Industrial Slab Design Report

General project information

Project name: **Industrial Warehouse**

Project location: **Stockholm**

Project designer: **John Doe**

Design method: **Concrete Society, Technical Report 34 (TR34), 4th Edition**

Slab Design Summary

Subgrade modulus k	$0.08 N/mm^3$
Slab thickness h	$200.0 mm$
Concrete cylinder nominal strength f_{ck}	$30.0 MPa$
Residual flexural strength of fiber reinforced concrete $[f_{r1}, f_{r2}, f_{r3}, f_{r4}]$	$[2.1, 1.8, 1.6, 1.2] MPa$
Steel reinforcement $[A_{sx}(mm^2), A_{sy}(mm^2), d(mm), f_y(MPa)]$	$[200.0, 200.0, 165.0, 500.0]$
Load transfer across joints	0.15
Dowels capacity	$24000.0 N$

Calculations summary

Point loads

Load case	Internal bending	Edge bending	Corner bending	Internal punching	Corner punching
Mains Racks	0.32	0.47	0.89	0.17	0.15
Forklift	0.18	0.26	0.46	0.13	0.12
Isolated Upright	0.22	0.4	0.88	0.25	0.22
2 Uprights	0.3	0.43	0.79	0.23	0.2
4 Wheels Axle	0.31	0.45	0.93	0.13	0.12

Line and uniformly distributed loads

Load case	Working ratio
Bulk Storage	0.72
Line Storage	0.84

Design Methodology

The present design is based on Concrete Society's Technical Report 34 (TR34), 4th Edition.

Detailed Calculations

Safety Factors

Concrete and fiber reinforced concrete	$\gamma_c = 1.5$
Steel mesh/bars	$\gamma_s = 1.15$
Defined racking loads	$\gamma_{rack} = 1.2$
Dynamic loads (eg. MHE)	$\gamma_{dynamic} = 1.6$

Materials and slab properties

Concrete's design flexural tensile strength	$f_{ctd,fl} = 2.73N/mm^2$
Concrete's modulus of elasticity	$E_{cm} = 32836.57N/mm^2$
Concrete's Poisson's ratio	$\nu = 0.2$
Slab's radius of relative stiffness:	$l = (\frac{E_{cm}h^3}{12(1-\nu^2)k})^{0.25} = 730.7mm$
Steel reinforcement ratio:	$\rho_1 = \frac{\sqrt{A_{sx}A_{sy}}}{bd}$
Eurocode 2's k_s	$k_s = 1 + \sqrt{\frac{200}{d}} < 2$

Slab bending capacity

The slab's flexure verification under point loads is based on the yield line theory. Maximum hogging and sagging moments of this slab are calculated below.

Hogging moment $M_n = \frac{h^2}{6} f_{ctd,fl} = 18228.0N.m/m$

Sagging moment $M_p = \frac{h^2}{\gamma_m}(0.29\sigma_{r4} + 0.16\sigma_{r1}) + A_s f_y(d - 0.048h)/\gamma_s = 20978.6N.m/m$

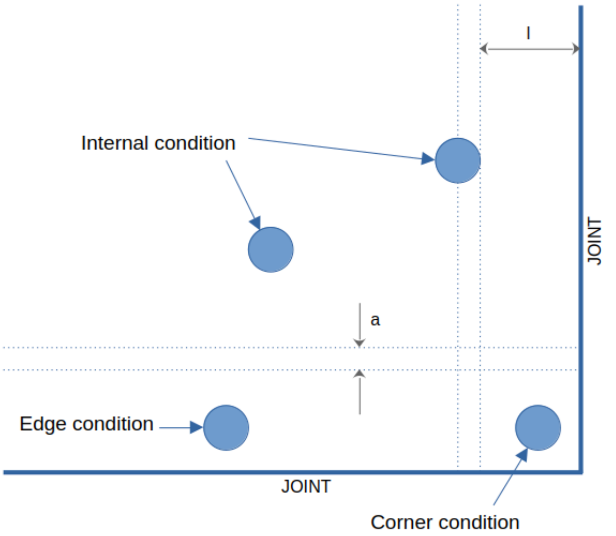
Slab punching shear capacity

Slab's shear strength, including steel mesh/bars: $v_{Rd,c} = max(\frac{0.18k_s}{\gamma_c}(100\rho_1 f_{ck})^{0.33}, 0.035k_s^{1.5}f_{ck}^{0.5}) = 0.58MPa$

Contribution of fibers to shear strength $v_f = 0.015(f_{r1} + f_{r2} + f_{r3} + f_{r4}) = 0.1MPa$

Slab panels areas

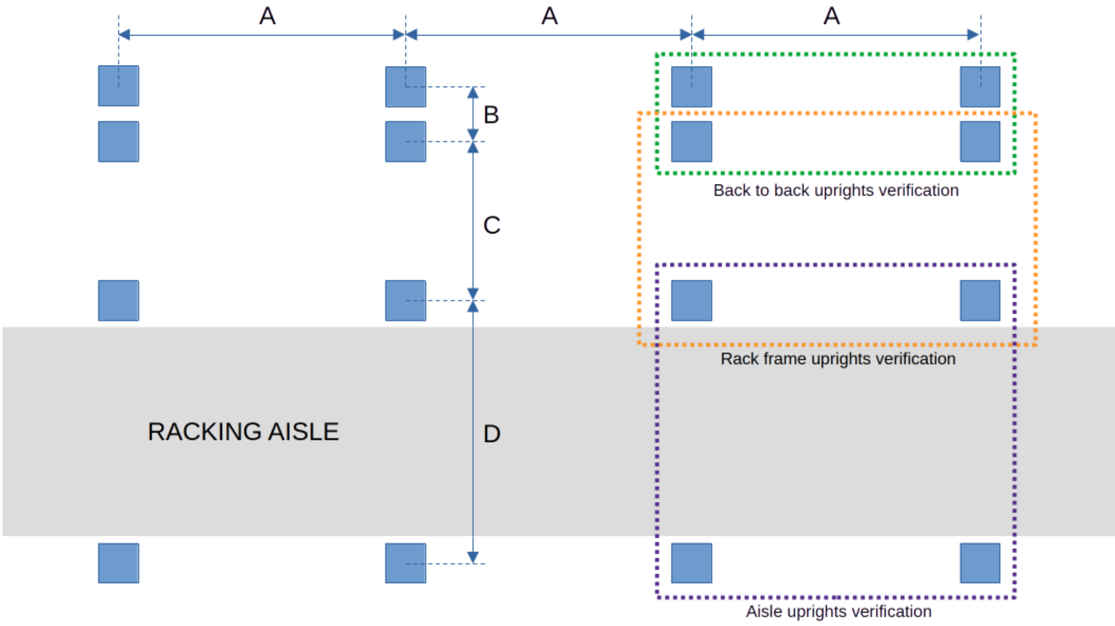
Depending on the radius of relative stiffness l calculated above, slab panels are divided in 3 areas: internal, edge and corner. These are illustrated in the drawing below.



Racking verification

As per TR34 §7.8.4., verification of each racking load case is done in 3 steps:

1. Verification of the set of 4 back-to-back uprights
2. Verification of the set of 4 uprights that make the frame
3. Verification of the set of 4 uprights along both sides of the aisle



In each step, we check both the bending and punching effects of racks on the slab.

Racking Case 1: Mains Racks

Loads and geometry

Single upright load	Rack length (A)	Back-to-back spacing (B)	Rack depth (C)	Aisle width (D)	Baseplate length	Baseplate width
55000.0 N	1800.0 mm	300.0 mm	1000.0 mm	2500.0 mm	120.0 mm	120.0 mm

Slab bending verification - Back-to-back uprights

Given the geometry of the inner back-to-back uprights, loads are too close in one direction and were combined. They are interacting in the other direction

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 687617.6N$	$P_{u,edge} = 466552.3N$	$P_{u,corner} = 122912.8N$
Slab's Working Ratio	0.32	0.47	0.89

NB. The slab's ultimate load is compared to the sum of interacting loads to calculate working ratios.

Slab bending verification - Rack frame uprights

Given the geometry of the racking frame, the four loads are interacting with each as a true quadruple point loads

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 644257.0N$	$P_{u,edge} = 322206.4N$	$P_{u,corner} = 90818.0N$
Slab's Working Ratio	0.28	0.34	0.61

NB. The slab's ultimate load is compared to the sum of interacting loads to calculate working ratios.

Slab bending verification - Uprights along aisle

Given the geometry of the racking frame, the four loads are interacting with each as a true quadruple point loads

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 792393.8N$	$P_{u,edge} = 372711.3N$	$P_{u,corner} = 90818.0N$
Slab's Working Ratio	0.23	0.3	0.61

NB. The slab's ultimate load is compared to the sum of interacting loads to calculate working ratios.

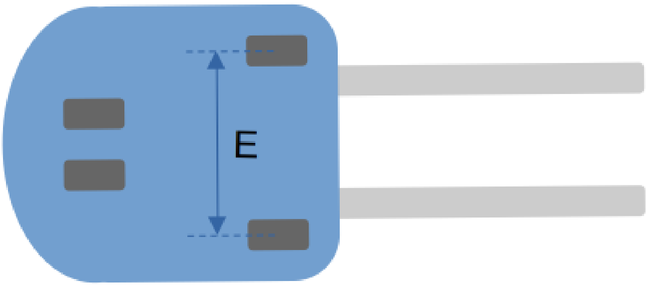
Slab verification vis-à-vis punching shear

Punching capacity of suspended slab at the face of loaded areas: $P_{p,max} = 370593.4N$

Punching capacity of suspended slab at the critical perimeter: $P_p = 282131.0N$

	Internal	Edge
Ground Support	$R_p = 5843.9N$	$R_{cp} = 11626.5N$
Working Ratio, Face of loaded area	0.13	0.12
Working Ratio, on the critical perimeter	0.17	0.15

Materials Handling Equipments



Conventional MHEs are verified as a set of 2 point loads, which represent the wheels of their loaded axle.

MHE Case 1: Forklift

Loads and geometry

Max. static wheel load	Wheel contact area	Load axle width
25000.0 N	10000.0 mm²	1000.0 mm

Slab bending verification

The loaded axle is considered a set of 2 point loads for verification against bending.

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 444546.2N$	$P_{u,edge} = 308853.7N$	$P_{u,corner} = 86219.1N$
Slab's Working Ratio	0.18	0.26	0.46

Slab punching shear verification

Punching capacity of suspended slab at the face of loaded areas: $P_{p,max} = 308827.8N$

Punching capacity of suspended slab at the critical perimeter: $P_p = 274126.1N$

	Internal	Edge
Ground Support	$R_p = 4017.7N$	$R_{cp} = 7862.3N$
Working Ratio, Face of loaded area	0.12	0.1
Working Ratio, on the critical perimeter	0.13	0.12

MHE's are verified independently. If significant interactions with other point loads are expected, please consider them in the dual and/or quadruple point loads input.

Uniformly distributed loads (UDL)

Uniformly distributed load are assumed to have any possible geometry.

Calculations are conducted according to TR34 §7.12.

UDL Case 1: Bulk Storage

Load

Load	Safety Factor
0.05 N/mm² = 5.0 T/m²	1.5

Slab bending verification

Based on the geometry above and slab performances, the characteristic length is $\lambda = (\frac{3k}{E_{cm}h^3})^{0.25} = 0.9777m^{-1}$.

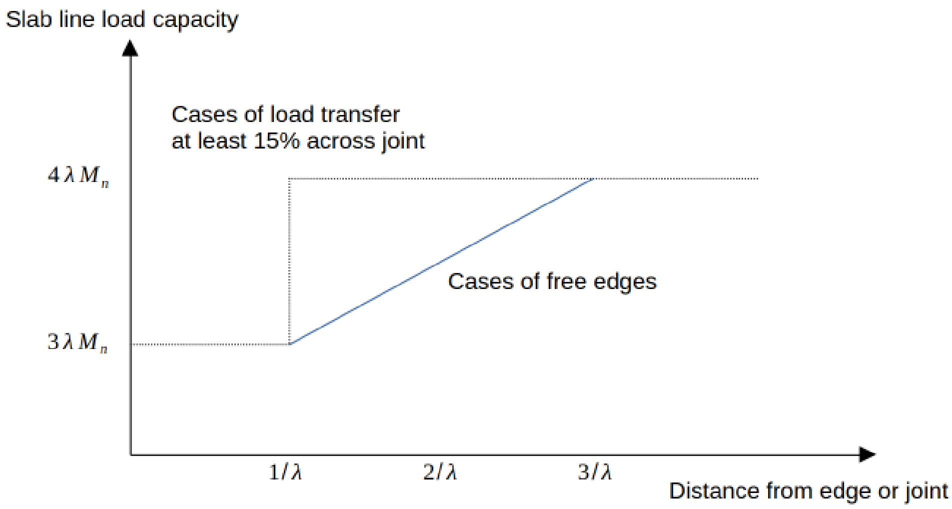
The maximum UDL capacity of the slab is therefore $q = 5.95\lambda^2 M_n = 0.1N/mm^2 = 10.37T/m^2$

This UDL case's working ratio is 0.72

Line loads

Calculations are conducted according to TR34 §7.11.

The capacity of the slab to resist line loads depend on the distance of line loads from edges.



Line load Case 1: Line Storage

Load and geometry

Load	Safety Factor	Distance from edge
40.0 N/mm = 4.0 T/m	1.5	1200.0

Slab bending verification

Based on the geometry above and slab performances, the characteristic length is $\lambda = (\frac{3k}{E_{cm}h^3})^{0.25} = 0.9777m^{-1}$.

The maximum line loads capacity of the slab at a distance of 1200.0 mm from edges is therefore $71.28N/mm = 7.13T/m^2$

This line load case's working ratio is 0.84

Isolated single point loads

Point loads are considered isolated when they are at least 2.557374700737456 meters apart.

Single point load Case 1: Isolated Upright

Loads and geometry

Point load	Safety Factor	Baseplate Width	Baseplate Length
50000.0 N	1.6	120.0 mm	120.0 mm

Slab bending verification

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 367735.1N$	$P_{u,edge} = 199814.0N$	$P_{u,corner} = 90818.0N$
Slab's Working Ratio	0.22	0.4	0.88

Slab punching shear verification

Punching capacity of suspended slab at the face of loaded areas: $P_{p,max} = 370593.4N$

Punching capacity of suspended slab at the critical perimeter: $P_p = 282131.0N$

	Internal	Edge
Ground Support	$R_p = 8500.2N$	$R_{cp} = 16911.3N$
Working Ratio, Face of loaded area	0.19	0.17
Working Ratio, on the critical perimeter	0.25	0.22

Dual point loads

Point loads are considered interacting if they are less than 2.557374700737456 (that is $3.5 \times l$) meters apart.

Dual point load Case 1: 2 Uprights

Loads and geometry

Point load	Safety Factor	Load Spacing	Baseplate Width	Baseplate Length
45000.0 N	1.6	1200.0 mm	120.0 mm	120.0 mm

Slab bending verification

Based on the geometry above, loads are interacting as a true dual point load.

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 486244.5N$	$P_{u,edge} = 334832.6N$	$P_{u,corner} = 90818.0N$
Slab's Working Ratio	0.3	0.43	0.79

NB. The slab's ultimate load is compared to the sum of interacting loads to calculate working ratios.

Slab punching shear verification

Punching capacity of suspended slab at the face of loaded areas: $P_{p,max} = 370593.4N$

Punching capacity of suspended slab at the critical perimeter: $P_p = 282131.0N$

	Internal	Edge
Ground Support	$R_p = 7650.1N$	$R_{cp} = 15220.2N$
Working Ratio, Face of loaded area	0.17	0.15
Working Ratio, on the critical perimeter	0.23	0.2

Quadruple point loads

Point loads are considered interacting if they are less than 2.6 (that is $3.5 \times l$) meters apart.

Quadruple point load Case 1: 4 Wheels Axle

Loads and geometry

Point load	Safety Factor	Load Spacing X	Load Spacing Y	Baseplate Width	Baseplate Length
25000.0 N	1.6	1800.0 mm	0.0 mm	100.0 mm	100.0 mm

Slab bending verification

Based on the geometry above, loads are too close in one direction and were combined. They are interacting in the other direction.

	Internal	Edge	Corner
Slab's Ultimate Load	$P_{u,internal} = 523011.4N$	$P_{u,edge} = 359132.2N$	$P_{u,corner} = 86219.1N$
Slab's Working Ratio	0.31	0.45	0.93

NB. The slab's ultimate load is compared to the sum of interacting loads to calculate working ratios.

Slab punching shear verification

Punching capacity of suspended slab at the face of loaded areas: $P_{p,max} = 308827.8N$

Punching capacity of suspended slab at the critical perimeter: $P_p = 274126.1N$

	Internal	Edge
Ground Support	$R_p = 4017.7N$	$R_{cp} = 7862.3N$

	Internal	Edge
Working Ratio, Face of loaded area	0.12	0.1
Working Ratio, on the critical perimeter	0.13	0.12

General guidelines (TR34)

The slab shall be constructed so that it has the ability to move freely while concrete shrinks. Particularly, it shall be cast on top of a slip membrane to reduce frictional restraint, and all fixed elements (columns, walls, pits, etc.) shall be dissociated from the slab by means of isolation joints.

Joint form panels in the slab. Pannels shall be ideally square or with an aspect ratio above 1 : 1.5. The biggest dimension of pannels shall not exceed 6m.

Sawn joints shall have a typical depth of 25% - 30%. Deeper joints may reduce load transfer.

Avoid point loads at joints when designing joints layout.

Avoid re-entrant corner when designing joints' layout.

A free-movement joint shall be provided between the slab and any adjacent structure, such as docks, machine bases, etc.