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Data :

Uniform distributed load q: 30 (kN/m^2)

Fork-lift truck:

Wheel load Q: 6.25 (kN)

Contact pressure p: 1.39 (N/mm^2)

Truck :

Wheel load Q: 15.63 (kN)

Contact pressure p: 1.95 (N/mm^2)

Concentrated loads:

Point loads Q 20 (kN)

Contact pressure p: 0.89 (N/mm^2)

Nearest distance to 2nd pt. Q 100 mm

Soil data:

Required CBR-value: 5.00 (%)

Modulus of subgrade reaction K: 0.039 (N/mm^3)

Proposed solution:

Concrete grade: C30

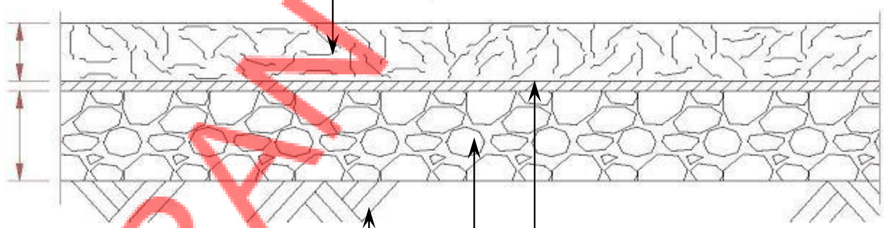
Type of fibre: STAHLCON HE 0.75/60

Fibre dosage rate: 20 (kg/m^3)

Slab thickness h: 150 (mm)

Distance between joints L: 6 (m)

150 mm thick grade C30 concrete slab reinforced with 20 kg/m^3 steel fibre type STAHLCON HE 0.75/60 only.
(Design $R_{e,3}$ value = 52%)



Kind Regards,

Ref	Calculation	Remarks

Steel Fibre Reinforced Concrete Slab On Grade Design

Design info:

SLAB LAYOUT

Total Width of the Floor :	B	=		m
Total Length of the Floor :	L	=		m

CONCRETE

Concrete density :	ρ_c	=	24	kN/m3
Characteristic cube compressive strength :	f_{cu}	=	30	N/mm2
Characteristic cylinder compressive strength :	f_{ck}	=	24	N/mm2
Mean cylinder compressive strength :	f_{cm}	=	32	N/mm2
Mean axial tensile strength :	f_{ctm}	=	2.5	N/mm2
Characteristic 5% fractile axial tensile strength :	$f_{ctk(0.05)}$	=	1.7	N/mm2
Secant Modulus of Elasticity (short-term) :	E_{cm}	=	31162	MPa
Concrete Poisson's Ratio :	ν	=	0.15	*(0.15~0.2)*
Slab Thickness :	h	=	150	mm
Characteristic flexural strength of plain concrete :	$f_{ctk,fl}$*	=	3.41	N/mm2

The value has taken into account of shrinkage effect.

Distance Between Shrinkage Joints :	Ls	=	6	m (5~12m, 0 for Jointless Floor)

Note: *For jointed floor, bays for joints side length ratio range from 1 to 1.5, side length = 5m ~ 12m.*
For jointless floor, bays for "expansion joints" side length ratio: 1~1.5, max. side length = 45m.
Both jointed and jointless floor require "isolation joint"(1~2.5cm) to separate from other structures.

FIBRE

Fibre type : **STAHLCON HE 0.75/60**
Fibre dosage : 20 kg/m3

Equivalent flexural ratio :	R_{e3}	=	52	%

SOIL

California Bearing Ratio :	CBR	=	5	%
Westergaard Modulus of Subgrade Reaction :	*k*	=	0.039	N/mm3

(min. k value for jointed floor is 0.03N/mm3; for jointless floor is 0.05N/mm3)

SOIL-CONCRETE

soil-concrete friction parameter :	c	=	1.0	
Radius of Relative Stiffness :	l	=	693	mm

MATERIAL SAFETY FACTOR

Safety Factor for plain concrete or SFRC:	γ_c	=	1.5
Safety Factor for steel bars:	γ_{st}	=	1.15

LOAD SAFETY FACTOR

Static Load Safety Factor :	γ_s	=	1.5
Number of Load Repetition :	N	=	500000
Dynamic Load Safety Factor :	γ_d	=	2.0

LOADING

1) Uniform Load

Applied Uniform Distributed Load (UDL) :	q	=	30	kN/m2
Load Safety Factor for UDL :	γ_q	=	1.5	

2) Line Load

Applied Line Load :	P_{lin}	=	10	kN/m
Load Safety Factor for Line Load :	γ_p	=	1.5	

3) Point Loads

Fork-Lift Operational Capacity :	W_1	=	5	Tons
Numbers of aisles :	Na_1	=	2	nos.
Numbers of wheels per aisle :	N_1	=	4	nos.
Aisle width along moving direction :	B_{aa1}	=	600	mm
Aisle width perpendicular to moving direction :	B_{ap1}	=	1200	mm
Closest wheel to wheel distance :	B_{wm1}	=	600	mm

Ref	Calculation				Remarks
	Contact width per wheel :	b_1	=	150 mm	
	Contact length per wheel :	t_1	=	30 mm	
	Contact radius per wheel :	a_1	=	37.85 mm	
	Contact pressure per wheel :	p_1	=	1.39 N/mm2	
	Truck Load Capacity :	W_2	=	50 Tons	
	Numbers of aisles :	Na_2	=	8 nos.	
	Numbers of wheels per aisle :	N_2	=	4 nos.	
	Aisle width along moving direction :	B_{aa2}	=	600 mm	
	Aisle width perpendicular to moving direction :	B_{ap2}	=	2400 mm	
	Closest wheel to wheel distance :	B_{wm2}	=	250 mm	
	Contact width per wheel :	b_2	=	200 mm	
	Contact length per wheel :	t_2	=	40 mm	
	Contact radius per wheel :	a_2	=	50.46 mm	
	Contact pressure per wheel :	p_2	=	1.95 N/mm2	
	Other concentrated loads : Point Load 3 :	W_3	=	20 kN	
	Contact width :	b_3	=	150 mm	
	Contact length :	t_3	=	150 mm	
	Contact radius :	a_3	=	84.63 mm	
	Contact pressure :	p_3	=	0.89 N/mm2	
	Distance(eg. between rack legs at "back-to-back" arrangement) :	D_3	=	100 mm	

ANALYSIS

TR34, 2003 Chapter 9

General moment capacity per m width of a plain concrete section:

$$M = (f_{ctk,fl}/\gamma_c)(h^2/6)$$
$$= 8.54 \text{ kNm/m}$$

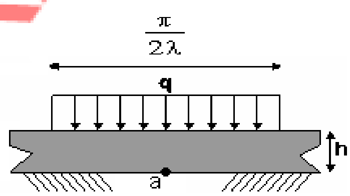
Positive bending moment capacity per m width of steel-fibre-reinforced concrete:

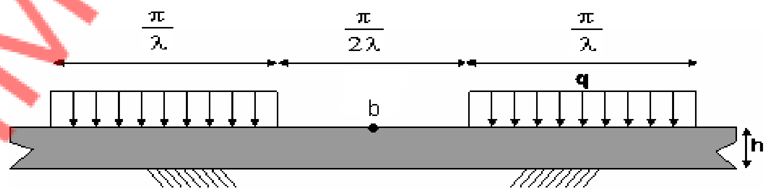
$$M_p = (f_{ctk,fl}/\gamma_c)\, R_{e3}\, (h^2/6)$$
$$= 4.44 \text{ kNm/m}$$

Negative bending moment capacity per m width of steel-fibre-reinforced concrete:

$$M_n = (f_{ctk,fl}/\gamma_c)(h^2/6)$$
$$= 8.54 \text{ kNm/m}$$

a)"Uniformly Load Capacity"





According to Hetényi's work that based on elastic analysis approach, for a slab strip of 1 m width, the critical sagging moment is caused by a patch load of breadth π/2λ that shall arise at point a; while the critical hogging moment is caused by two patch loads of breadth π/λ spaced at π/2λ distance (also called critical aisle width) that shall arise at point b.

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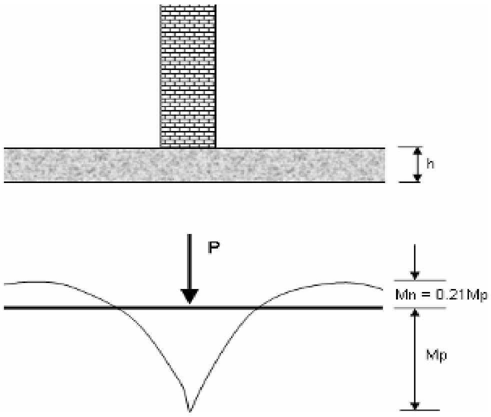
$$\lambda = \sqrt[4]{\frac{3k}{E_{cm} h^3}}$$ = 0.001026 mm^{-1} , where 1/l is the characteristic length of the system.

Thus, uniform load capacity per unit area, w = $(1/0.168)\ \lambda^2$ M

= 53.51 kN/m2 > q (30 kN/m2) **OK!**

(In practice, γ_q is not required since γ_c has been accounted for here)

b)"Linear Load Capacity"



Hetényi's elastic analysis determined that the distribution of bending moment induced by a line load applied to a slab is as shown, with $M_n = 0.21M_p$

Load capacity per unit length of slab,

P_{clin} = 4 λ M

= 35.04 kN/m

\> P_{lin} **OK!**

c)"Concentrated loads"

i) Single Point Loads:

Technical Report TR34 adopts the design equations given by Meyerhof's plastic analysis for point loads on slab-on-ground. However, Meyerhof's method is not explicit in dealing with values of a/l < 0.2; this setback has been resolved by linear interpolating the results for values of a/l equal to 0 and 0.2

For an internal load: *when a/l = 0,* $P_{iu} = 2\pi\ (M_p + M_n)$

when a/l ≥ 0.2, $P_{iu} = 4\pi\ (M_p + M_n)/[1-a/(3l)]$

For a free edge load: *when a/l = 0,* $P_{eu} = \pi\ (M_p + M_n)/2 + 2M_n$

when a/l ≥ 0.2, $P_{eu} = [\pi\ (M_p + M_n) + 4M_n]/[1-2a/(3l)]$

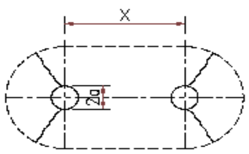
For a free corner load: *when a/l = 0,* $P_{cu} = 2\ M_n$

when a/l ≥ 0.2, $P_{cu} = 4\ M_n/[1-(a/l)]$

In calculating the edge and corner load capacities, it is assumed that there is no load transfer between slabs.
If load transfer mechanism is present,
the calculated free corner load capacity can be increased by dividing 0.7
,and the calculated free edge load capacity can be increased by dividing 0.85

Hence, is load transfer mechanism present? *1: yes* *2 : no* 1

ii) Dual Point Loads:



If the centre line spacing, x between two point loads is lesser than 2h (h = thickness of slab), Technical Report TR34 suggests that the loads shall be checked base on simplified approach similar to the method for single point load; or else, the following method shall be adopted to check their combined effects.

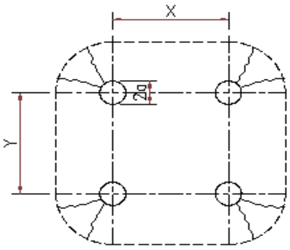
Ref	Calculation	Remarks

For internal loads: *when a/l = 0,* P_{i2u} = $[2\pi + (1.8x/l)] (M_p + M_n)$

when a/l ≥ 0.2, P_{i2u} = $\{4\pi/[1-a/(3l)] + 1.8x/[l-(a/2)]\} (M_p + M_n)$

For free edge loads: P_{e2u} = $0.5*P_{i2u}$

iii) Quadruple Point Loads:



If the centre line spacing, x between two point loads in a row and centre line spacing, y between adjacent point loads in a column are both lesser than 2h (h = thickness of slab), Technical Report TR34 suggests that the quadruple point loads shall be checked for their combined effects.

For internal loads: *when a/l = 0,* P_{i4u} = $\{2\pi + [1.8(x+y)/l]\} (M_p + M_n)$

when a/l ≥ 0.2, P_{i4u} = $\{4\pi/[1-a/(3l)] + 1.8(x+y)/[l-(a/2)]\} (M_p + M_n)$

For free edge loads: P_{e4u} = $0.5*P_{i4u}$

The above collapse load computed shall be compared against the sum of each single collapse load and also the sum of each dual collapse load; the lesser value shall be adopted.

LOAD CAPACITY CHECK FOR SINGLE LOAD				
		Load 1	Load 2	Load 3
Load per wheel,P(kN)		6.25	15.63	20
Load safety factor, γ		2.0	2.0	1.50
$P_u = \gamma P$ (kN)		12.50	31.25	30.00
When a/l = 0:				
$P_{iu,0}$ (kN)		81.53	81.53	81.53
$P_{eu,0}$ (kN)		37.45	37.45	37.45
$P_{cu,0}$ (kN)		17.07	17.07	17.07
When a/l = 0.2:				
$P_{iu,0.2}$ (kN)		174.70	174.70	174.70
$P_{eu,0.2}$ (kN)		86.43	86.43	86.43
$P_{cu,0.2}$ (kN)		42.68	42.68	42.68
contact radius,a(mm)		37.85	50.46	84.63
a/l		0.0546	0.0728	0.1221
Load capacity (kN):				
Internal	P_{iu}	106.97	115.45	138.41
Edge	P_{eu}	59.80	65.04	79.25
Corner	P_{cu}	34.38	37.71	46.73
min (P_{iu}, P_{eu}, P_{cu}) > P_u, OK?		***OK!***	***OK!***	***OK!***

OK!

Ref	Calculation	Remarks

LOAD CAPACITY CHECK FOR DUAL LOADS

		Comb 1	Comb 2	Comb 3	Comb 4	Comb 5	Comb 6
		Load 1 & Load 1	Load 2 & Load 3	Load 3 & Load 3	Load 1 & Load 2	Load 1 & Load 3	Load 2 & Load 3
Dual Load, P_{2u} (kN)		25.00	62.50	60.00	43.75	42.50	61.25
Distance, x (mm)		100	100	100	100	100	100
Contact area, A(mm^2)		12,069	18,093	39,426	15,081	25,748	28,759
When a/l = 0:							
$P_{i2u,0}$ (kN)		81.53	81.53	81.53	81.53	81.53	81.53
$P_{e2u,0}$ (kN)		37.45	37.45	37.45	37.45	37.45	37.45
When a/l = 0.2:							
$P_{i2u,0.2}$ (kN)		168.06	169.23	172.34	168.67	170.47	170.92
$P_{e2u,0.2}$ (kN)		79.66	80.81	83.96	80.26	82.05	82.50
contact radius,a(mm)		37.85	50.46	84.63	37.85	37.85	50.46
equivalent radius,a_{eq}(mm)		61.98	75.89	112.02	69.29	90.53	95.68
a/l		0.0546	0.0728	0.1221	0.0546	0.0546	0.0728
a_{eq}/l		0.0894	0.1095	0.1617	0.1000	0.1306	0.1381
Load capacity (kN):							
Internal	P_{i2u}	120.22	129.54	154.92	125.09	139.62	143.23
Edge	P_{e2u}	66.27	71.99	88.28	69.24	78.34	80.65
min (P_{i2u},P_{e2u}) > P_{2u}, OK?		***OK!***	***OK!***	***OK!***	***OK!***	***OK!***	***OK!***

OK!

LOAD CAPACITY CHECK FOR QUADRUPLE LOADS

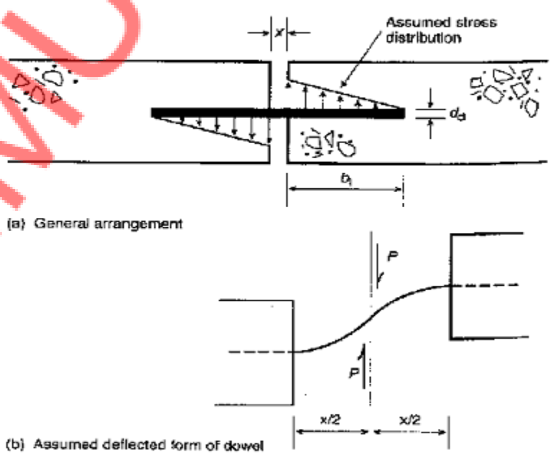
		2 x Comb 1	2 x Comb 2	2 x Comb 3	2 x Comb 4	2 x Comb 5	2 x Comb 6
Load, P_{4u} (kN)		50.00	125.00	120.00	87.50	85.00	122.50
Distance, x (mm)		300	300	300	300	300	300
Distance, y (mm)		600	600	600	600	600	600
Contact area, A(mm^2)		252,625	278,833	354,831	265,729	303,728	316,832
When a/l = 0:							
$P_{i4u,0}$ (kN)		111.86	111.86	111.86	111.86	111.86	111.86
$P_{e4u,0}$ (kN)		55.93	55.93	55.93	55.93	55.93	55.93
When a/l = 0.2:							
$P_{i4u,0.2}$ (kN)		197.26	198.58	202.27	197.26	197.26	198.58
$P_{e4u,0.2}$ (kN)		98.63	99.29	101.14	98.63	98.63	99.29
contact radius,a(mm)		37.85	50.46	84.63	37.85	37.85	50.46
a/l		0.0546	0.0728	0.1221	0.0546	0.0546	0.0728
Load capacity (kN):							
Internal	P_{i4u}	-	-	-	-	-	-
Edge	P_{e4u}	-	-	-	-	-	-
min (P_{i4u},P_{e4u}) > P_{4u}, OK?		-	-	-	-	-	-

Not required as x or y > 2h

d)"Load Transfer at Joint"

TR34, 2003 Sec 9.10

Load transfer at joint is simplified by considering quantitative dowel bar actions only, other methods such as aggregate interlock and steel fibre pull-out resistance at joints are disregard here.



(a) General arrangement

(b) Assumed deflected form of dowel

d_d = diameter of dowel bar (mm)

b_1 = effective bearing length (mm)

(≤ 8 x d_d for design purpose)

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Say, provide dowel bars T16 @ 300 mm

Gross sectional area of bar, A = 201.06 mm^2
Shear area of bar, $A_v = 0.9 \times A$ = 180.96 mm^2
Yield strength of dowel bar, f_y = 250 N/mm^2
Plastic section modulus of dowel, Z_p = 682.67 mm^3
Joint width opening, x = 10 mm

Shear capacity per dowel, P_{sh} = $0.6\ f_y\ A_v\ /\gamma_{st}$ = 23.6 kN

Bearing capacity per dowel, P_{bear} = $0.5\ f_{cu}\ b_1\ d_d\ /\ \gamma_c$ = 20.5 kN

Bending capacity per dowel, P_{bend} = $2\ f_y\ Z_p\ /\ (x\ \gamma_{st})$ = 29.7 kN

Under combined shear and bending, the load-transfer capacity per dowel, P_{app} is controlled by the following interaction formula:

$P_{app}/P_{sh} + P_{app}/P_{bend}$ ≤ 1.4

, hence P_{app} ≤ 18.4 kN

In this case, load-transfer capacity per dowel, P_{app} = 18.4 kN

Corresponding max. allowable transfer load per unit length, P_{all} = 61.4 kN/m

Existing maximum load transfer at joint, P = 9.38 kN/m — *(15% load transfer at edge of slab)*

< 61.4 kN/m — ***OK!***

Maximum load per dowel (kN) to avoid bursting (punching of slabs):

Dowel diameter (mm)	Slab thickness (mm)						
	100	125	150	175	200	225	250
10	6.0	12.5	19.1	25.1	32.1	38.6	45.2
12	7.7	14.5	21.3	27.7	35.0	41.8	48.6
16	9.0	16.2	23.4	30.2	37.8	45.0	52.2
20	10.5	18.0	25.6	32.7	40.7	48.2	55.7

In this case, bursting force per dowel, P_{burst} = 19.1 kN > 2.8 kN (total force per dowel) — ***OK!***

e)"Shear at the face of loaded area"

Maximum allowable shear stress, $v_{max} = 0.5k_2f_c'/\gamma_c$

, where f_c' = concrete cylinder compressive strength = 0.8fcu = 24 N/mm2
$k_2 = 0.6(1-f_c'/250)$ = 0.54
γ_c = safety factor for concrete = 1.5

Thus, v_{max} = 4.34 N/mm2

Max. shear stress at the face of critical loaded area,
$v_f = (V/p)_{max}/(0.75h)$ = 1.06 N/mm2 < 4.34 N/mm2 — ***OK!***
,where p = contact perimeter of loaded area

f)"Punching shear check"

Equivalent Flexural Ratio, $R_{e,3}$ = 52 %

Characteristic axial strength at 5% fractile, $f_f = 0.18fcu^{2/3}$ = 1.74 N/mm2
flexural strength of concrete, $f_{fl} = [1+(200/h)^{0.5}]f_f$ = 3.48 N/mm2 <= $2f_f$

effective depth d = 0.85h = 127.5 mm
critical perimeter $u_i = p+2\pi*2*d$ = 1902 mm (assume $p = p_{min}$ = 300mm)
$k_1 = 1+ (200/d)^{0.5}$ = 2.25 or 2.0, whichever lesser

Punching shear capacity, $v_c = 0.035k_1^{3/2}(f_c')^{1/2} + 0.12R_{e,3}f_{fl}$ = 0.702 N/mm2

Hence, slab load capacity, $P_p = v_c\ u_i\ d$ = 170 kN > all point loads — ***OK!***

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g)"Serviceability check"

I) Deflection control:

Westergaard had given an approximate quantification of slab deflections under a concentrated load P as follow:

Immediate deflection, δ = $c\,[P/(kl^2)]$

Long-term deflection, δ_L = $c\,[P/(kl_L^2)]$

, where c = deflection coefficient =
- 0.125 , for internal loading;
- 0.442 , for free-edge loading;
- [1.1-1.24 (a/l)] , for free-corner loading;

; and l_L = modified radius of relative stiffness due to creep = $l/(1+\phi)^{0.25}$

; and ϕ = creep factor = 2.0 (recommended value)

P = critical concentrated load under service load condition

a = contact radius for concentrated load P = 112 mm

Position of load	P (kN)	c	l (mm)	l_L (mm)	δ (mm)	δ_L (mm)
Internal	40	0.125	693	527	0.3	0.5
Free-edge	40	0.442	693	527	0.9	1.6
Free-corner	40	0.900	693	527	1.9	3.3

The deflection is small and yet the load-transfer at joint which may reduce the deflections at edge and corner of slab has not been considered. ***OK!***

Hence, For a slab thickness of 150 mm, concrete grade C30 and a fibre dosage rate of 20 kg/m3 STAHLCON HE 0.75/60 ***The design is OK!***