1. Preamble

Containers are designed to carry their full payload, including a vertical dynamic acceleration of 0.8 g, uniformly distributed over the entire floor area. It should however be kept in mind that this is not the only strength requirement that influence the design of containers. According to the ISO standard containers are also designed to withstand the following test criteria:

- Side wall test
- Top lift test
- Rigidity tests
- Wheel load test

The rules of thumb for calculating required distribution of concentrated loads presently in use are based solely on the uniformly distributed payload criteria. Although correct from that perspective, they provide solutions which are clearly not practical and that are not in line with what can be regarded as sufficient based on experience. If other test criteria for strength are also taken under consideration, it is shown that dry containers have a capacity to facilitated cargo weights close to or equal to the payload even if the weight is not uniformly distributed of the entire floor area.

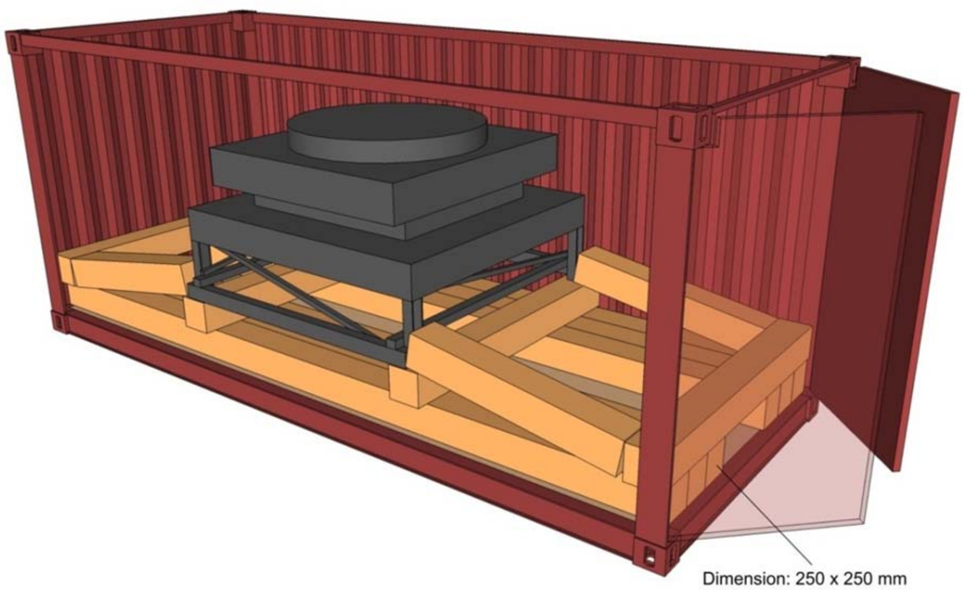


Figure 1. Example of unreasonable arrangement for load distribution based on currently applied rules-of-thumb.

The currently used rules-of-thumb mainly considers distribution of loads in the longitudinal direction, while it in dry containers would be more efficient to distribute the loads in the transverse direction, thereby taking advantage of the strength of the side wall construction.

In this paper, the bending moment capacity of typical container sides designed according to the standard has been investigated. Furthermore, the strength of typical transverse beams in the container floors has also been investigated and a comparison between the strength required to facilitate a uniformly distributed payload and the wheel load produced by a forklift have been made. Typical container designs have been analysed both globally and locally with calculations.

2. Global longitudinal strength

Each side of a container can be considered to be a beam with a thin web consisting of the corrugated side wall and top and bottom flanges consisting of profiles designed to stiffen the construction.

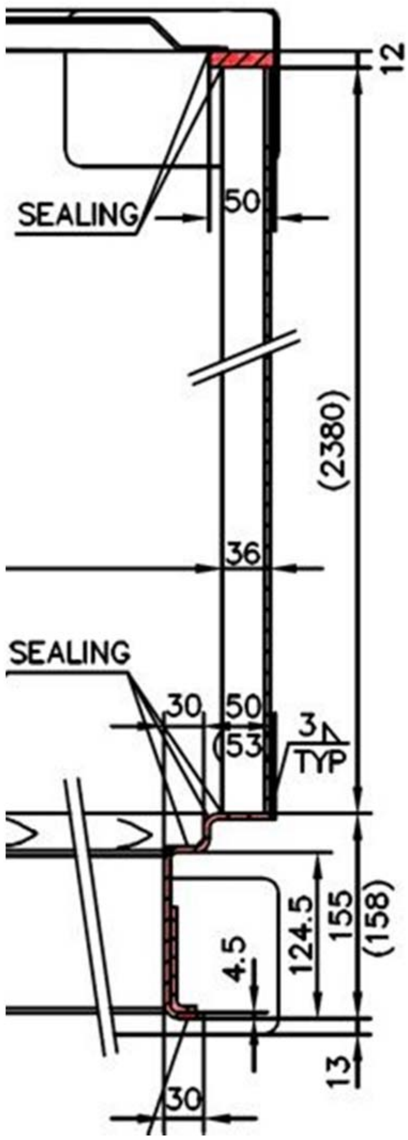


Figure 2a. Typical side structure of an older 20 foot container.

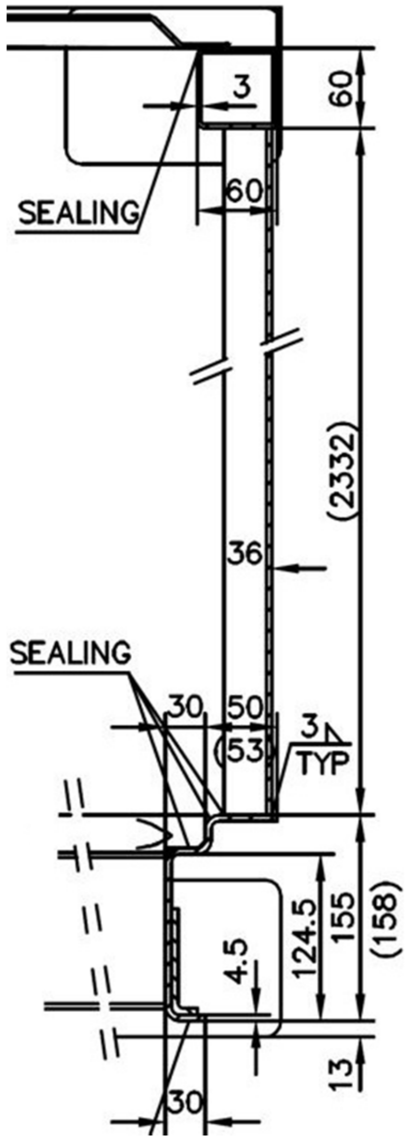


Figure 2b. Typical side structure of a modern 40 foot container.

The 20 foot container above is stiffened by a solid bar of 50 × 12 mm in the top. Modern containers are typically stiffened by 60x60x3 mm square profile. Both container types are equipped with a bent profile at the bottom, designed both to stiffen the container and to provide support for the flooring. Examples of typical side structures of 20 and 40 foot containers are found in figure 2a and 2b above.

The maximum bending stress in a beam is given by:

$$M_{allowed} = \sigma_{allowed} \cdot \frac{I}{|z_{max}|}$$

Where:

$M_{allowed}$	=	*Allowed bending moment*
$\sigma_{allowed}$	=	*Allowed stress in the material due to bending*
I	=	*Moment of inertia*
z_{max}	=	*Largest distance from the centre of gravity*

Since the test criteria specifies that after the test the container shall show no permanent deflection, the allowed stress is given by the yield stress of the material in the critical component. Both 20 and 40 foot containers are typically made of higher grad steel with a yield strength of 350 N/mm^2 and an elastic limit of 345 N/mm^2. The solid bar in the older 20 foot container is however made of normal steel grade with a yield strength of 250 N/mm^2.

The moment of inertia can be conservatively estimated by the following formula:

$$I = A_1 \cdot (h - h_{CG})^2 + A_2 \cdot \mathrm{h}_{CG}^2 + \frac{h_{wall}^3 \cdot t_{wall}}{12} + h_{wall} \cdot t_{wall} \cdot \left(\frac{h_{wall}}{2} - h_{CG}\right)^2$$

Where:

A_1	=	*Area of top flange*
A_2	=	*Area of bottom flange*
h	=	*Distance between top and bottom flange (Between CGs)*
h_{CG}	=	*Distance between bottom flange and Centre of Gravity*
h_{wall}	=	*Height of side wall*
t_{wall}	=	*Thickness of side wall*

Due to the thickness of only 1.6 mm, the material in the corrugated side wall plate, has been omitted from calculation of the moment of inertia below.

The moment of inertia as well as the maximum allowed bending moment for the two side beams of typical 20 and 40 foot containers are calculated in the table below:

Parameter / Dimension	**20' container**	**40' container**
A_1	600 mm^2	684 mm^2
A_2	1582 mm^2	1582 mm^2
h	2466 mm	2442 mm
h_{CG}	1054 mm	1054 mm
h_{wall}	2380 mm	2332 mm
t_{wall}	0 mm	0 mm
I	**2.95 · 10^9 mm^4**	**3.08 · 10^9 mm^4**
z_{max}	1418 mm	1442 mm
$\sigma_{allowed}$	250 N/mm^2	345 N/mm^2
$M_{allowed}$ (for 2 sides)	**1.03 · 10^9 Nmm = 105 tonm**	**1.47 · 10^9 Nmm = 150 tonm**

2.1. Maximum point load

For a simply supported beam, representing the container resting on its corner fittings, subjected to a point load W the maximum inner bending moment can be calculated by the following formula:

$$M_{max} = \frac{f_{dyn} \cdot l}{8} \cdot (T + 2 \cdot W)$$

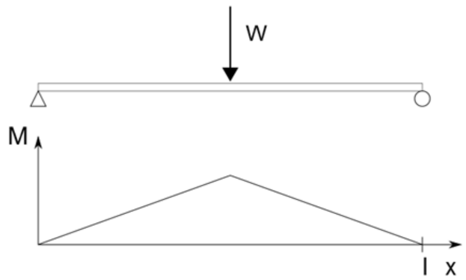
Where:

f_{dyn} = *Factor for taking account of dynamic variations in the vertical load,* $f_{dyn} = 1.8$

T = *Tare weight of container*

W = *Point load*

l = *Length of container*



$$M_{max} = \frac{f_{dyn} \cdot l}{8} \cdot (T + 2 \cdot W)$$

Figure 3. The inner bending moment for a simply supported beam subjected to a point load.

Based on this formula and the allowed bending moments calculated above, the maximum point loads in the centre of typical containers have been calculated for both 20 and 40 foot containers, see table below.

Parameter / Dimension	**20' container**	**40' container**
Tare weight, T	2.25 ton	3.75 ton
Length of container, l	6.0 m	12.0 m
$M_{allowed}$	105 tonm	150 tonm
Maximum point load	**37 ton**	**27 ton**

2.2. Conclusions and recommendations regarding global strength

Due to similar design, the global bending strength of 20 and 40 foot containers are similar. This indicates that other strength criteria than the uniformly distributed payload governs the design of dry container side walls.

Furthermore, it has been shown that short cargoes does not generating critical bending moments neither in 20 nor 40 foot containers.

3. Local longitudinal strength

3.1. Strength of the weld between the bottom beams and the container side plate

The container sides are typically welded to the base structure with a weld thickness of a = 3 mm.

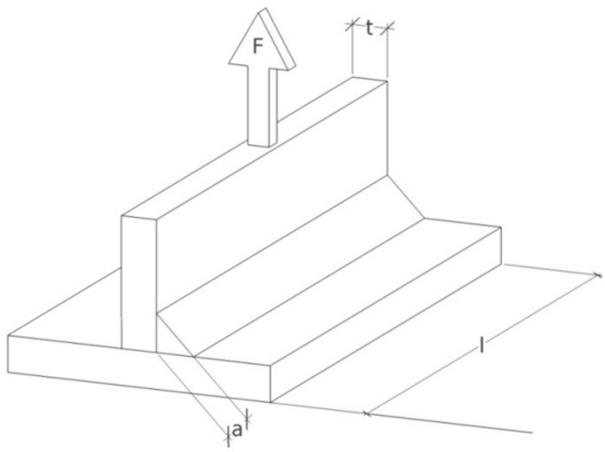


Figure 4. A fillet weld loaded in tension by a force F.

The maximum allowed force F_{max} for a fillet weld is given by:

$$F_{max} = \frac{A}{c} \cdot f_{yd}$$

where A is the effective area of the weld, c is the seam factor and f_{yd} is the maximum allowed stress. The following values have been used:

c = 1.2 which is for a fillet weld in tension and with a seam class A: weld of ordinary class
f_{yd} = 176 N/mm² which is for S235 steel with normal safety class.

The effective area A is the product of weld thickness multiplied by the length of the weld l.

$$A = \sum a \cdot l$$

This gives a maximum load F per weld length of

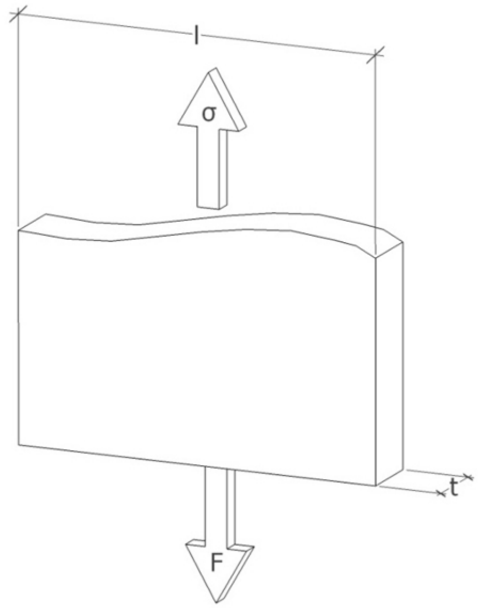
$$\frac{F}{l} = \frac{a}{c} \cdot f_{yd} = \frac{3}{1.2} \cdot 176 \text{ N/mm} = 440\text{N/mm} = 44 \text{ ton/m}$$

The allowable cargo weight q per meter is calculated by considering both sides of the container and taking into account the dynamic variation of forces in the vertical direction:

$$q_{weld} = \frac{F}{l} \cdot \frac{2}{1.8} = 48\ ton/m$$

3.2. Strength of the side walls

The container sides are typically corrugated plate with a minimum thickness of t = 1.6 mm. The stress in a plate loaded in tension is the force F divided by the cross section area.



$$\sigma = \frac{F}{l \cdot t}$$

Figure 5. Plate loaded in tension.

For a maximum allowed stress of $\sigma_{max} = 345 \text{ N/mm}^2$ this gives a maximum load per unit length of

$$\frac{F}{l} = \sigma_{max} \cdot t = 345 \cdot 1.6 \text{ N/mm} = 552 \text{ N/mm} = 56.2 \text{ ton/m}$$

The allowable cargo weight per meter q is calculated by considering both sides of the container and taking into account the dynamic variation of forces in the vertical direction:

$$q_{weld} = \frac{F}{l} \cdot \frac{2}{1.8} = 613\ N/mm = 62.5\ ton/m$$

From this it is possible to conclude that it is the weld rather than the side plate that limits the maximum point load at the container side.

The minimum length of concentrated loads due to local strength can thus be calculated as:

$$r = \frac{P}{48}$$

Where:

r	=	*Minimum length of distributed load*
P	=	*Weight of cargo*

3.3. Required width of transverse beams

If beams, laid on top of the flooring and the side profiles, are used to distribute the load to the container sides, there will be local stresses in the side walls. It is reasonable to assume that also some part of the side wall forward and aft of the contact surface will contribute to carry the load. A conservative assumption is that the load distribution in the side plate will be as shown in figure 6, where **a** is the contact surface from a transversal wooden beam (width of beam).

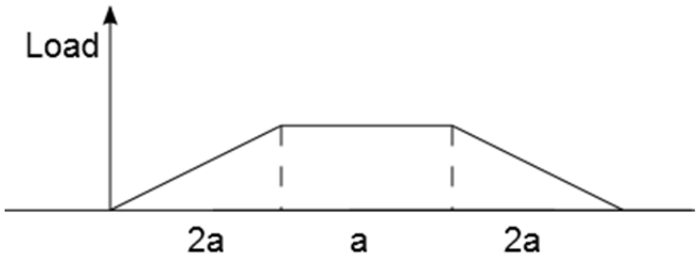


Figure 6. Load distribution in the container side.

The maximum cargo weight that can be carried by transverse beams laid on top of the flooring and side profiles of the container may then be calculated be the following formula:

$$P_{max} = 3 \cdot q \cdot n \cdot a = 3 \cdot 48 \cdot n \cdot a = 144 \cdot n \cdot a$$

Where:

q	=	*Maximum load per meter, q = 48 ton/m*
n	=	*Number of beams*
a	=	*Width of beams in meter*

The formula above is valid provided that the longitudinal distances between the beams are at least 2 times their width.

4. Bending strength of transverse flooring structure

The container floor is typically made by plywood which is supported by transverse beams made of steel, and it can be seen as a stiffened plate. However, as a conservative approach, the strength of the plywood boards has been disregarded in this analysis. The transverse beams are typically spaced some 280 mm apart in the longitudinal direction.

There are two strength criteria that the flooring must be able to withstand:

- The payload of the container homogeneously distributed over the entire floor area, taking into account the dynamic load variations in the vertical direction during sea transport (i.e. test loading with 2 times the cargo weight).

- Manoeuvring test with a forklift where the wheels are separated by a distance of 760 mm and the load on each wheel is 2.73 ton. The print area of the wheels is to be no more than 100 x 180 mm.

(It should be noted that most containers appears to be tested by using a forklift with an axle load of 7.26 tons, see also Second Draft of the Packing Code, paragraph 7.1.2.5)

The design bending moment in the transverse direction per meter of the container floor due to a **homogeneous load** can be calculated by the following formula:

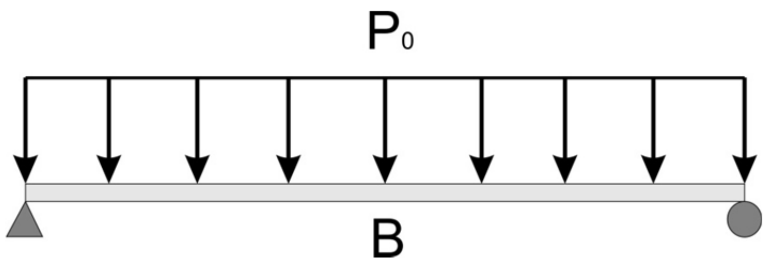


Figure 7. Homogeneously distributed load over the container floor.

$$m_{floor1} = \frac{f_{dyn} \cdot P_0 \cdot B}{8 \cdot L}$$

Where:

f_{dyn}	=	*Factor for taking account of dynamic variations in the vertical load,* $f_{dyn} = 2$
P_0	=	*Payload*
B	=	*Floor width*
L	=	*Floor length*

Based on this formula the design bending moment per meter length of the container has been calculated for both 20 and 40 foot containers in the table below:

Parameter / Dimension	**20' container**	**40' container**
Payload, P_0	28.0 ton	29.0 ton
Length of container, L	6.0 m	12.0 m
Width of container, B	2. m	2.3 m
Design bending moment, m_{floor1}	**2.7 tonm/m**	**1.4 tonm/m**

The design bending moment in the transverse direction per meter of the container floor **based on the forklift manoeuvring test** can be calculated by the following formula:

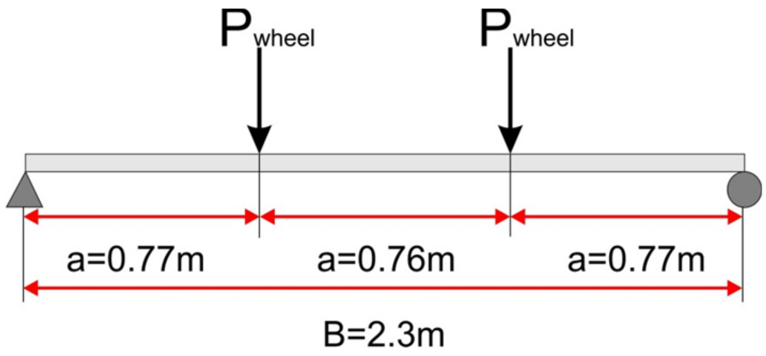


Figure 8. Two point loads from the wheels of the forklift.

$$m_{floor2} = \frac{P_{wheel} \cdot a}{l_{effective}}$$

Where:

P_{wheel} = *Load on each wheel,* P_{wheel} *= 2.73 ton*
$l_{effective}$ = *Effective length of container floor that take up the load from the fork lift wheels.*

This test criterion is identical for both 20 and 40 foot containers.

It is reasonable to assume that the plywood flooring is capable of distributing the load over not more than 3 individual floor beams, each loaded with 33% of the load from the cargo. With a distance between the floor beams of 0.28 m, the following design bending moment per meter of container length can be calculated:

$$m_{floor2} = \frac{2.73 \cdot 0.77}{3 \cdot 0.28} = 2.5\ tonm/m$$

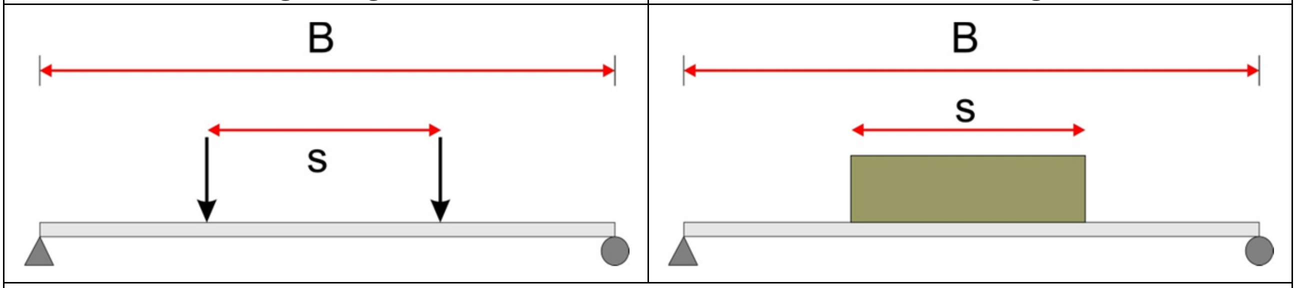
It should be noted that most containers are tested with an even heavier forklift (7.26 tons) and there is some uncertainty of how the load is spread over the adjacent beams in the container floor. It can be concluded that the fork lift test requires a strength in the container floor that is very close to that of the uniformly distributed load in a 20 foot container. Given the near identical construction of floorings for both 20 and 40 foot containers it can be assumed that the same dimensioning moment of **2.7 tonm/m** can be used in both cases.

5. Bedding Arrangements

Short or narrow cargoes may overload the floor structure. This may be prevented either by using longitudinal support beams underneath the cargo to distribute the load over more transverse flooring beams, or by the use of transverse beams, to distribute the load towards the strong side structures of the container.

Different models for estimating the stress in the wooden support beams and their required bending strength have been proposed. If the wooden beams are to carry the full load of the cargo by themselves, a both-ends-suspended beam resting only on its ends can be used, see below.

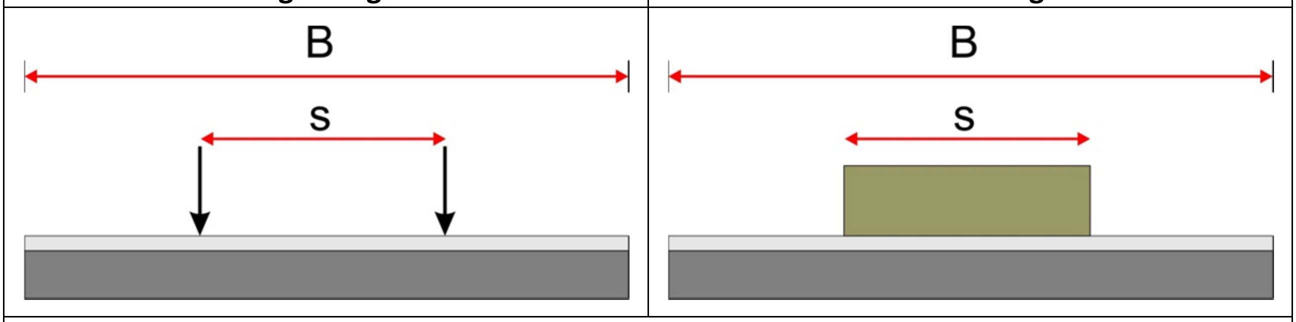
Rigid cargo	Flexible cargo



Loading of both-ends-suspended beams carrying the weight of the cargo without help from the floor.

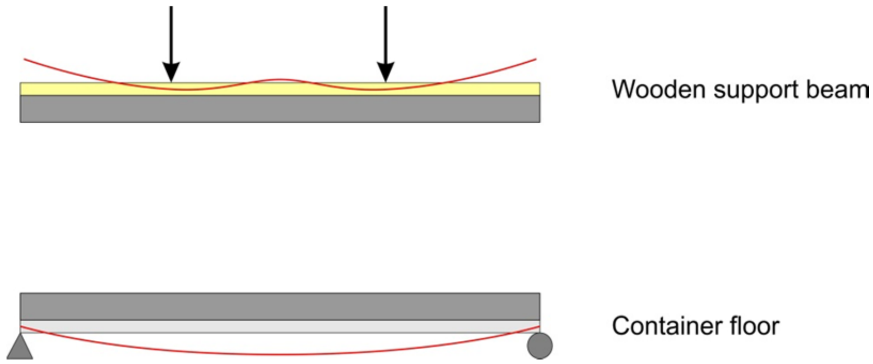
It is however not likely that the wooden beams are so stiff that they don't get contact with the floor beneath them and support at other points than the ends. Furthermore, the purpose of the beam is rather to supplement the strength of the floor and spread the load of the cargo over a wider are. Optimally, the wooden beams would spread the footprint of the cargo evenly over the entire floor area underneath it, as illustrated in the figure below.

Rigid cargo	Flexible cargo



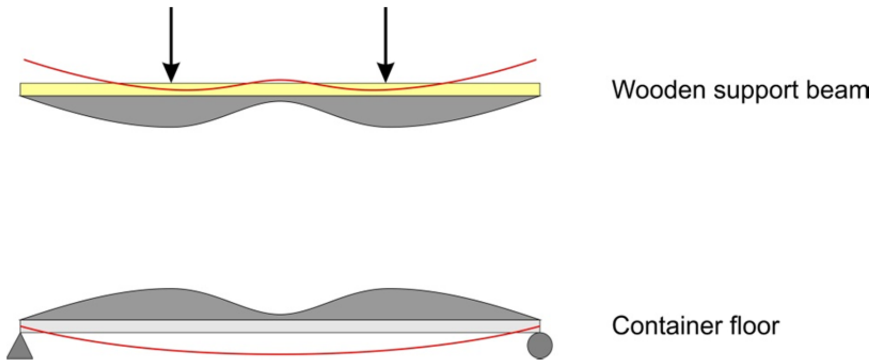
Loading of beams which distribute the cargo weight evenly over their entire length.

The model above is suitable for flexible cargo, but due to the relative flexibility of wood compared to steel, the wooden beams have a limited capacity to spread the load over a great length when subjected to the point loads resulting from rigid cargo.



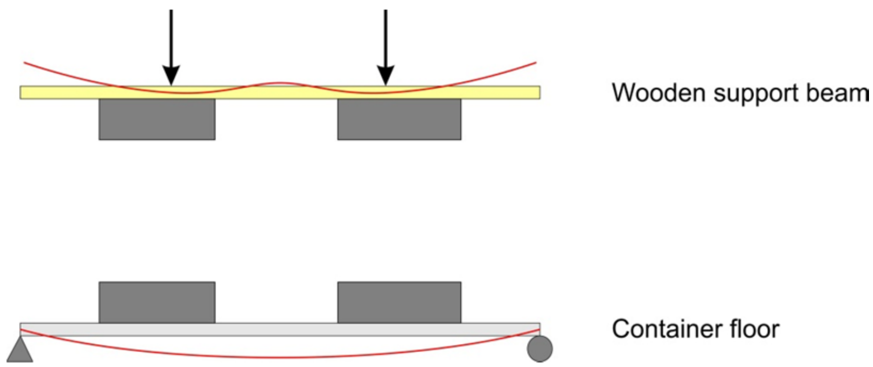
Deflection of beam with rigid cargo, supported by uniformly distributed load from underneath.

The red line in the illustration above shows the deflection of the beam. As can be seen for the rigid cargo case, the beam would deflect upwards at the centre if subjected to a uniformly distributed load from below, at least for wide rigid cargoes. This means that there would be little pressure between the wooden beam and the floor at the centre and at the ends. Thus, a more realistic model for rigid cargoes is given below:



Deflection of beam with rigid cargo, supported by variably distributed load based on the contact pressure between the wooden beam and the container floor. The contact pressure is based on the deflection of the wooden beam and the container floor.

The above realistic model takes care of the fact that wooden beams deflect more than the steel beams of a container floor. However, as this model is too complex to base any regulations on, it is suggested to use a simplified model where the contact force is uniformly distributed but concentrated around the support points of the cargo:



Simplified model with the load concentrated around the support points of the cargo.

5.1. Required length of longitudinal support beams for narrow cargoes

Cargoes with smaller width than the inner width of the container may be supported from underneath by longitudinal beams in order not to overload the transverse floor beams. By this, the weight of the cargo is distributed to a greater number of floor beams.

Then this method is used, the beams should be placed at the sides of the cargo, thereby loading the transvers beams as close as possible to the side of the container.

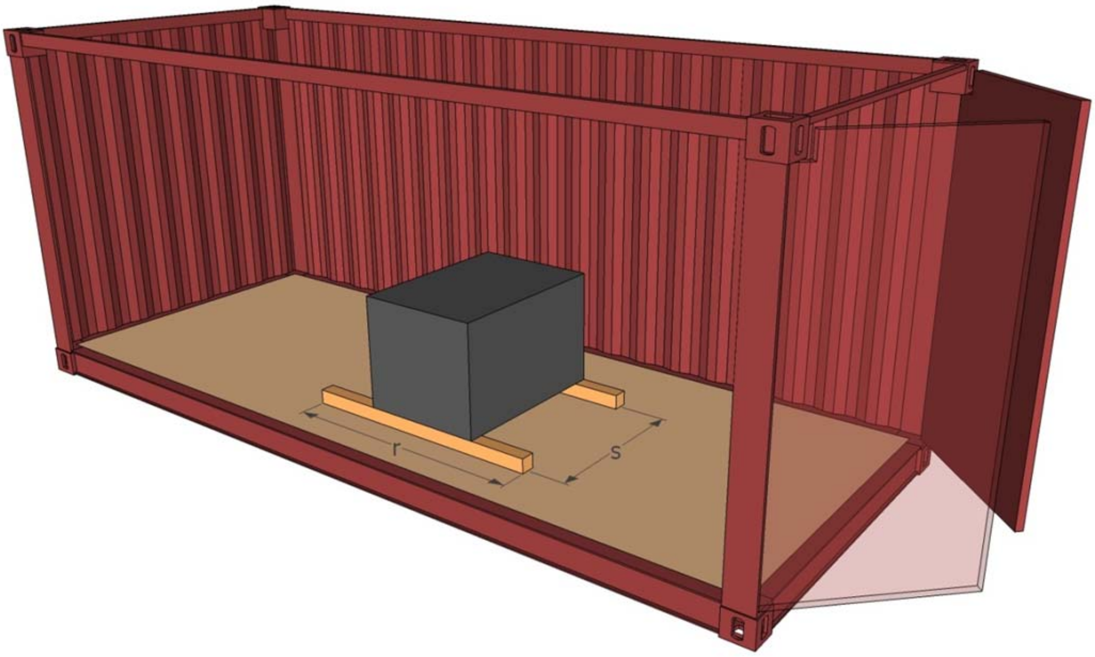


Figure 10. Narrow cargo placed on longitudinal support beams.

If the cargo is resting on 2 beams placed underneath the outermost parts of the cargo, the transverse beams in the container floor are subjected to 2 point loads and the resulting bending moment in the floor structure in the transverse direction can be calculated by the following formula:

$$M = \frac{f_{dyn} \cdot P}{4} \cdot (B - s)$$

Where:

f_{dyn}	=	*Factor for taking account of dynamic variations in the vertical load,* f_{dyn} *=1.8*
P	=	*Cargo weight*
B	=	*Floor width*
s	=	*Distance between longitudinal support beams*

This bending moment should be less or equal to the design bending moment of the floor structure:

$$M = \frac{f_{dyn} \cdot P}{4} \cdot (B - s) = m_{floor} \cdot r$$

Where:

m_{floor} = *2.7 tonm/m*

r = *Length of longitudinal support beams [m]*

The required length of longitudinal support beams can thus be calculated as (with the weight in ton and the lengths in meters):

$$r = \frac{f_{dyn} \cdot P}{4 \cdot m_{floor}} \cdot (B - s) = \frac{1.8 \cdot P}{4 \cdot 2.7} \cdot (B - s) = 0.17 \cdot P \cdot (B - s)$$

By proposal of Hermann Kaps the required section modulus of the support beams (calculated as a both-end-suspended beam) is given by:

$$W = \frac{123 \cdot P \cdot (r_{beams} - r_{cargo})}{\sigma \cdot n}$$

Where:

W = *Section modulus of beams [cm^3]*

r_{cargo} = *Length of cargo [m]*

n = *Number of support beams*

σ = *Permissible bending stress in beam [kN/cm^2]*

Alternatively the required section modulus for the support beams (if considered to be uniformly supported from underneath over the entire length) could be calculated by:

$$W = \frac{9.81 \cdot 1000 \cdot f_{dyn} \cdot P}{8 \cdot r_{beams} \cdot \sigma_{allowed} \cdot n} \left(r_{beams} - r_{cargo}\right)^2 = 221 \cdot \frac{P}{\sigma_{allowed} \cdot n} \cdot \frac{\left(r_{beams} - r_{cargo}\right)^2}{r_{beams}}$$

Where:

W = *Section modulus of support beams [cm^3]*

n = *Number of support beams*

P = *Cargo weight, [ton]*

f_{dyn} = *Factor for taking account of dynamic variations in the vertical load,* $f_{dyn} = 1.8$

r_{beams} = *Length of support beams, [m]*

r_{cargo} = *Length of cargo, [m]*

$\sigma_{allowed}$ = *Allowed stress in in support beams, [kN/cm^2]*

For wood: $\sigma_{allowed} = 2.4$ *kN/cm^2*

For steel: $\sigma_{allowed} = 18$ *kN/cm^2*

Example

Two coils are to be loaded on longitudinal wooden support beams in a 20-foot container. The coils are 1.3m wide, has got a diameter of 1.3m and weigh 10 tons each. Assume that the coils rest on wedges separated by a distance of 0.9m in the longitudinal direction.

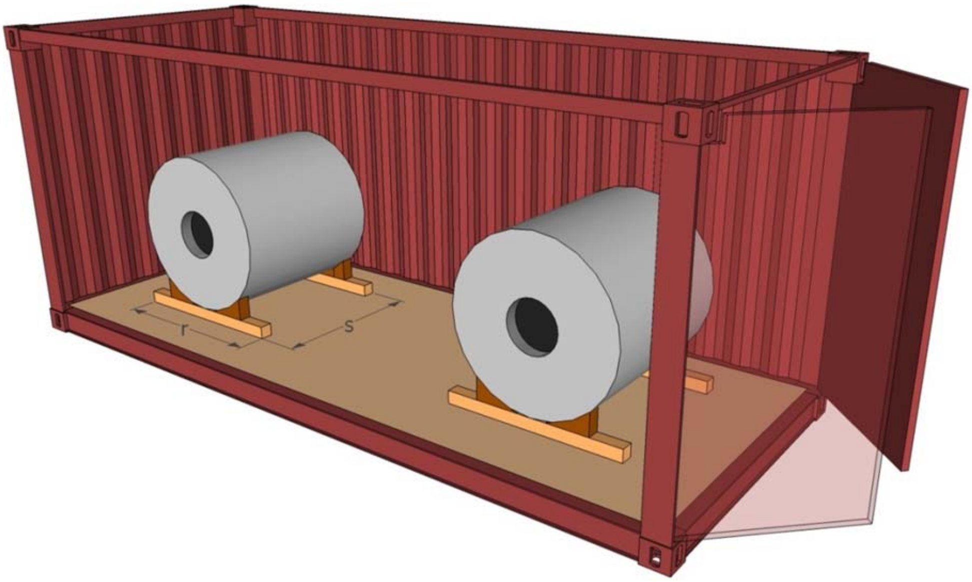


Figure 11. Coils loaded on longitudinal support beams.

The minimum length of the beams is given by

$$r_{beam} = 0.17 \cdot P \cdot (B - s) = 0.17 \cdot 10 \cdot (2.3 - 1.3) = 1.7\ m$$

The required section modulus of these beams becomes

$$W = \frac{123 \cdot P \cdot (r_{beams} - r_{cargo})}{\sigma \cdot n} = \frac{123 \cdot 10 \cdot (1.7 - 0.9)}{2 \cdot 2.4} = 205\ cm^3$$

Alternatively, the section modulus becomes:

$$W = 221 \cdot \frac{P}{\sigma_{allowed} \cdot n} \cdot \frac{(r_{beams} - r_{cargo})^2}{r_{beams}} = 221 \cdot \frac{10}{2 \cdot 2.4} \cdot \frac{(1.7 - 0.9)^2}{1.8} = 164\ cm^3$$

Beams with a dimensions of 4’’ × 5’’ (10 cm × 12.5 cm) have a section modulus of W = 208 cm^3).

5.2. Required bending strength of transverse support beams

If narrow cargoes are instead placed on transverse support beams with a length equal to the inner width of the container, both the beams and the flooring structure will help support the cargo.

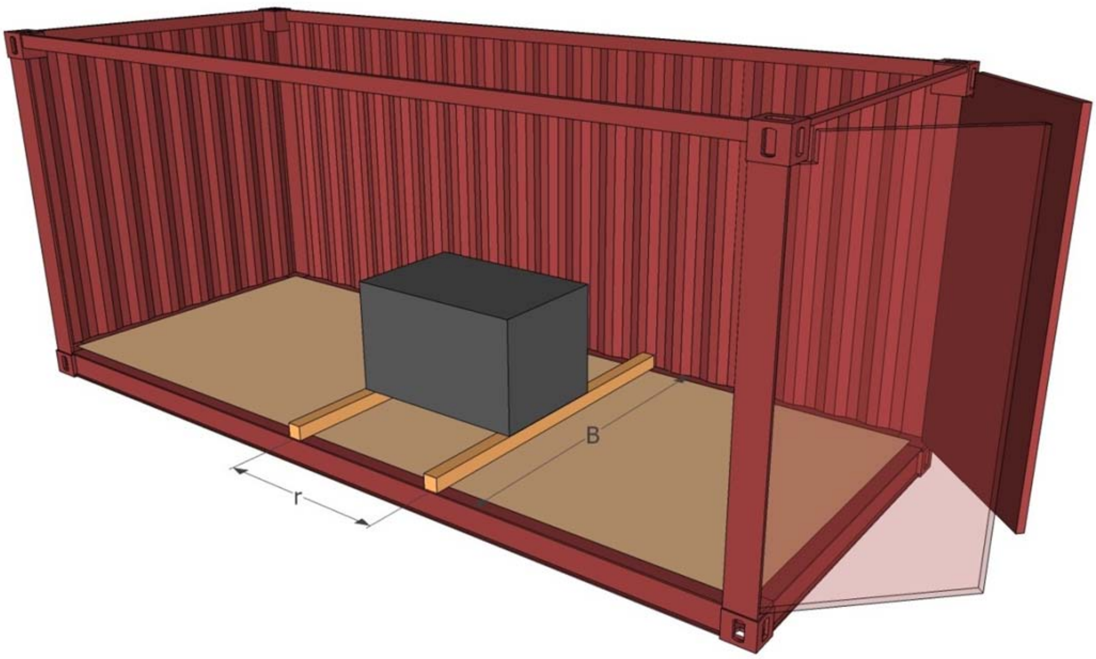
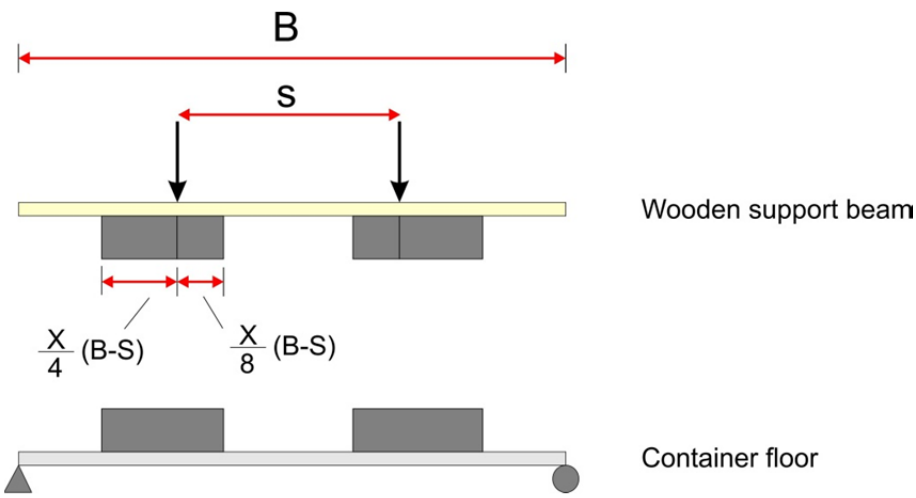


Figure 12. Narrow cargo placed on transverse support beams with a width equal to the inner width of the container.

Even though weight of the cargo might not be fully distributed to the whole length of the wooden beam, it is none the less recommended that they in all cases stretch over the entire width of the container.

Rigid cargoes

The bending moment in the wooden beams and the floor beams due to the load from a rigid cargo and the distributed load between the two elements are illustrated below.



The bending moment in the floor beam can be calculated according to the following formula:

$$M_c = \frac{q}{8} \cdot [a \cdot (2B - a) - b \cdot (2B - b)]$$

With:

$$a = s + \frac{x}{2} \cdot (B - s)$$

$$b = s - \frac{x}{4} \cdot (B - s)$$

$$q = \frac{f_{dyn} \cdot P}{\frac{3}{4} \cdot x \cdot (B - s)}$$

the moment can be calculated as:

$$M_c = \frac{f_{dyn} \cdot P \cdot (B - s)}{32} \cdot [8 - x]$$

The moment in the floor beam should as a maximum equal the allowable moment derived in Chapter 4. In parallel with the forklift test criteria this effective length can be estimated by assuming that each transverse wooden beam distributes the load over three floor beams, which are spaced 0.28 m apart.

$$M_c = \frac{f_{dyn} \cdot P \cdot (B - s)}{32} \cdot [8 - x] = m_{floor} \cdot l_{effective}$$

Where:

- n = *Number of transverse support beams*
- f_{dyn} = *Factor for taking account of dynamic variations in the vertical load,* f_{dyn} *=1.8*
- P = *Cargo weight [m]*
- B = *Floor width [m]*
- s = *Width of cargo [m]*
- m_{floor} = *Strength of the container floor, 2.7 tonm/m*
- $l_{effective}$ = *Contributing length of container floor [m], taken as minimum of*
  - *Beams spaced **more** than 0.84 m apart:* $l_{effective} = 3 \cdot n \cdot 0.28$
  - *Beams spaced **less** than 0.84 m apart:* $l_{effective} = r + 0.56$
- r = *Length of cargo [m]*

$l_{effective}$ is the length of container floor that the wooden beams are able to distribute the load from the cargo to. In parallel with the forklift test criteria this effective length can be estimated by assuming that each transverse wooden beam distributes the load over three floor beams, which are spaced 0.28 m apart. Alternatively, if the wooden beams are spaced closer than 3 x 0.28 =0.84 meters apart, the effective length should be taken as the length of the cargo plus 2 x 0.28 = 0.56 m.

The factor **x**, which indicates how wide the wooden beams have to be able to distribute the load, can be calculated as:

$$x = 8 - \frac{m_{floor} \cdot l_{effective} \cdot 32}{f_{dyn} \cdot P \cdot (B - s)}$$

The bending moment in the centre of the wooden beam can be calculated as:

$$M_b = \frac{f_{dyn} \cdot P}{2} \cdot \left[\frac{b}{2} + \frac{a-b}{4} - \frac{s}{2}\right] = \frac{f_{dyn} \cdot P \cdot x \cdot (B-s)}{32}$$

Thus, the required section modulus of the wooden support beams for a rigid cargo can be calculated as:

$$W = \frac{f_{dyn} \cdot P \cdot x \cdot (B-s)}{32 \cdot n \cdot \sigma_{allowed}} = \frac{f_{dyn} \cdot P \cdot (B-s) - 4 \cdot m_{floor} \cdot l_{effective}}{4 \cdot n \cdot \sigma_{allowed}}$$

With lengths in meters and weights in ton and with the material strength to be inserted in kN/cm^2, the bending strength becomes:

$$W = \frac{245 \cdot f_{dyn} \cdot P \cdot (2.3 - s) - 2650 \cdot l_{effective}}{n \cdot \sigma_{allowed}}$$

Where:

W = *Bending strength [cm^3]*
n = *Number of support beams*
P = *Cargo weight, [ton]*
s = *Cargo width, [m]*
$\sigma_{allowed}$ = *Allowed stress in the material due to bending, [kN/cm^2]*
For wood: $\sigma_{allowed} = 2.4\ kN/cm^2$
For steel: $\sigma_{allowed} = 18\ kN/cm^2$

Furthermore, in order to satisfy the local strength of the side walls, see chapter 3.3, the minimum width of the transverse beams should be calculated from the following formula:

$$a = \frac{P}{3 \cdot q \cdot n} = \frac{P}{3 \cdot 63.4 \cdot n} = \frac{P}{190 \cdot n}$$

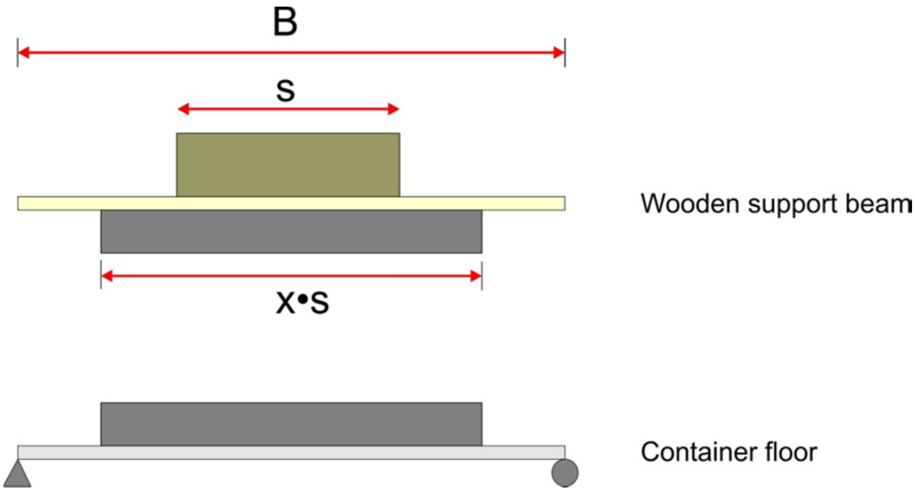
Where:

a = *Width of beams, [m]*
P = *Cargo weight, [ton]*
q = *Maximum load per meter, q = 63.4 ton/m*
n = *Number of beams*

The gap between the beams should be at least 2 times their width.

Flexible cargoes

The bending moment in the wooden beams and the floor beams due to the load from a flexible cargo and the distributed load between the two elements are illustrated below.



The bending moment in the floor beam can be calculated according to the following formula:

$$M_c = \frac{f_{dyn} \cdot P}{8} \cdot (2B - xs)$$

The moment in the floor beam should as a maximum equal the allowable moment derived in Chapter 4. In parallel with the forklift test criteria this effective length can be estimated by assuming that each transverse wooden beam distributes the load over three floor beams, which are spaced 0.28 m apart.

$$M_c = \frac{f_{dyn} \cdot P}{8} \cdot (2B - xs) = m_{floor} \cdot l_{effective}$$

Where:

n = Number of transverse support beams
f_{dyn} = Factor for taking account of dynamic variations in the vertical load, f_{dyn} =1.8
P = Cargo weight [m]
B = Floor width [m]
s = Width of cargo [m]
m_{floor} = Strength of the container floor, 2.7 tonm/m
$l_{effective}$ = Contributing length of container floor [m], taken as minimum of
*Beams spaced **more** than 0.84 m apart:* $l_{effective} = 3 \cdot n \cdot 0.28$
*Beams spaced **less** than 0.84 m apart:* $l_{effective} = r + 0.56$
r = Length of cargo [m]

$l_{effective}$ is the length of container floor that the wooden beams are able to distribute the load from the cargo to. In parallel with the forklift test criteria this effective length can be estimated by assuming that each transverse wooden beam distributes the load over three floor beams, which are spaced 0.28 m apart. Alternatively, if the wooden beams are spaced closer than 3 x 0.28

=0.84 meters apart, the effective length should be taken as the length of the cargo plus 2 x 0.28 = 0.56 m.

The factor x, which indicates how wide the wooden beams have to be able to distribute the load, can be calculated as:

$$x = \frac{1}{s} \cdot \left[2B - \frac{m_{floor} \cdot l_{effective} \cdot 8}{f_{dyn} \cdot P} \right]$$

The bending moment in the centre of the wooden beam can be calculated as:

$$M_c = \frac{f_{dyn} \cdot P}{2} \cdot \left(\frac{x \cdot s}{4} - \frac{s}{4} \right) = \frac{f_{dyn} \cdot P \cdot s}{8} \cdot (x - 1)$$

The required section modulus of the wooden support beams for a rigid cargo can be calculated as:

$$W = \frac{f_{dyn} \cdot P \cdot s}{8 \cdot n \cdot \sigma_{allowed}} \cdot (x - 1) = \frac{f_{dyn} \cdot P \cdot (2 \cdot B - s) - 8 \cdot m_{floor} \cdot l_{effective}}{8 \cdot n \cdot \sigma_{allowed}}$$

With lengths in meters and weights in ton and with the material strength to be inserted in kN/cm^2, the bending strength becomes:

$$W = \frac{120 \cdot f_{dyn} \cdot P \cdot (4.6 - s) - 2650 \cdot l_{effective}}{n \cdot \sigma_{allowed}}$$

Where:

W = *Bending strength [cm^3]*
n = *Number of support beams*
P = *Cargo weight, [ton]*
s = *Cargo width, [m]*
$\sigma_{allowed}$ = *Allowed stress in the material due to bending, [kN/cm^2]*
For wood: $\sigma_{allowed}$ *=2.4 kN/cm^2*
For steel: $\sigma_{allowed}$ *=18 kN/cm^2*

Furthermore, in order to satisfy the local strength of the side walls, see chapter 3.3, the minimum width of the transverse beams should be calculated from the following formula:

$$a = \frac{P}{3 \cdot q \cdot n} = \frac{P}{3 \cdot 63.4 \cdot n} = \frac{P}{190 \cdot n}$$

Where:

a = *Width of beams, [m]*
P = *Cargo weight, [ton]*
q = *Maximum load per meter, q = 63.4 ton/m*
n = *Number of beams*

The gap between the beams should be at least 2 times their width.

Example

Steel rods are to be loaded on transverse wooden beams in a 20-foot container. The payload is, P = 20 ton and the width of the cargo, s = 2 m. The steel rods are resting on 5 beams.

Figure 14. Steel rods loaded on transverse support beams.

The effective length of the 5 beams becomes:

$$\mathrm{l}_{\mathrm{effective}} = 3 \cdot n \cdot 0.28 = 3 \cdot 5 \cdot 0.28 = 4.2\ m$$

The required section modulus for the support beams becomes,

$$W = \frac{120 \cdot f_{dyn} \cdot P \cdot (4.6 - s) - 2450 \cdot l_{effective}}{n \cdot \sigma_{allowed}} = \frac{120 \cdot 1.8 \cdot 20 \cdot (4.6 - 2) - 2450 \cdot 4.2}{5 \cdot 2.4} = 79\ cm^3$$

which correspond to beams with a dimensions of 3’’×4’’ (7.5 cm × 10 cm, W = 94 cm^3)

6. Conclusions

It has been found that the sides of a container can take up much larger bending moments than what is created by the payload if it is uniformly distributed and thus the technique to distribute concentrated loads in a dry container, designed according to the standard, should be to transfer the load to the sides rather than spreading it out in longitudinal direction.

When nominating the minimum length of concentrated cargoes, the global strength, i.e. bending of the whole container resting on its corner fittings, need not be considered for all practical applications. Only the local strength, i.e. tension in the side walls, should be considered.

Concentrated cargo weights with lesser width than the container should be supported either by longitudinal support beams, thereby transferring the load to a greater part of the flooring structure, or by transverse support beams which transfers the loads to the side structure of the container. The latter is to be regarded as the preferred method.

Regarding the capability of the flooring to distribute forces in the transverse direction, it has been found that the real strength required by the wheel load test is larger than what the uniformly distributed payload requires for typical containers, especially for 40 foot containers. Due to nearly identical design, the same ability to resist bending can be assumed for both 20 and 40 foot containers when designing the required support under the load to distribute it to the container sides.

7. Recommendations

7.1. Minimum length of longitudinal support beams for narrow cargoes

The required length of longitudinal support beams for narrow cargoes can thus be calculated as:

$$r = 0.17 \cdot P \cdot (B - s)$$

Where:

r_{beams} = *Length of support beams [m]*
P = *Cargo weight [ton]*
B = *Floor width [m]*
s = *Distance between longitudinal support beams [m]*

By proposal of Hermann Kaps the required section modulus of the support beams is given by

$$W = \frac{123 \cdot P \cdot (r_{beams} - r_{cargo})}{\sigma \cdot n}$$

Where:

W = *Section modulus of beams [cm^3]*
r_{cargo} = *Length of cargo [m]*
n = *Number of support beams*
σ = *Permissible bending stress in beam [kN/cm^2]*

Alternatively the required section modulus for the support beams could be calculated by

$$W = 221 \cdot \frac{P}{\sigma_{allowed} \cdot n} \cdot \frac{(r_{beams} - r_{cargo})^2}{r_{beams}}$$

Where:

W = *Section modulus of support beams [cm^3]*
n = *Number of support beams*
P = *Cargo weight, [ton]*
f_{dyn} = *Factor for taking account of dynamic variations in the vertical load,* $f_{dyn} = 1.8$
r_{beams} = *Length of support beams, [m]*
r_{cargo} = *Length of cargo, [m]*
$\sigma_{allowed}$ = *Allowed stress in in support beams, [kN/cm^2]*
For wood: $\sigma_{allowed} = 2.4$ *kN/cm^2*
For steel: $\sigma_{allowed} = 18$ *kN/cm^2*

7.2. Required bending strength of transverse support beams

It is suggested that the required section modulus for **load bearing** transverse support beam is calculated by the following formulae:

Rigid cargo: $$W = \frac{330 \cdot f_{dyn} \cdot P \cdot (2.3 - s) - 2650 \cdot l_{effective}}{n \cdot \sigma_{allowed}}$$

Flexible cargo: $$W = \frac{120 \cdot f_{dyn} \cdot P \cdot (4.6 - s) - 2650 \cdot l_{effective}}{n \cdot \sigma_{allowed}}$$

Where:

W = *Section modulus of support beams [cm^3]*
n = *Number of support beams*
P = *Cargo weight, [ton]*
s = *Cargo width, [m]*
$\sigma_{allowed}$ = *Allowed stress in in support beams, [kN/cm^2]*
For wood: $\sigma_{allowed}$ *=2.4 kN/cm^2*
For steel: $\sigma_{allowed}$ *=18 kN/cm^2*
$l_{effective}$ = *Contributing length of container floor [m], taken as minimum of*
*Beams spaced **more** than 0.84 m apart:* $l_{effective} = 3 \cdot n \cdot 0.28$
*Beams spaced **less** than 0.84 m apart:* $l_{effective} = r + 0.56$

In order to satisfy the local strength of the side walls, the minimum width of the transverse beams should be calculated from the following formula:

$$a = \frac{P}{144 \cdot n}$$

Where:

P = *Cargo weight [ton]*
n = *number of beams*
a = *width of beams [m]*

The gap between the beams should be at least 2 times their width.