REVISS

REVISS Services
Quality and Regulatory Group

Technical Memorandum

Strength of Tie-down System for R7021 Transport Container on the R8055 ISO Flatrack

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1. Purpose and Scope

This document calculates the stresses in the R7021 transport container and its tie-down system when it is transported on an R8055 ISO flatrack using the REVISS clamp plates, under the combined worst-case IAEA and US accelerations, and compares them against the design criteria.

Due to their similar construction, the results also apply to the R8053 & R8091 flatrack designs.

2. Assessment

2.1 Criteria

- The design strength (yield) shall not be exceeded under the simultaneous application of the worst case regulatory or modal acceleration factors.
- The ability of the transport container to comply with the Type B(U) requirements specified in TS-R-1 shall not be impaired should the tie-down system be overloaded to failure.

2.2 Assumptions

- Loads spread over more than one component are equally distributed.
- The contribution from friction between components clamped together is ignored.
- Loads in the pallet are taken by the central channels only.

2.3 Acceleration Data

Acceleration data is taken from Tables IV.1 & IV.2 of TS-G-1.1. The most demanding resultant from any regulatory or modal accelerations is the US requirement.

Mode	**Acceleration (g)**			
	Longitudinal	**Lateral**	**Vertical (down)***	**Resultant** $\sqrt{\Sigma a^2}$
Road	2	1	2	3.00
Rail	5	2	1	5.48
Sea	2	2	1	3.00
Air	1.5	1.5	5	5.43
US	10	5	1	11.2

* Allowing for gravity.

2.4 Load Path

When the R7021 (Fig 2) is transported on the R8055 ISO flatrack (Fig 1) it is tied down with two stainless steel clamp plate assemblies (Fig 5). The clamp plates pass through the fork lift channels in the pallet (Fig 4) and are bolted (Fig 7) directly to two full length, carbon steel rails (R8055/002) that are welded to the ISO chassis (Fig 9). Loads pass from the flask body through its feet (Fig 3) to the pallet via the studs (Fig 8) and dowels (Fig 6).

2.5 DESIGN STRENGTHS

Component	Material, Specification and Grade	Design Strength (N/mm^2)	
		Tension	Shear*1
Flask feet	Stainless Steel BS EN 10088-2 Grade 1.4307 (304L)	210*2	121
Flask studs/dowels	Carbon Steel BS 3692 Grade 8.8	640	369
Pallet	Carbon Steel BS EN 10025-2 Grade S355	400*3	231
Clamp assembly	Stainless Steel BS EN 10088-2 Grade 1.4307 (304L)	210*2	121
M24 bolt	Stainless Steel BS EN ISO 3506-1 Grade A2-80	600*2	346
Rail	Carbon Steel Minimum yield 245 N/mm^2	245	141

*1 0.577 x tension (von Mises).
*2 0.2% elongation.
*3 Specified on drawing (R7021/004).

2.6 RESTRAINED MASSES

The mass restrained by each element in the load path is:

Element	Restrained Mass (kg)
Flask feet	4,350
Flask studs/dowels	
Pallet pad weldments	
Channel weldments	4,600
Clamp assembly weldments	
M24 bolts	
Rail weldments	

3. ANALYSIS

3.1 METHOD

The stress in each element of the load path is calculated for each of the accelerations in turn. These are then combined to give the worst case load combination stresses.

The preload stress in the bolts and studs will then be calculated and compared to the tie-down stress to ascertain which is the maximum.

3.2 LONGITUDINAL ACCELERATION

3.2.1 Longitudinal accelerations generate the following loads:

a) Weld shear (S_1): Longitudinal loads in the flask are conducted into the feet via their weldments.

b) Dowel shear (S_2): Longitudinal loads in the flask feet are conducted into the pallet pads via the dowels, which are subject to a shearing force.
c) Weld shear (S_3): Longitudinal loads in the pallet pads are conducted into the top plate via their weldments.
d) Weld shear (S_4): Longitudinal loads in the top plate are conducted into the central channels via their weldments.
e) Weld shear (S_5): Longitudinal loads are taken by the clamp angles and conducted into the clamp plates via their weldments.
f) Bolt shear (S_6): Longitudinal loads in the plates are conducted into the rails via the bolts, which are subject to a shearing force.
g) Weld shear (S_7): Longitudinal loads in the rails are conducted to the ISO chassis via their weldments.
h) Weld shear (S_8): The weldments in the trailing feet restrain the flask as it tries to lift up.
i) Stud tension (T_1): The studs retaining the trailing feet restrain the flask as it tries to lift up.
j) Weld shear (S_9): The weldments in the trailing pallet pads restrain the flask as it tries to lift up.
k) Weld shear (S_{10}): The central channel weldments restrain the flask and pallet top plate as they try to lift up.
l) Bolt tension (T_2): The bolts retaining the trailing clamp assembly restrain the pallet as it tries to lift up.

3.2.2 The stresses arising from each of these loads are as follows:

a) Weld shear (S_1): In the welds joining the flask feet to the body and lifting fins. The load on each foot, W_1, is:

$$W_1 = \frac{M_1 \text{ x } G_1 \text{ x } g}{N}$$

where

M_1 = R7021 maximum gross weight without pallet = 4,350 kg
G_1 = longitudinal acceleration = 10g
g = gravitational acceleration = 9.81 m/s^2
N = number of feet taking load = 4

thus

$$W_1 = \frac{4{,}350 \text{ x } 10 \text{ x } 9.81}{4} = 107 \text{ kN}$$

The stress, S_1, in the welds is:

$$S_1 = \frac{W_1}{A_1}$$

where

A_1 = cross-sectional area of weld = (l_1 x t_1) +(l_2 x t_2)

where

l_1 = fillet weld length = 2 x 77.5 + 180 = 335 mm
l_2 = weld length = 2 x 112 + 25 = 249 mm
t_1 = fillet weld throat width = 10 x 0.707 = 7.07 mm
t_2 = weld throat width = 10 mm

thus

$A_1 = 4 \times ((335 \times 7.07) + (249 \times 10)) = 19{,}400\ mm^2$

thus

$$S_1 = \frac{107 \times 10^3}{19{,}400} = 5.52\ N/mm^2$$

b) Dowel shear (S_2): In the dowels locating the flask on the pallet. One dowel locates each flask foot on a pallet pad. The stress in each dowel is:

$$S_2 = \frac{W_1}{A_2}$$

where

A_2 = dowel cross-sectional area on plain portion = $\pi \times 20^2 = 1{,}260\ mm^2$

thus

$$S_2 = \frac{107 \times 10^3}{1{,}260} = 84.9\ N/mm^2$$

c) Weld shear (S_3): In the welds joining the pallet pads to the top plate. The stress in each weld is:

$$S_3 = \frac{W_1}{A_3}$$

where

A_3 = cross-sectional area of weld = $l \times t$

where

l = weld length = $2(180 + 150) = 660$ mm

t = weld throat width = $6 \times 0.707 = 4.24$ mm

therefore

$A_3 = 660 \times 4.24 = 2{,}800\ mm^2$

thus

$$S_3 = \frac{107 \times 10^3}{2{,}800} = 38.2\ N/mm^2$$

d) Weld shear (S_4): In the weld joining the central pallet channels to the top plate. The load on each channel, W_2, is:

$$W_2 = \frac{M_2 \times G_1 \times g}{N}$$

where

M_2 = R7021 maximum gross weight = 4,600 kg

N = number of channels taking load = 4

thus

$$W_2 = \frac{4{,}600 \times 10 \times 9.81}{4} = 113\ kN$$

The stress, S_3, in the welds in each channel is:

$$S_4 = \frac{W_2}{A_4}$$

where
A_4 = cross-sectional area of weld = l x t

where
l = weld length = 2(272 + 40) = 624 mm
t = weld throat width = 5 x 0.707 = 3.53 mm

therefore
A_4 = 624 x 3.53 = 2,200 mm^2

thus
$$S_4 = \frac{113 \times 10^3}{2{,}200} = 51.4 \text{ N/mm}^2$$

e) Weld shear (S_5): In the weld joining the angles to each clamp plate. One angle takes the load in each assembly.

The load on each assembly, W_3, is:

$$W_3 = \frac{M_2 \times G_1 \times g}{N}$$

where
M_2 = R7021 maximum gross weight = 4,600 kg
N = number of clamp assemblies taking load = 2

thus
$$W_3 = \frac{4{,}600 \times 10 \times 9.81}{2} = 226 \text{ kN}$$

The stress, S_4, in the welds in each clamp assembly is:

$$S_5 = \frac{W_3}{N \times A_5}$$

where
N = number of welds per angle = 2
A_5 = cross-sectional area of each weld = l x t

where
l = weld length = 2(105 + 72) = 354 mm
t = weld throat width = 6 x 0.707 = 4.24 mm

therefore
A_5 = 354 x 4.24 = 1,500 mm^2

thus

$$S_5 = \frac{226 \times 10^3}{2 \times 1,500} = 75.3 \text{ N/mm}^2$$

f) Shear stress (S_6): In the clamp bolts.

$$S_6 = \frac{W_3}{N \times A_6}$$

where

N = number of bolts per clamp assembly = 4

A_6 = bolt cross-sectional area on plain portion = $\pi \times 12^2 = 452 \text{ mm}^2$

thus

$$S_6 = \frac{226 \times 10^3}{4 \times 452} = 125 \text{ N/mm}^2$$

g) Weld shear (S_7): Rail to ISO chassis weldments.

$$S_7 = \frac{W_4}{A_7}$$

where

W_4 = total longitudinal load on each rail

$$= \frac{M_2 \times G_1 \times g \times N_1}{N_2}$$

where

N_1 = maximum number of R7021 containers = 4

N_2 = number of rails = 2

thus

$$W_4 = \frac{4,600 \times 10 \times 9.81 \times 4}{2} = 903 \text{ kN}$$

A_7 = total cross-sectional area of rail welds

$= \sum (L \times W \times N)$

As the rails are welded to each cross-member, each fork pocket and at each end the total area, A_7, is:

Cross-members

L = 2(55 + 75) = 260 mm

W = weld throat width = 0.707 x 3 = 2.12 mm

N = number of cross-members = 10

Fork pockets

L = 2(300 + 75) = 750 mm

W = weld throat width = 0.707 x 6 = 4.24 mm

N = number of fork pockets = 4

Ends

L = 2(50 + 75) = 250 mm

W = weld throat width = 0.707 x 6 = 4.24 mm

N = number of ends = 2

thus

A_7 = (260 x 2.12 x 10) + (750 x 4.24 x 4) + (250 x 4.24 x 2) = 20.4 x 10^3 mm^2

thus

$$S_7 = \frac{903 \times 10^3}{20.4 \times 10^3} = 44.3 \text{ N/mm}^2$$

h) Weld shear (S_8): In the weldments retaining the trailing feet of the flask.

An upwards load is generated at the back of the flask when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_5, in each foot is as follows:

$$W_5 = \frac{M_1 \times G_1 \times g \times L_1}{N \times L_2} - \frac{M_1 \times g \times L_3}{N \times L_2} = \frac{M_1 \times g\ ((G_1 \times L_1) - L_3)}{N \times L_2}$$

where

L_1 = height of container centre of gravity above pallet pads = 546 mm

L_2 = distance from edge of leading feet to centre of trailing feet = 677 mm

L_3 = distance from edge of leading feet to flask centre = 389 mm

N = number of feet restraining the flask = 2

thus

$$W_5 = \frac{4{,}350 \times 9.81 \times ((10 \times 546) - 389)}{2 \times 677} = 160 \text{ kN}$$

$$S_8 = \frac{W_5}{A_1} = \frac{160 \times 10^3}{19{,}400} = 8.25 \text{ N/mm}^2$$

i) Stud tensile stress (T_1): In the studs retaining the trailing feet of the flask. The stress in each stud is:

$$T_1 = \frac{W_5}{N \times A_8}$$

where

A_8 = tensile stress area of M24 thread = 353 mm^2 (BS 3692)

N = number of studs per foot = 3

thus

$$T_1 = \frac{160 \times 10^3}{3 \times 353} = 151 \text{ N/mm}^2$$

j) Weld shear (S_9): In the trailing pallet pad welds. The stress in each weld is:

$$S_9 = \frac{W_5}{A_3} = \frac{160 \times 10^3}{2{,}800} = 57.1 \text{ N/mm}^2$$

k) Weld shear (S_{10}): In the channel weldments restraining the rear of the flask and top plate.

An upwards load is generated at the back of the flask when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_6, is as follows:

$$W_6 = \frac{M_2 \times G_1 \times g \times L_4}{L_5} - \frac{M_2 \times g \times L_6}{L_5} = \frac{M_2 \times g\,((G_1 \times L_4) - L_6)}{L_5}$$

where

L_4 = height of container centre of gravity above top of channel = 589 mm

L_5 = distance from leading edge of pallet to centre of trailing channels = 868 mm

L_6 = distance from leading edge of pallet to centre = 625 mm

thus

$$W_6 = \frac{4{,}600 \times 9.81 \times ((10 \times 589) - 625)}{868} = 274 \text{ kN}$$

$$S_{10} = \frac{W_6}{N \times A_4}$$

where

N = number of channels = 2

thus

$$S_{10} = \frac{274 \times 10^3}{2 \times 2{,}200} = 62.3 \text{ N/mm}^2$$

l) Bolt tensile stress (T_2): In the bolts retaining the trailing clamp assembly.

An upwards load is generated at the back of the container when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_7, is as follows:

$$W_7 = \frac{M_2 \times G_1 \times g \times L_7}{L_8} - \frac{M_2 \times g \times L_6}{L_8} = \frac{M_2 \times g\,((G_1 \times L_7) - L_6)}{L_8}$$

where

L_7 = height of container centre of gravity from pallet base = 756 mm

L_8 = distance from front of pallet to centre of rear clamp assembly = 1,050 mm

thus

$$W_7 = \frac{4{,}600 \times 9.81 \times ((10 \times 756) - 625)}{1{,}050} = 298 \text{ kN}$$

$$T_2 = \frac{W_7}{N \times A_8}$$

where

N = number of bolts = 4

thus

$$T_2 = \frac{298 \times 10^3}{4 \times 353} = 211 \text{ N/mm}^2$$

3.3 LATERAL ACCELERATION

3.3.1 Lateral accelerations generate the following loads:

a) Weld shear (S_{11}): Lateral loads in the flask are conducted into the feet via their weldments.
b) Dowel shear (S_{12}): Lateral loads in the flask feet are conducted into the pallet pads via the dowels, which are subject to a shearing force.
c) Weld shear (S_{13}): Lateral loads in the pallet pads are conducted into the top plate via their weldments.
d) Weld shear (S_{14}): Lateral loads in the top plate are conducted into the central channels via their weldments.
e) Weld shear (S_{15}): Lateral loads in the central channels are conducted into the base plate via their weldments.
f) Clamp compression (C_1): On the contact face of the clamps on one side.
g) Bolt shear (S_{16}): Lateral loads in the clamp plates are conducted into the rails via the bolts, which are subject to a shearing force.
h) Weld shear (S_{17}): Lateral loads in the rails are conducted to the ISO chassis via their weldments.
i) Weld shear (S_{18}): The weldments in the trailing feet restrain the flask as it tries to lift up.
j) Stud tension (T_3): The studs retaining the trailing feet restrain the flask as it tries to lift up.
k) Weld shear (S_{19}): The pallet pad weldments in the trailing pads restrain the flask as it tries to lift up.
l) Weld shear (S_{20}): The central channel weldments restrain the flask and pallet top plate as they try to lift up.
m) Bolt tension (T_4): The bolts retaining the trailing edges of the clamp assemblies restrain the pallet as it tries to lift up.

3.3.2 The stresses arising from each of these loads are as follows:

a) Weld shear (S_{11}): In the welds joining the flask feet to the body and lifting fins. The load on each foot, W_8, is:

$$W_8 = \frac{M_1 \times G_2 \times g}{N}$$

where
M_1 = R7021 maximum gross weight = 4,350 kg
G_2 = lateral acceleration = 5g
N = number of feet taking load = 4

thus

$$W_8 = \frac{4{,}350 \times 5 \times 9.81}{4} = 53.3 \text{ kN}$$

The stress, S_{10}, in the welds is:

$$S_{11} = \frac{W_8}{A_1} = \frac{53.3 \times 10^3}{19{,}400} = 2.75 \text{ N/mm}^2$$

b) Dowel shear (S_{12}): In the dowels locating the flask on the pallet. The stress in each dowel is:

$$S_{12} = \underline{W_8} = \underline{53.3 \times 10^3} = 42.3 \text{ N/mm}^2$$

$A_2 \quad 1{,}260$

c) Weld shear (S_{13}): In the welds joining the pallet pads to the top plate. The stress in each weld is:

$$S_{13} = \frac{W_8}{A_3} = \frac{53.3 \times 10^3}{2{,}800} = 19.0 \text{ N/mm}^2$$

d) Weld shear (S_{14}): In the welds joining the central pallet channels to the top plate. The load on each channel, W_9, is:

$$W_9 = \frac{M_2 \times G_2 \times g}{N}$$

where

N = number of channels taking load = 4

thus

$$W_9 = \frac{4{,}600 \times 5 \times 9.81}{4} = 56.4 \text{ kN}$$

The stress, S_{14}, in the welds in each channel is:

$$S_{14} = \frac{W_9}{A_4} = \frac{56.4 \times 10^3}{2{,}200} = 25.6 \text{ N/mm}^2$$

e) Weld shear (S_{15}): In the welds joining the base plate to the central pallet channels. The stress is the same as that in the welds joining the central pallet channels to the top plate, thus:

$$S_{15} = 25.6 \text{ N/mm}^2$$

f) Clamp compression (C_1): The lateral load on each clamp, W_{10}, is:

$$W_{10} = \frac{M_2 \times G_2 \times g}{N}$$

where

N = number of clamps = 2

thus

$$W_{10} = \frac{4{,}600 \times 5 \times 9.81}{2} = 113 \text{ kN}$$

The stress on each contact face, C_1, is:

$$C_1 = \frac{W_{10}}{A_9}$$

where

A_9 = the area of each contact face = 6 x 276 = 1,660 mm^2

thus

$C_1 = \underline{113 \times 10^3} = 68.1 \text{ N/mm}^2$

$$1{,}660$$

g) Shear stress (S_{16}): In the retaining bolts.

$$S_{16} = \frac{W_9}{N \times A_6}$$

where

N = number of bolts per clamp assembly = 4

thus

$$S_{16} = \frac{113 \times 10^3}{4 \times 452} = 62.5\ \text{N/mm}^2$$

h) Weld shear (S_{17}): Rail to ISO chassis weldments.

$$S_{17} = \frac{W_{11}}{A_6}$$

where

W_{11} = total longitudinal load on each rail

$$= \frac{M_2 \times G_2 \times g \times N_1}{N_2}$$

thus

$$W_{11} = \frac{4{,}600 \times 5 \times 9.81 \times 4}{2} = 451\ \text{kN}$$

thus

$$S_{17} = \frac{451 \times 10^3}{20.4 \times 10^3} = 22.1\ \text{N/mm}^2$$

i) Weld shear (S_{18}): In the weldments retaining the trailing feet of the flask.

An upwards load is generated at the back of the flask when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_{12}, in each foot is as follows:

$$W_{12} = \frac{M_1 \times G_2 \times g \times L_1}{N \times L_2} - \frac{M_1 \times g \times L_3}{N \times L_2} = \frac{M_1 \times g\ ((G_2 \times L_1) - L_3)}{N \times L_2}$$

where

N = number of feet restraining the flask = 2

thus

$$W_{12} = \frac{4{,}350 \times 9.81 \times ((5 \times 546) - 389)}{2 \times 677} = 73.8\ \text{kN}$$

$$S_{18} = \frac{W_{12}}{A_1} = \frac{73.8 \times 10^3}{19{,}400} = 3.80\ \text{N/mm}^2$$

j) Stud tensile stress (T_3): In the studs retaining the trailing feet of the flask.

$$T_3 = \frac{W_{12}}{N \times A_8}$$

where

N = number of studs per foot = 3

thus

$$T_3 = \frac{73.8 \times 10^3}{3 \times 353} = 69.7 \text{ N/mm}^2$$

k) Weld shear (S_{19}): In the trailing pallet pad welds. The stress in each weld is:

$$S_{19} = \frac{W_{12}}{A_3} = \frac{73.8 \times 10^3}{2{,}800} = 26.4 \text{ N/mm}^2$$

l) Weld shear (S_{20}): In the channel weldments restraining the rear of the flask and top plate.

An upwards load is generated at the back of the flask when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_{13}, is as follows:

$$W_{13} = \frac{M_2 \times G_2 \times g \times L_4}{L_5} - \frac{M_2 \times g \times L_6}{L_5} = \frac{M_2 \times g\ ((G_2 \times L_4) - L_6)}{L_5}$$

thus

$$W_{13} = \frac{4{,}600 \times 9.81 \times ((5 \times 589) - 625)}{868} = 121 \text{ kN}$$

$$S_{20} = \frac{W_{13}}{N \times A_4}$$

where

N = number of channels = 2

thus

$$S_{20} = \frac{121 \times 10^3}{2 \times 2{,}200} = 27.5 \text{ N/mm}^2$$

m) Bolt tensile stress (T_4): In the bolts retaining the trailing edges of the clamp assemblies.

An upwards load is generated at the back of the container when it tries to rotate forward over its front edge. This is countered, to a degree, by gravity acting downwards. The load, W_{14}, is as follows:

$$W_{14} = \frac{M_2 \times G_2 \times g \times L_7}{L_9} - \frac{M_2 \times g \times L_6}{L_9} = \frac{M_1 \times g\ ((G_2 \times L_7) - L_6)}{L_9}$$

where

L_9 = width of pallet = 1,250 mm

thus

$W_{14} = \frac{4{,}600 \times 9.81 \times ((5 \times 756) - 625)}{1{,}250} = 114$ kN

$T_4 = \frac{W_{14}}{N \times A_8}$

where

N = number of bolts = 4

thus

$T_4 = \frac{114 \times 10^3}{4 \times 353} = 80.7$ N/mm^2

3.4 VERTICAL UPWARDS ACCELERATION

A vertical upwards acceleration compresses the container into the ISO chassis and therefore does not generate any stresses in the tie-down system.

3.5 VERTICAL DOWNWARDS ACCELERATION

3.5.1 Vertical downwards accelerations generate the following loads:

a) Weld shear (S_{21}): Vertical loads in the flask are conducted into the feet through their weldments

b) Stud tension (T_5): Vertical loads in the flask feet are conducted into the pallet pads via the studs, which are subject to a tensile force.

c) Weld shear (S_{22}): Vertical loads in the pallet pads are conducted into the top plate via their weldments.

d) Weld shear (S_{23}): Vertical loads in the pallet are taken by the channels and conducted into the structure by their weldments.

e) Weld shear (S_{24}): Vertical loads in the pallet are taken by the channels and conducted into the structure by their weldments.

f) Bolt tension (T_6): Vertical loads in the clamp plates are conducted into the rails via the bolts, which are subject to a tensile force.

g) Weld shear (S_{25}): Vertical loads are conducted from the rails to the ISO chassis via their weldments.

3.5.2 The stress arising from each of these loads are as follows:

a) Weld shear (S_{21}): In the welds joining the flask feet to the body and lifting fins. The load on each foot, W_{15}, is:

$W_{15} = \frac{M_1 \times G_3 \times g}{N}$

where

G_3 = vertical upwards acceleration = 1g

g = gravitational acceleration = 9.81 m/s^2

N = number of feet taking load = 4

thus

$W_{15} = \frac{4{,}350 \times 1 \times 9.81}{4} = 10.7$ kN

The stress, S_{21}, in the welds is:

$$S_{21} = \frac{W_{15}}{A_1} = \frac{10.7 \times 10^3}{19{,}400} = 0.552 \text{ N/mm}^2$$

b) Stud tensile stress (T_5). In the studs retaining the flask feet.

$$T_5 = \frac{W_{15}}{N \times A_8}$$

where
N = number studs per foot = 3

thus

$$T_5 = \frac{10.7 \times 10^3}{3 \times 353} = 10.7 \text{ N/mm}^2$$

c) Weld shear (S_{22}): In the welds joining the pallet pads to the top plate. The stress in each weld is:

$$S_{22} = \frac{W_{15}}{A_3} = \frac{10.7 \times 10^3}{2{,}800} = 3.82 \text{ N/mm}^2$$

d) Weld shear (S_{23}): In the welds joining the central pallet channels to the top plate. The load on each channel, W_{16}, is:

$$W_{16} = \frac{M_2 \times G_3 \times g}{N}$$

where
N = number of channels taking load = 4

thus

$$W_{16} = \frac{4{,}600 \times 1 \times 9.81}{4} = 11.3 \text{ kN}$$

The stress, S_{23}, in the weld in each channel is:

$$S_{23} = \frac{W_{16}}{A_4} = \frac{11.3 \times 10^3}{2{,}200} = 5.14 \text{ N/mm}^2$$

e) Weld shear (S_{24}): In the welds joining the base plate to the central pallet channels. The stress is the same as that in the welds joining the central pallet channels to the top plate, thus:

$$S_{24} = 5.14 \text{ N/mm}^2$$

f) Bolt tensile stress (T_6): In the bolts retaining the clamp assemblies.

The force generates a tensile load, W_{17}, in each bolt:

$$W_{17} = \frac{M_2 \times G_3 \times g}{N}$$

where

N = number of retaining bolts = 8

thus

$$W_{17} = \frac{4{,}600 \times 1 \times 9.81}{8} = 5.64 \text{ kN}$$

$$T_6 = \frac{W_{17}}{A_8} = \frac{5.64 \times 10^3}{353} = 16.0 \text{ N/mm}^2$$

g) Weld shear (S_{25}). Rail to ISO chassis weldments:

$$S_{25} = \frac{W_{18}}{A_7}$$

where

W_{18} = total vertical load on each rail

$$= \frac{M \times G_3 \times g \times N_1}{N_2}$$

thus

$$W_{18} = \frac{4{,}600 \times 1 \times 9.81 \times 4}{2} = 90.3 \text{ kN}$$

thus

$$S_{25} = \frac{90.3 \times 10^3}{20.4 \times 10^3} = 4.43 \text{ N/ mm}^2$$

3.6 STRESSES FROM COMBINED ACCELERATIONS

Load Path Element	Stress Type and Direction		
	Longitudinal	Lateral	Vertical
Flask feet weldments	S_1	S_{11}	S_8, S_{18}, S_{21}
Dowels	S_2	S_{12}	-
Flask studs	-	-	T_1, T_3, T_5
Pallet pad weldments	S_3	S_{13}	S_9, S_{19}, S_{22}
Channel to top plate weldments	S_4	S_{14}	S_{10}, S_{20}, S_{23}
Base plate to channel weldments	-	S_{15}	S_{24}
Angle to clamp weldments	S_5	-	-
Clamp face	-	C_1	-
M24 bolts	S_6	S_{16}	T_2, T_4, T_6
Rail weldments	S_7	S_{17}	S_{25}

The stresses in all elements except the angle to clamp weldments and the clamp faces need combining to give the maximum stresses.

3.6.1 Flask feet weldments:

The maximum normal and shear stresses are found using the tri-axial stress analysis methodology (Machinery's Handbook). Thus:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = $S_8 + S_{18} + S_{21} = 8.25 + 3.80 + 0.552 = 12.6$ N/mm^2
S_{yz} = lateral shear = $S_{11} = 2.75$ N/mm^2
S_{zx} = longitudinal shear = $S_1 = 5.52$ N/mm^2

A $= S_x + S_y + S_z = 0$
B $= S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2 = -197$
C $= S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2 = 383$
D $= A^2/3 - B = 197$
E $= A \times B/3 - C - 2A^3/27 = -383$
F $= \sqrt{(D^3/27)} = 531$
G $= \cos^{-1}(-E/2F) = 68.9°$
H $= \sqrt{(D/3)} = 8.1$

the principal stresses are therefore:
I $= 2.H.\cos(G/3) + A/3 = 14.9$ N/mm^2
J $= 2.H.\cos(G/3 + 120°) + A/3 = -12.9$ N/mm^2
K $= 2.H.\cos(G/3 + 240°) + A/3 = -1.98$ N/mm^2

T_7, the maximum principal normal (tensile) stress, is therefore 14.9 N/mm^2

S_{26}, the maximum shear stress, is $0.5(T_7 - S_{min}) = 13.9$ N/mm^2

3.6.2 Dowels:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = 0
S_{yz} = lateral shear = S_{12} = 42.3 N/mm^2
S_{zx} = longitudinal shear = S_2 = 84.9 N/mm^2

A = $S_x + S_y + S_z = 0$
B = $S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2$ = -8,997
C = $S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2$ = 0
D = $A^2/3$ - B = 8,997
E = A x B/3 - C - $2A^3/27$ = 0
F = $\sqrt{(D^3/27)}$ = 164,243
G = $\cos^{-1}(-E/2F)$ = 90.0°
H = $\sqrt{(D/3)}$ = 54.8

the principal stresses are therefore:
I = 2.H.cos(G/3) + A/3 = 94.9 N/mm^2
J = 2.H.cos(G/3 + 120°) + A/3 = -94.9 N/mm^2
K = 2.H.cos(G/3 + 240°) + A/3 = 0 N/mm^2

T_8, the maximum principal normal (tensile) stress, is therefore 94.9 N/mm^2

S_{27}, the maximum shear stress, is $0.5(T_8 - S_{min})$ = 94.9 N/mm^2

3.6.3 Flask studs:

The sum of the tensile stresses due to the longitudinal, lateral and vertical accelerations gives the total tensile stress. Therefore:
T_9 = $T_1 + T_3 + T_5$ = 151 + 69.7 + 10.7 = 231 N/ mm^2

3.6.4 Pallet pad weldments:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = $S_9 + S_{19} + S_{22}$ = 57.1 + 26.4 + 3.82 = 87.3 N/mm^2
S_{yz} = lateral shear = S_{13} = 19.0 N/mm^2
S_{zx} = longitudinal shear = S_3 = 38.2 N/mm^2

A = $S_x + S_y + S_z = 0$
B = $S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2$ = -9,442
C = $S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2$ = 126,725
D = $A^2/3$ - B = 9,442
E = A x B/3 - C - $2A^3/27$ = -126,725
F = $\sqrt{(D^3/27)}$ = 176,556
G = $\cos^{-1}(-E/2F)$ = 69.0°
H = $\sqrt{(D/3)}$ = 56.1

the principal stresses are therefore:
I = 2.H.cos(G/3) + A/3 = 103 N/mm^2
J = 2.H.cos(G/3 + 120°) + A/3 = -89.6 N/mm^2

K $= 2.H.\cos(G/3 + 240°) + A/3 = -13.7$ N/mm^2

T_{10}, the maximum principal normal (tensile) stress, is therefore 103 N/mm^2

S_{28}, the maximum shear stress, is $0.5(T_{10} - S_{min}) = 96.4$ N/mm^2

3.6.5 Channel to top plate weldments:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = $S_{10} + S_{20} + S_{23} = 62.3 + 27.5 + 5.14 = 94.9$ N/mm^2
S_{yz} = lateral shear = $S_{14} = 25.6$ N/mm^2
S_{zx} = longitudinal shear = $S_4 = 51.4$ N/mm^2

A $= S_x + S_y + S_z = 0$
B $= S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2 = -12{,}303$
C $= S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2 = 249{,}746$
D $= A^2/3 - B = 12{,}303$
E $= A \times B/3 - C - 2A^3/27 = -249{,}746$
F $= \sqrt{(D^3/27)} = 262{,}635$
G $= \cos^{-1}(-E/2F) = 61.6°$
H $= \sqrt{(D/3)} = 64.0$

the principal stresses are therefore:
I $= 2.H.\cos(G/3) + A/3 = 120$ N/mm^2
J $= 2.H.\cos(G/3 + 120°) + A/3 = -98.9$ N/mm^2
K $= 2.H.\cos(G/3 + 240°) + A/3 = -21.1$ N/mm^2

T_{11}, the maximum principal normal (tensile) stress, is therefore 120 N/mm^2

S_{29}, the maximum shear stress, is $0.5(T_{11} - S_{min}) = 109$ N/mm^2

3.6.6 Base plate to channel weldments:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = $S_{24} = 5.14$ N/mm^2
S_{yz} = lateral shear = $S_{15} = 25.6$ N/mm^2
S_{zx} = longitudinal shear = 0

A $= S_x + S_y + S_z = 0$
B $= S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2 = -682$
C $= S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2 = 0$
D $= A^2/3 - B = 682$
E $= A \times B/3 - C - 2A^3/27 = 0$
F $= \sqrt{(D^3/27)} = 3{,}426$
G $= \cos^{-1}(-E/2F) = 90.0°$
H $= \sqrt{(D/3)} = 15.1$

the principal stresses are therefore:
I $= 2.H.\cos(G/3) + A/3 = 26.1$ N/mm^2

J = $2.H.\cos(G/3 + 120°) + A/3 = -26.1$ N/mm^2
K = $2.H.\cos(G/3 + 240°) + A/3 = 0$ N/mm^2

T_{12}, the maximum principal normal (tensile) stress, is therefore 26.1 N/mm^2

S_{30}, the maximum shear stress, is $0.5(T_{12} - S_{min}) = 26.1$ N/mm^2

3.6.7 M24 bolts:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = $T_2 + T_4 + T_6 = 211 + 80.7 + 16.0 = 308$ N/mm^2
S_z = normal lateral stress = 0
S_{xy} = vertical shear = 0
S_{yz} = lateral shear = $S_{16} = 62.5$ N/mm^2
S_{zx} = longitudinal shear = $S_6 = 125$ N/mm^2

A = $S_x + S_y + S_z = 308$
B = $S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2 = -16{,}531$
C = $S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2 = -4.81 \times 10^6$
D = $A^2/3 - B = 51{,}153$
E = $A \times B/3 - C - 2A^3/27 = 642{,}987$
F = $\sqrt{(D^3/27)} = 2.23 \times 10^6$
G = $\cos^{-1}(-E/2F) = 98.3°$
H = $\sqrt{(D/3)} = 131$

the principal stresses are therefore:
I = $2.H.\cos(G/3) + A/3 = 322$ N/mm^2
J = $2.H.\cos(G/3 + 120°) + A/3 = -130$ N/mm^2
K = $2.H.\cos(G/3 + 240°) + A/3 = 115$ N/mm^2

T_{13}, the maximum principal normal (tensile) stress, is therefore 322 N/mm^2

S_{31}, the maximum shear stress, is $0.5(T_{13} - S_{min}) = 226$ N/mm^2

3.6.8 Rail to ISO weldments:

S_x = normal longitudinal stress = 0
S_y = normal vertical stress = 0
S_z = normal lateral stress = 0
S_{xy} = vertical shear = $S_{25} = 4.43$ N/mm^2
S_{yz} = lateral shear = $S_{17} = 22.1$ N/mm^2
S_{zx} = longitudinal shear = $S_7 = 44.3$ N/mm^2

A = $S_x + S_y + S_z = 0$
B = $S_x.S_y + S_y.S_z + S_z.S_x - S_{xy}^2 - S_{yz}^2 - S_{zx}^2 = -2{,}471$
C = $S_x.S_y.S_z + 2.S_{xy}.S_{yz}.S_{zx} - S_x.S_{yz}^2 - S_y.S_{zx}^2 - S_z.S_{xy}^2 = 8{,}674$
D = $A^2/3 - B = 2{,}471$
E = $A \times B/3 - C - 2A^3/27 = -8{,}674$
F = $\sqrt{(D^3/27)} = 23{,}632$
G = $\cos^{-1}(-E/2F) = 79.4°$
H = $\sqrt{(D/3)} = 28.7$

the principal stresses are therefore:

$I = 2.H.\cos(G/3) + A/3 = 51.4$ N/mm^2
$J = 2.H.\cos(G/3 + 120°) + A/3 = -47.9$ N/mm^2
$K = 2.H.\cos(G/3 + 240°) + A/3 = -3.53$ N/mm^2

T_{14}, the maximum principal normal (tensile) stress, is therefore 51.4 N/mm^2

S_{32}, the maximum shear stress, is $0.5(T_{14} - S_{min}) = 49.6$ N/mm^2

3.7 BOLT/STUD PRELOAD

The flask studs and clamp bolts both have M24 threads and are tightened to the same torque, therefore the preload in each will be the same. The stress, T_{15}, from the preload is obtained as follows:

$$T_{15} = \frac{Q}{A}$$

where:
Q = load (kgf)
A = tensile stress area of M24 thread = 353 mm^2 (BS 3643)

From Machinery's Handbook, p178:

$$F = Q \times \frac{p + 6.2832\mu r}{6.2832r - \mu p} \times \frac{r}{R}$$

rearranging gives:

$$Q = \frac{F.R}{r} \times \frac{6.2832r - \mu p}{p + 6.2832\mu r}$$

where:
Q = load (kgf)
F.R = torque = 15 kgf.m (R8055A/001)
r = pitch radius of thread = 0.0110 m (BS 3643)
p = thread pitch = 0.0030 m (BS 3643)
μ = coefficient of friction = 0.16 (for lubricated threads, Machinery's Handbook, p173)

thus:

$$Q = \frac{15}{0.0110} \times \frac{6.2832 \times 0.0110 - 0.16 \times 0.0030}{0.0030 + 6.2832 \times 0.16 \times 0.0110} = 6{,}660 \text{ kg} = 65{,}300 \text{ N}$$

The tensile stress, T_{15}, in the bolt is therefore:

$$T_{15} = \frac{65{,}300}{353} = 185 \text{ N/mm}^2$$

The maximum tie-down tensile stress generated in the studs, T_9 (231 N/ mm^2), and the maximum principal normal tensile stress generated in the bolts, T_{13} (322 N/ mm^2), therefore represent the worst cases for these components.

3.8 SUMMARY OF STRESSES FROM ACCELERATION LOADS

Ref	Acceleration	Description	Calculated Stress (N/mm^2)	Design Stress (N/mm^2)	Safety Factor
C_1	Compressive	On the side contact face of each clamp	68.1	210	3.08
S_5	Shear	In the clamp/angle weldments	75.3	121	1.61
S_{26}	Shear	In the flask feet weldments	13.9	121	8.71
S_{27}	Shear	In the dowels	94.9	369	3.89
S_{28}	Shear	In the pallet pad weldments	96.4	231	2.40
S_{29}	Shear	In the channel to top plate weldments	109	231	2.12
S_{30}	Shear	In the base plate to channel weldments	26.1	231	8.85
S_{31}	Shear	In the M24 bolts	226	346	1.53
S_{32}	Shear	In the rail to ISO weldments	49.6	141	2.84
T_7	Tensile	In the flask feet weldments	14.9	210	14.1
T_8	Tensile	In the dowels	94.9	640	6.74
T_9	Tensile	In the flask studs	231	640	2.77
T_{10}	Tensile	In the pallet pad weldments	103	400	3.88
T_{11}	Tensile	In the channel to top plate weldments	120	400	3.33
T_{12}	Tensile	In the base plate to channel weldments	26.1	400	15.3
T_{13}	Tensile	In the M24 bolts	322	600	1.86
T_{14}	Tensile	In the rail to ISO weldments	51.4	245	4.77
Minimum Safety Factor					1.53

4. CONCLUSIONS

- Design Criteria: The R7021 transport container tie-down system meets its design criteria and the tie-down requirements for Type B(U) packages as specified in TS-G-1.1 with a minimum factor of safety of 1.53.
- Overload: Should the tie-down system be overloaded to the point of failure the bolts would fail first leaving the container intact. This therefore would not impair its ability to meet all Type B(U) requirements.

5. REFERENCES

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- TS-R-1: “Regulations for the Safe Transport of Radioactive Material”, 2005 Edition, IAEA, Vienna.
- BS 3692:2001: ISO metric precision hexagon bolts, screws and nuts – Specification.
- BS EN 10025-2:2004: Hot rolled products of structural steels, Part 2: Technical delivery conditions for non-alloy structural steels.
- BS EN 10088-2:2005: Stainless steels, Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes.
- BS EN ISO 3506-1:2009: Mechanical properties of corrosion-resistant stainless steel fasteners. Bolts, screws and studs.
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- R8055/002 issue D: Rail, REVISS Services (UK) Ltd.
- R8055A/001 issue E: Tie-down details for platform container R8055, REVISS Services (UK) Ltd.
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- Machinery’s Handbook, 28th Edition, Industrial Press Inc, 2008.

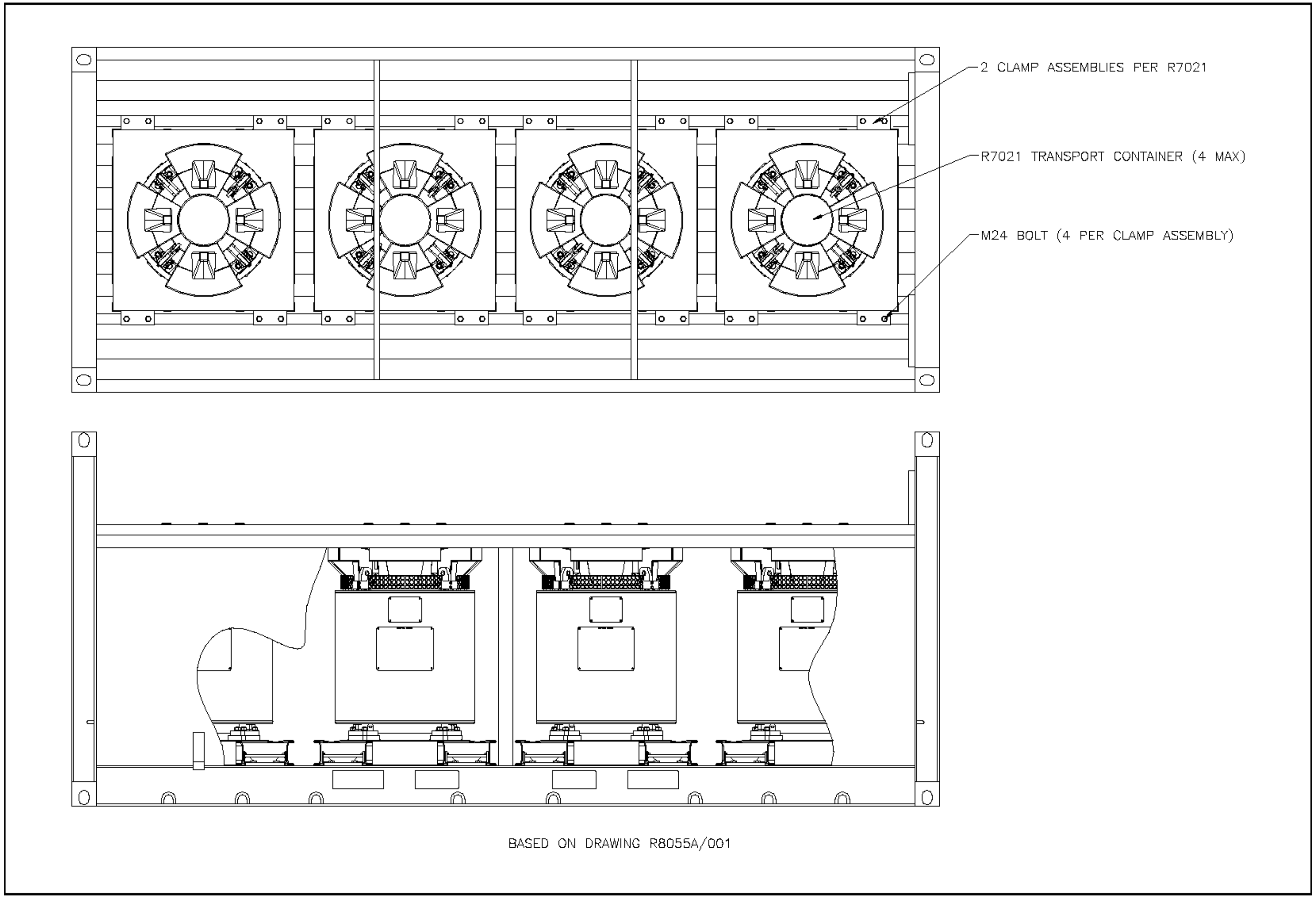

Figure 1: Four R7021 containers on an R8055 ISO flatrack

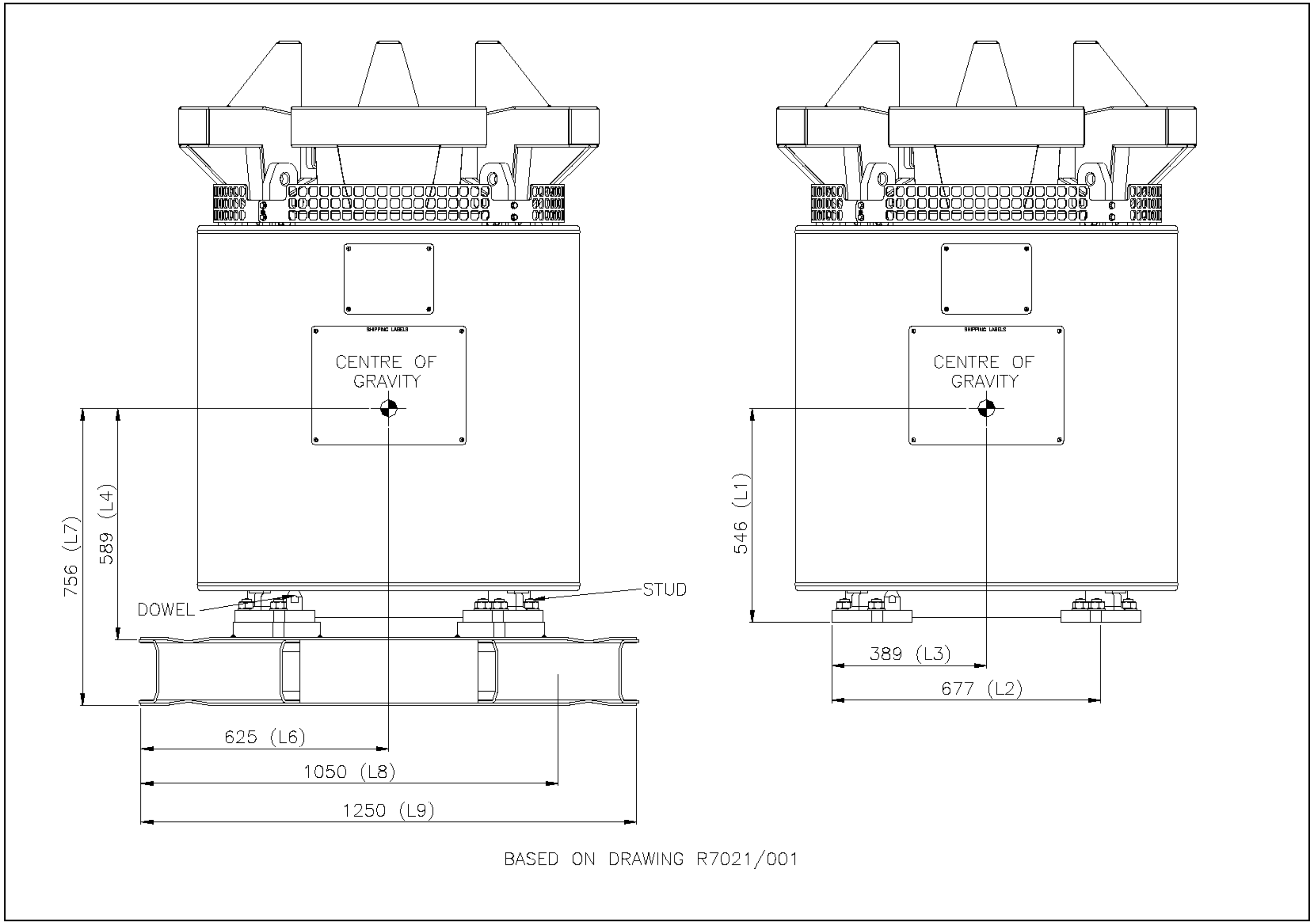

Figure 2: R7021 transport container assembly

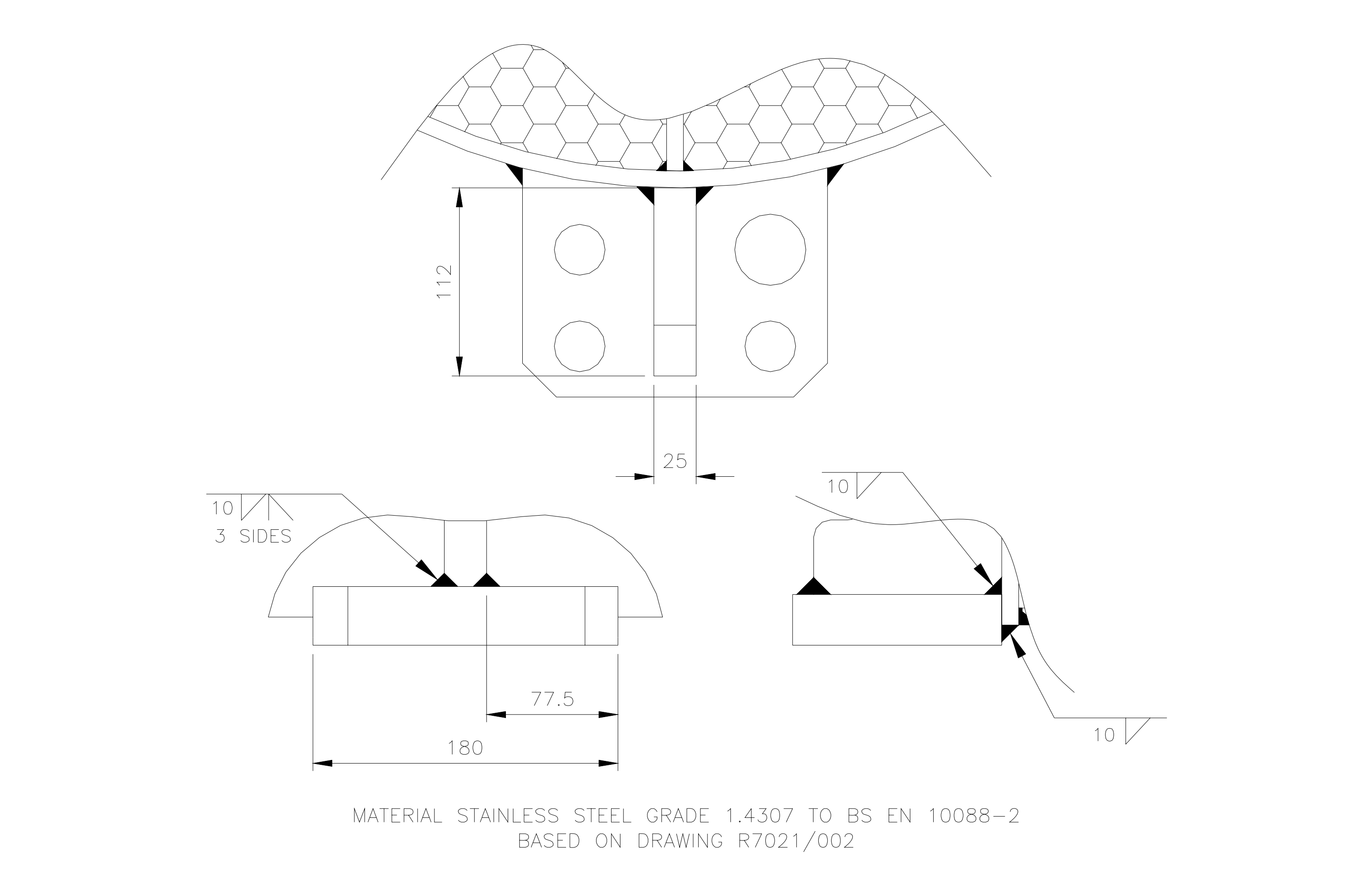

Figure 3: Flask feet details

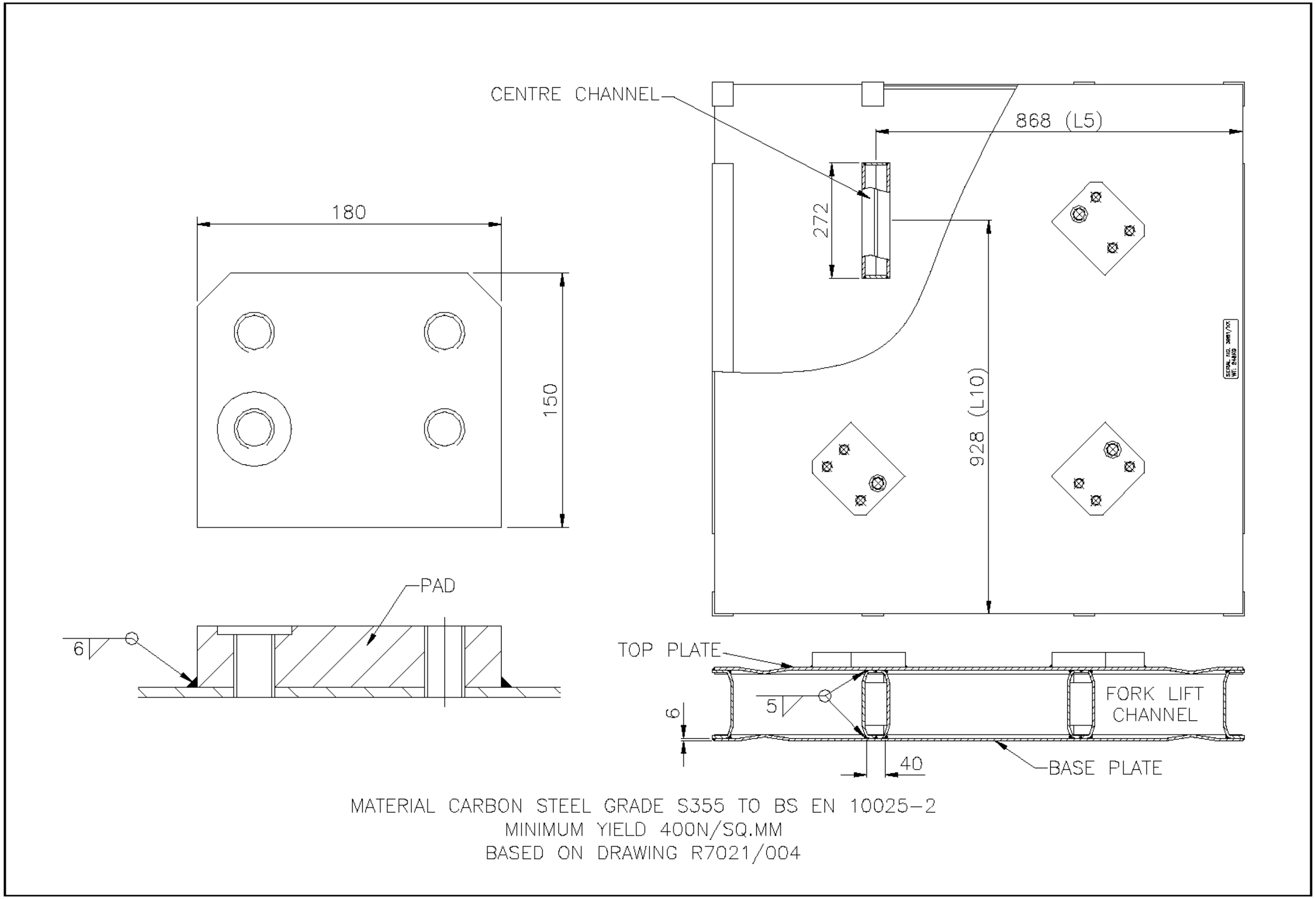

Figure 4: Pallet details

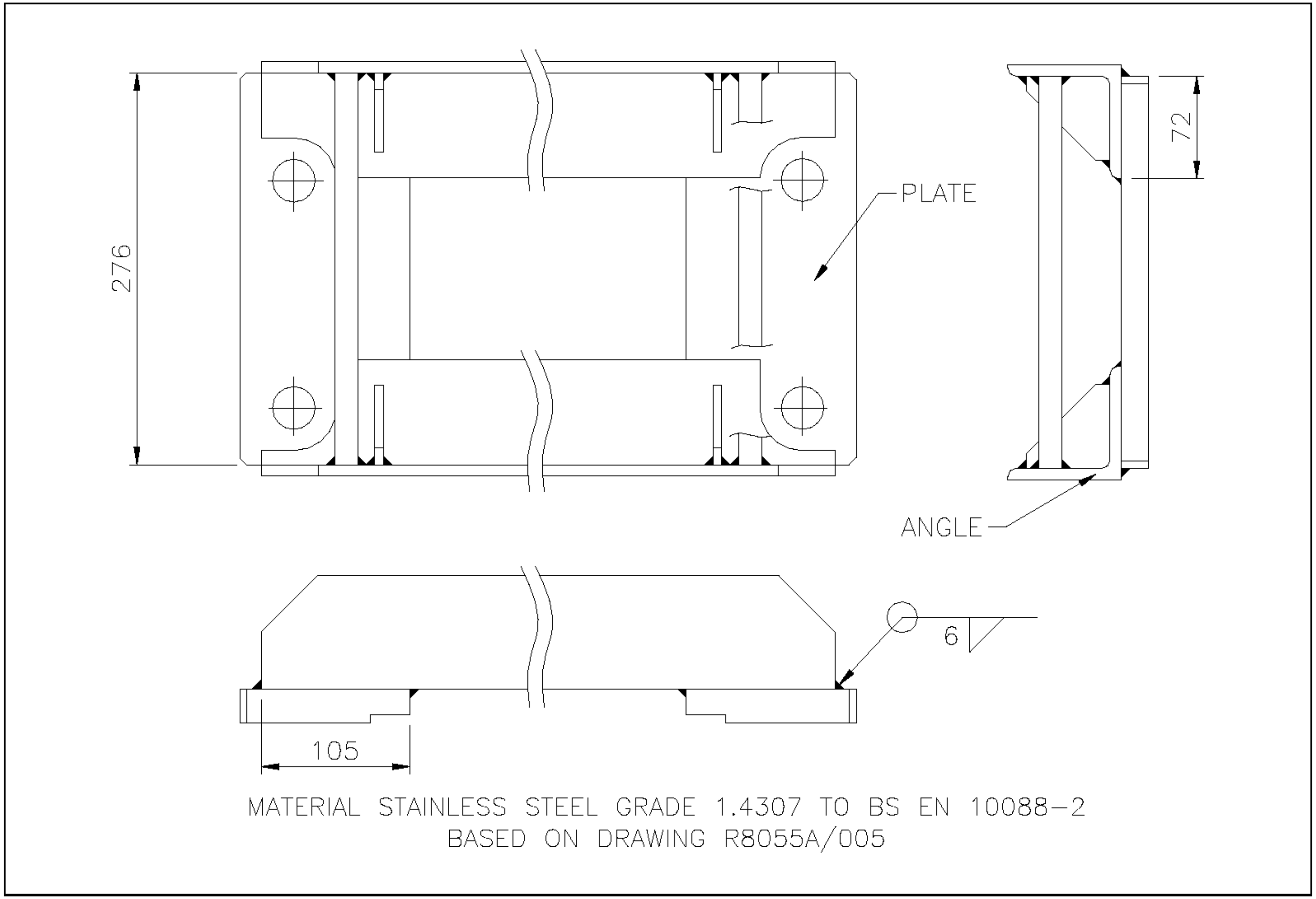

Figure 5: Clamp plate assembly details

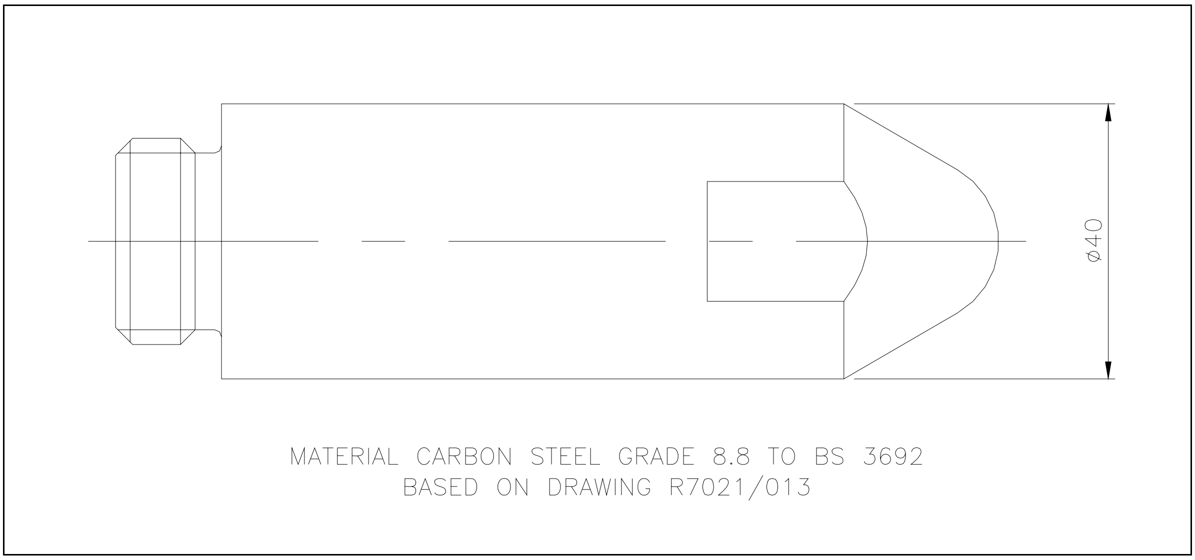

Figure 6: Dowel details

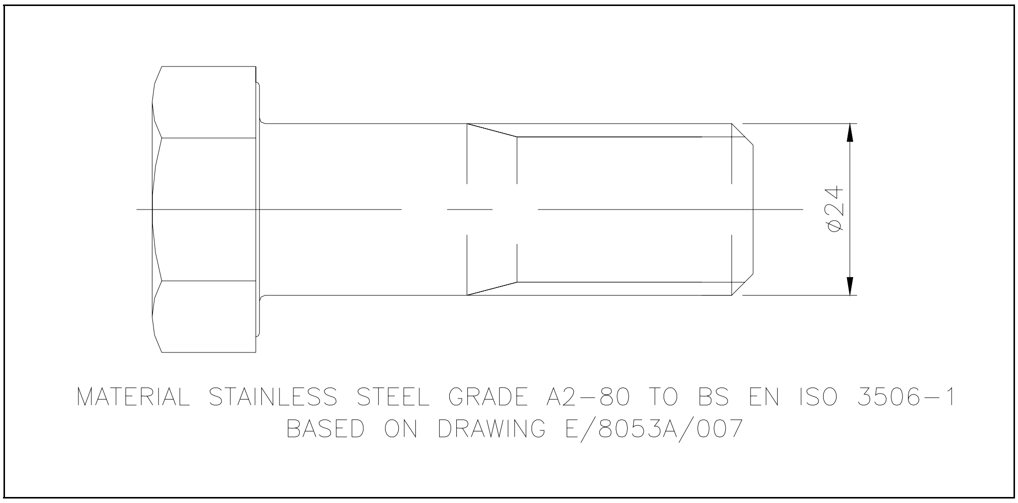

Figure 7: M24 bolt details

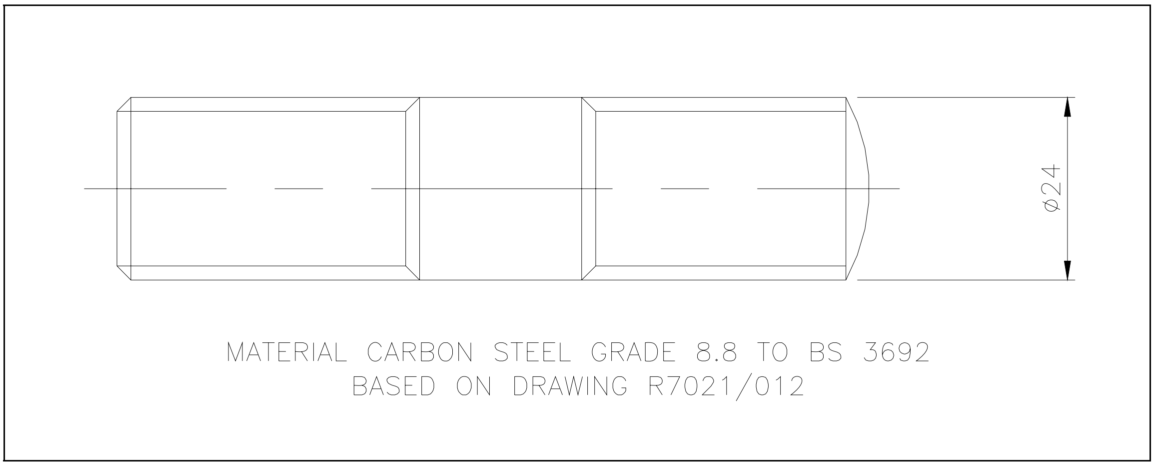

Figure 8: M24 stud details

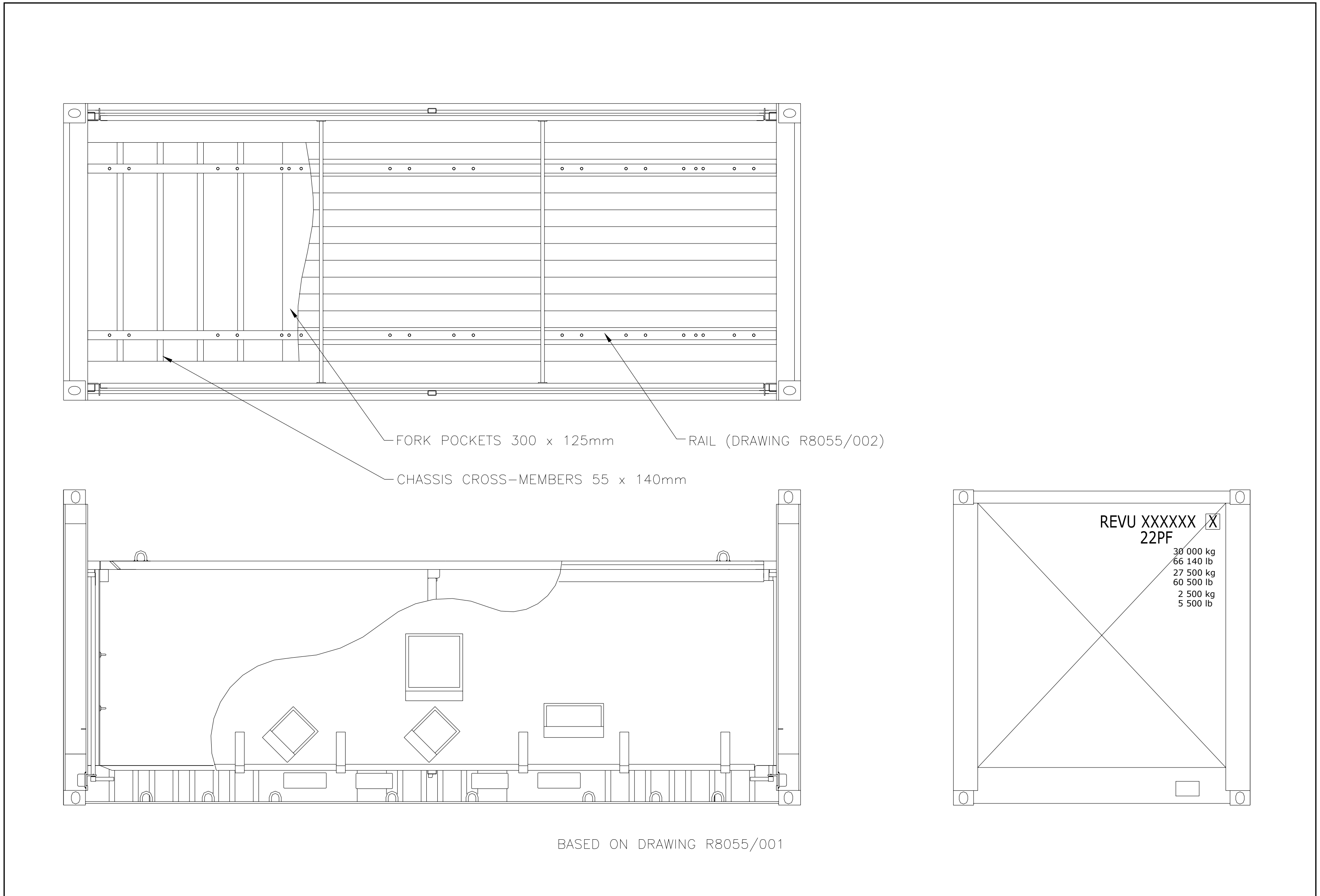

Figure 9: R8055 ISO chassis details