 & -0,057 & 0,005 & -0,02 & 0 \\ 0,943 & -0,236 & 0,943 & 0,005 & -0,02 & 0 \\ 0,923 & -0,231 & 0,923 & -0,24 & -0,041 & 0 \\ 0,923 & -0,231 & 0,923 & -0,24 & 0,959 & 0 \\ 0,923 & -0,231 & 0,923 & -0,24 & 0,959 & -0,25 \end{bmatrix}$$

The horizontal displacements, in mm, are:

$$d = \begin{bmatrix} 0 \\ -14,93 \\ -14,93 \\ -21,31 \\ -21,31 \\ -21,31 \end{bmatrix}$$

1.2.2 Horizontal lashing reactions

The horizontal lashing reactions are derived using the horizontal displacements (see Tab 5).

Table 5 : Horizontal lashing reactions on left and right sides (kN)

R_5	$-(K_{l,HH,5}\ d_5 + K_{l,HV,5}\ s_5)$ $-(0,088 \times -21,31)$	1,87
R_3	$-(K_{l,HH,3}\ d_3 + K_{l,HV,3}\ s_3)$ $-(0,154 \times -14,93)$	2,29

1.2.3 Vertical lashing reactions

The vertical lashing reactions are derived using the horizontal displacements (see Tab 6).

Table 6 : Vertical lashing reactions (kN)

Left side		
V_5	$-(K_{l,VV,5}\ s_5 + K_{l,VH,5}\ d_5)$ $-(-0,261 \times -21,31)$	–5,56
V_3	$-(K_{l,VV,3}\ s_3 + K_{l,VH,3}\ d_3)$ $-(0,154 \times -14,93)$	2,29

Right side		
V_5	$-(K_{l,VV,5}\ s_5 + K_{l,VH,5}\ d_5)$ $-(0,261 \times -21,31)$	5,56
V_3	$-(K_{l,VV,3}\ s_3 + K_{l,VH,3}\ d_3)$ $-(-0,154 \times -14,93)$	–2,29

1.2.4 Total lashing reactions

The total lashing reactions are derived using the horizontal and vertical lashing reactions (see Tab 7).

Table 7 : Total lashing reactions (kN)

Left side		
L_5	$(R_5\delta y + V_5\delta z)/\ell$ $(1,87 \times (-1,65) + (-5,56) \times 4,88)/5,19$	–5,82
L_3	$(R_3\delta y + V_3\delta z)/\ell$ $(2,29 \times 2,44 + 2,29 \times 2,44)/3,45$	3,24

Right side		
L_5	$(R_5\delta y + V_5\delta z)/\ell$ $(1,87x\ 1,65 + 5,56 \times 4,88)/5,19$	5,82
L_3	$(R_3\delta y + V_3\delta z)/\ell$ $(2,29x\ (-2,44) + (-2,29) \times 2,44)/3,45$	–3,24

1.2.5 Container reactions

The racking forces are derived using the horizontal displacements (see Tab 8).

Table 8 : Racking forces (kN)

T_6	$-K_{r,3}\ (d_6 - d_5)$ $-4 \times (-21,31 + 21,31)$	0
T_4	$-K_{r,2}\ (d_4 - d_3)$ $-4 \times (-21,31 + 14,93)$	25,52
T_2	$-K_{r,1}\ (d_2 - d_1)$ $-4 \times (-14,93)$	59,72

1.2.6 Twistlock reactions

The shear forces between tiers are derived using the summation formula (see Tab 9).

Table 9 : Shear forces (kN)

T_5	$-(F_{Y,5} + R_5) - (F_{Y,6} + R_6)$ $-(-27,39 + 1,87)$	25,52
T_3	$-(F_{Y,3} + R_3) - (F_{Y,4} + R_4) - (F_{Y,5} + R_5) - (F_{Y,6} + R_6)$ $-(-36,52 + 2,29) - (-27,39 + 1,87)$	59,75
T_1	$-(F_{Y,1} + R_1) - (F_{Y,2} + R_2) - (F_{Y,3} + R_3) - (F_{Y,4} + R_4) - (F_{Y,5} + R_5) - (F_{Y,6} + R_6)$ $-(-36,52 + 0) - (-36,52 + 2,29) - (-27,39 + 1,87)$	96,27

1.2.7 Vertical forces at container's corner

The vertical forces at top and bottom corners are derived from the vertical lashing reactions, starting from the upper level 6 (see Tab 10 and Tab 11).

Table 10 : Vertical forces on left side (kN)

$P_{6,L}$	$tc_6\ V_6$	0
$P_{5,L}$	$P_{6,L} + tc_5\ V_5 + F_{Z,5,L} + T_6\ H_3/B$ $1 \times (-5,56) + (-20,11)$	–25,67
$P_{4,L}$	$P_{5,L} + tc_4\ V_4$	–25,67
$P_{3,L}$	$P_{4,L} + tc_3\ V_3 + F_{Z,3,L} + T_4\ H_2/B$ $-25,67 + (-26,81) + (25,52 \times 2,438)/2,438$	–26,96
$P_{2,L}$	$P_{3,L} + tc_2\ V_2$	–26,96
$P_{1,L}$	$P_{2,L} + tc_2\ V_2 + F_{Z,1,L} + T_2\ H_1/B$ $-26,96 + (-26,81) + (59,72 \times 2,438)/2,438$	5,95

Table 11 : Vertical forces on right side (kN)

$P_{6,R}$	$(1 - tc_6)\ V_6$	0
$P_{5,R}$	$P_{6,R} + (1 - tc_5)\ V_5 + F_{Z,5,R} - T_6\ H_3/B$ $(1 - 1) \times (-5,56) + (-44,75)$	–44,75
$P_{4,R}$	$P_{5,R} + (1 - tc_4)\ V_4$	–44,75
$P_{3,R}$	$P_{4,R} + (1 - tc_3)\ V_3 + F_{Z,3,R} - T_4\ H_2/B$ $-44,75 + 1\ (-2,29) + (-59,67) - (25,52 \times 2,438)/2,438$	–132,23
$P_{2,R}$	$P_{3,R} + (1 - tc_2)\ V_2$	–132,23
$P_{1,R}$	$P_{2,R} + (1 - tc_2)\ V_2 + F_{Z,1,R} - T_2\ H_1/B$ $-132,23 + (-59,67) - (59,72 \times 2,438)/2,438$	–251,62