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Design for Load Transfer in Industrial Concrete Pavement Joints

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DANLEY Systems
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Introduction

Industrial pavements, for the purposes of this document are rigid pavements, and may be either:

- Jointed unreinforced concrete pavements
- Jointed reinforced concrete pavements
- Steel fibre reinforced concrete pavements
- Post tensioned concrete pavements

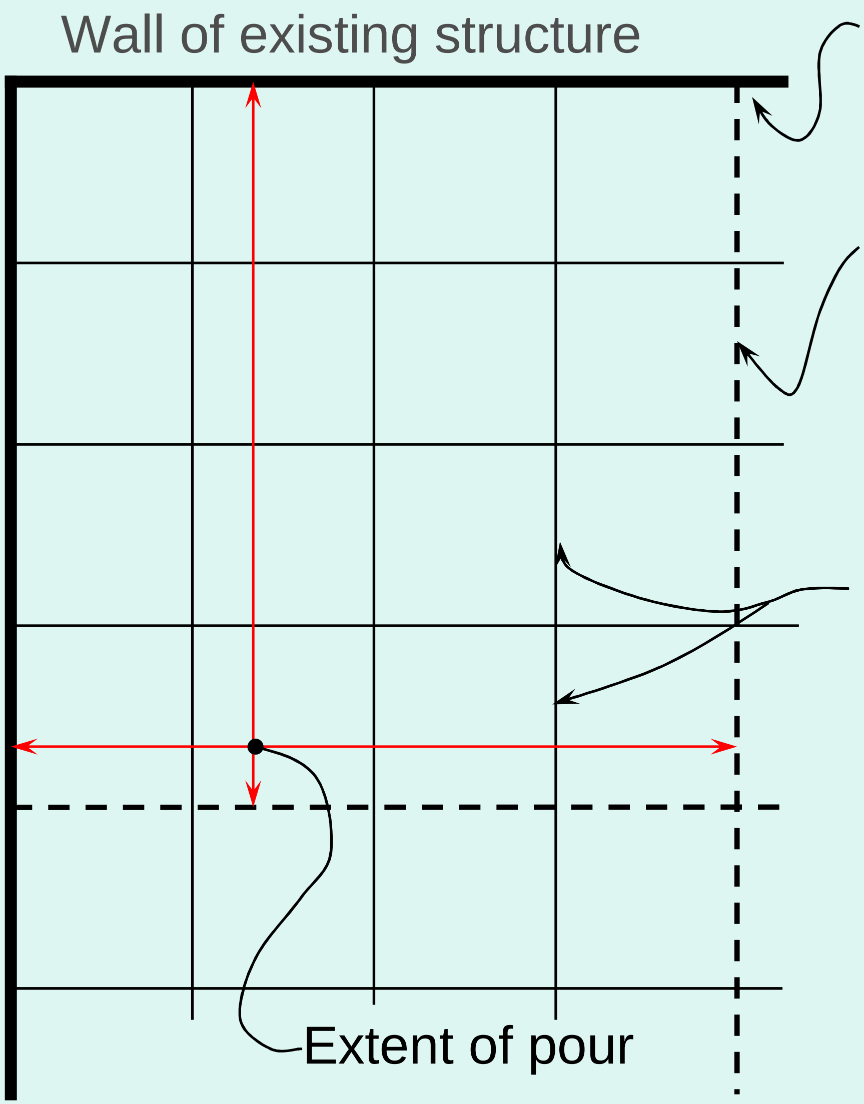
Recognized design guides such as the Australian CCAA T48 or the U.K. Concrete Society Technical Reports TR34 and TR66 may be used to determine slab thickness, but you should be cautioned that they do have some shortcomings with regard to load transfer

This design methodology should not be used as the sole determination of slab thickness; however, it may well be that load transfer requirements are the controlling factor in determining slab thickness

Basis of design

- Concrete shrinks – so dowels require sleeves that allow movement both perpendicular and parallel to the joint
- Concrete slabs curl, so perimeter of slab will be unsupported by sub-grade
- Slab design needs to be based on edge loading condition
- Edge thickenings at joints should not be used
- There needs to be sufficient concrete surrounding the dowels to resist the loads, or supplementary reinforcement may be required
- Select dowel systems with known characteristics [Note that rule-of-thumb design may not be appropriate for the design conditions]

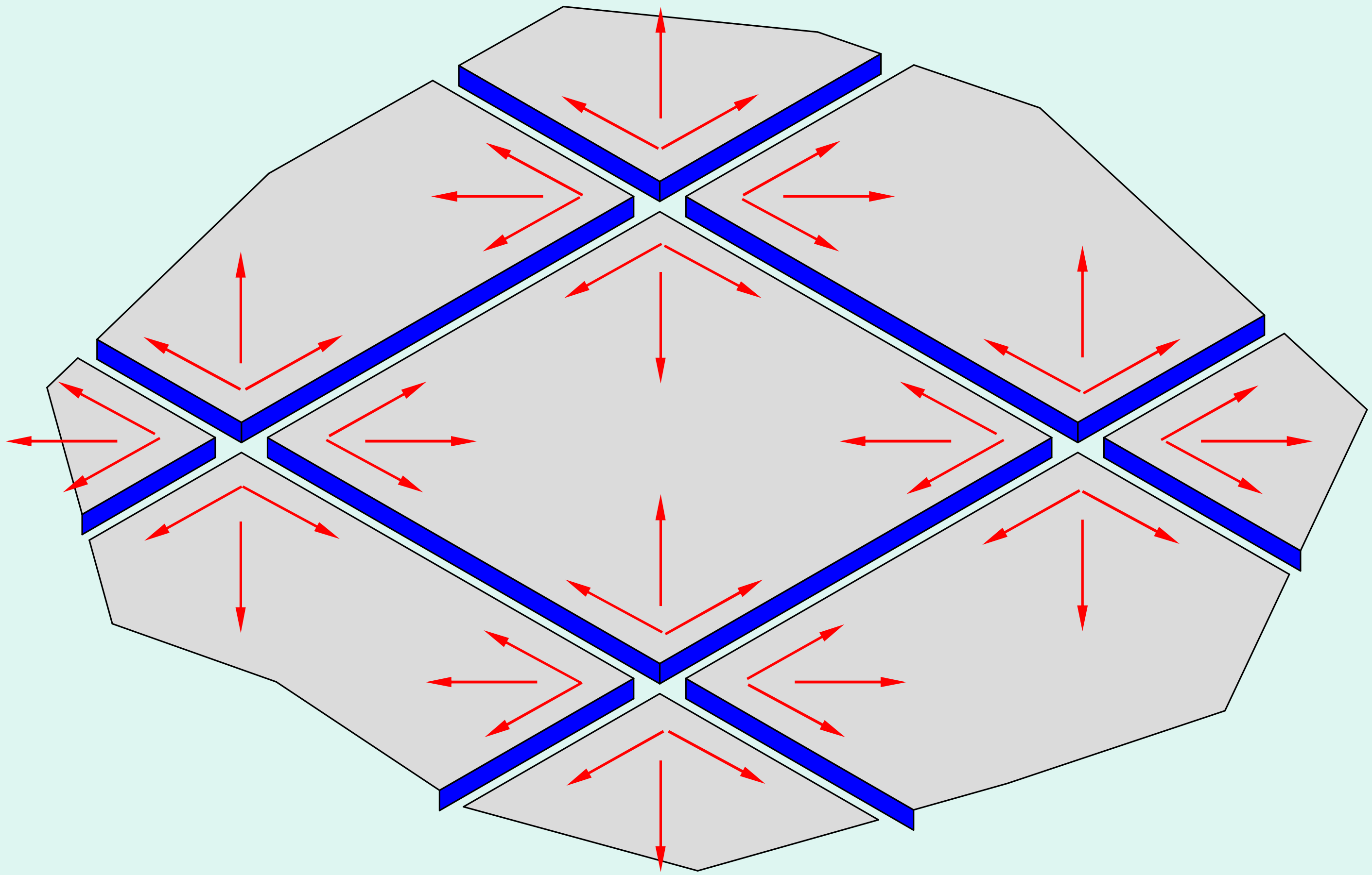
Controlling drying shrinkage with joints



- Isolation joints between slab and adjacent structures, column footings, machinery bases, pits, walls, etc
- Construction joints around the perimeter of each concrete pour - placement is dictated by paving geometry, paving equipment, paving crew size and availability of concrete
- Contraction joints to control random drying shrinkage cracking - position depends on paving geometry, concrete type and mix, predicted concrete shrinkage, intended use for facility, aesthetics, and judgement based on experience
- Not shown are expansion joints [usually construction joints] in exterior pavements

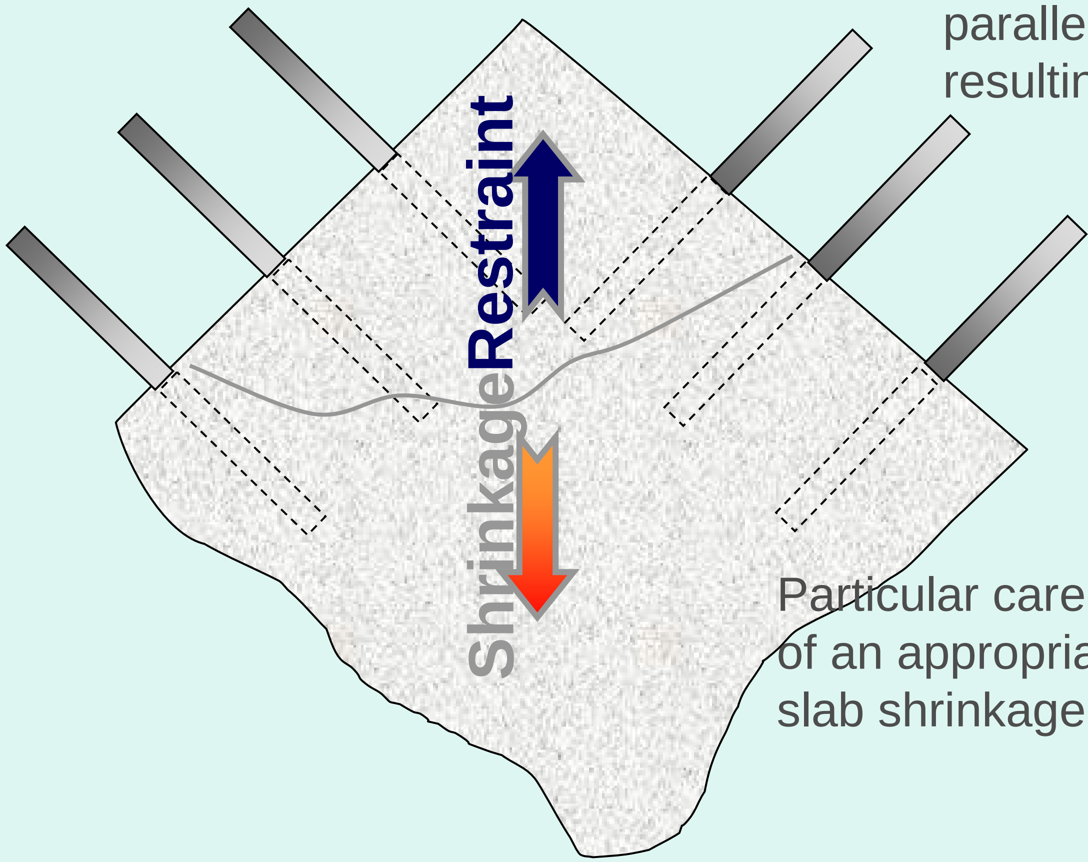
Slab shrinkage dynamics

Designs should allow for independent ‘floating’ panels



Accommodating slab shrinkage

If the sleeve elements of the dowel system do not allow the dowel to move parallel to the line of the joint, the resulting restraint will cause slab failure



Particular care needs to be taken in the choice of an appropriate dowel system, so that these slab shrinkage effects are accommodated

This is particularly important in post tensioned slabs with wide joints.
Joint widths of say 35 mm need to a cater for 18 mm lateral movement

Round dowels

In industrial pavement applications, where contractors want to place large areas of concrete in each pour, with the least number of joints, round dowels consistently fail to perform as expected:

- Use of round dowels perpetuates 1940s technology when slabs were hand placed in 10 to 12 ft squares hence shrinkage effect was minimal
- There are no round dowel systems in the market that accommodate shrinkage parallel to the joint
- Are quite often poorly or incorrectly placed
- Induce higher stresses on concrete than other types of dowels
- Are inefficient in load resistance and deflection properties compared to other dowel systems

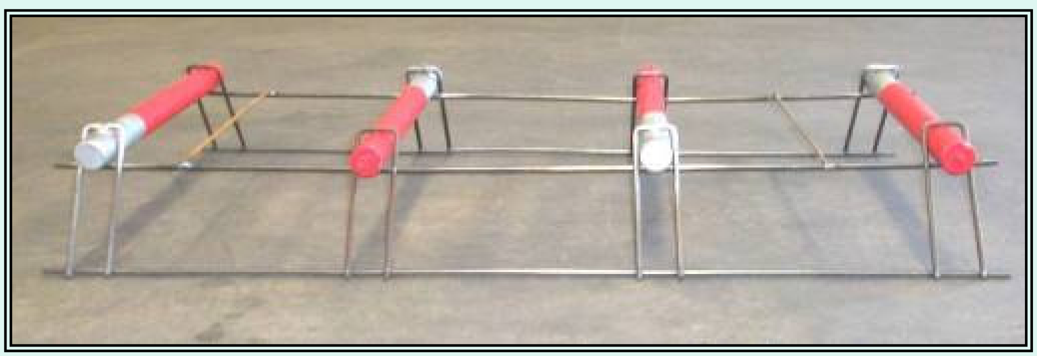
If you want to specify or use round dowels:

- Space joints close together [3 to 4 m max] so that the effects of shrinkage parallel to the joint are minimised

- Use large aggregates in the mix [even 40 mm] to reduce the rate of curing shrinkage

- Use properly supported dowel sleeves in the first pour

- In sawn contraction joint applications, appropriate round dowel cradles should be used

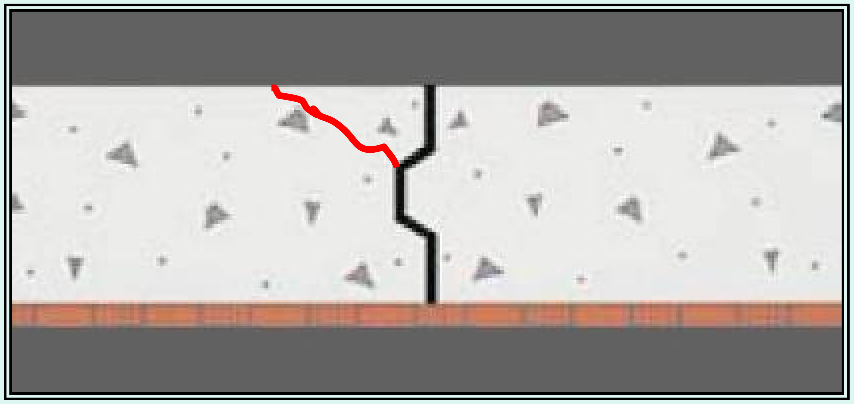


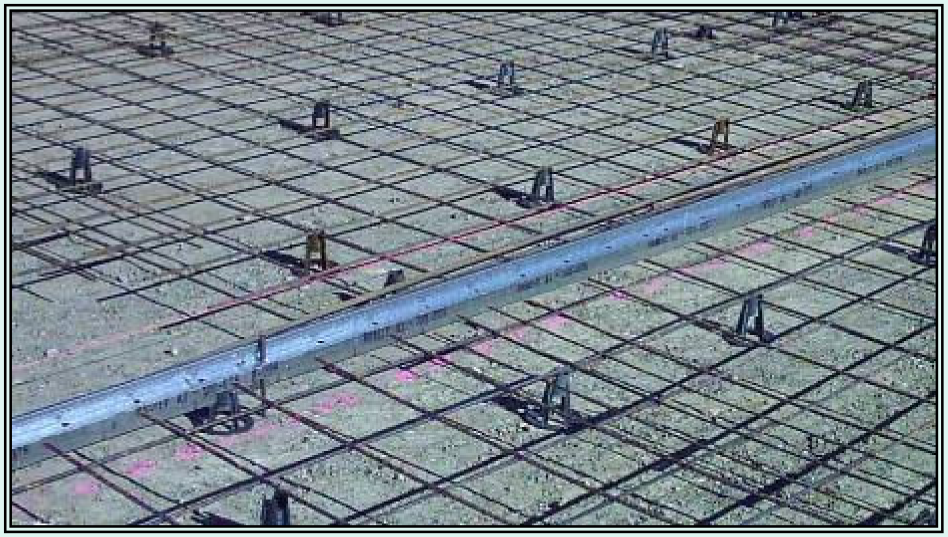
Key joints

Key joints are suitable for lightly loaded applications only where height differential between slabs is of little importance.

If the (joint) opening is greater than 1 mm, … load transfer by key ways … cannot be relied upon and … an effective load transfer device [should be] installed [CCAA T48: 2.1.1 and 2.1.2]

The key on key joints begins at 1/3rd of the depth of the slab, and this where most failures originate – keyed joints cause the adjacent concrete to perform as if it were only 2/3rds of its actual thickness [even when used with dowels]





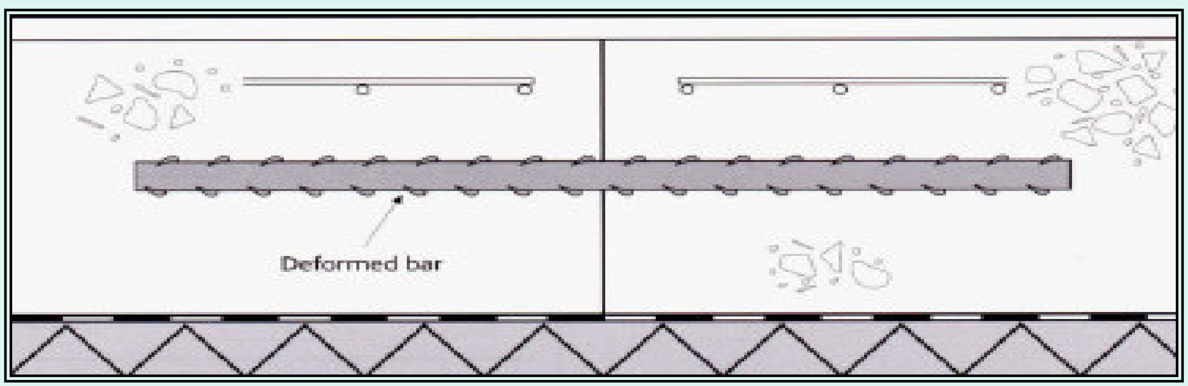
Aggregate interlock

Joint effectiveness deteriorates with every load repetition, and becomes ineffective if joint opens more than 10 to 15% of the size of the largest grade of aggregate used [assuming that there are sufficient pieces of that size aggregate in the fracture plane!]

Also note that depth of sawcut reduces the area available for aggregate interlock to develop

If the (joint) opening is greater than 1 mm, … load transfer by aggregate interlock … cannot be relied upon and … an effective load transfer device [should be] installed [T48:2.2.1]

Even with tied joints, the effectiveness diminishes over time



Dowel systems for construction joints

Diamond® Dowels

Square Dowels with either Dowelmaster® Sleeves for 16 or 20 mm dowels or Flanged Dowel Boxes to suit dowels up to 40 mm square

Dowel systems for sawn contraction joints

6 mm or 10 mm PD^{3} Cradles®
or Plate Dowel Cradles™

Square Dowel Cradles with Dowelmaster®
Sleeves for 16 or 20 mm dowels or Metal
Dowel Covers for dowels up to 40 mm

Dowel design parameters

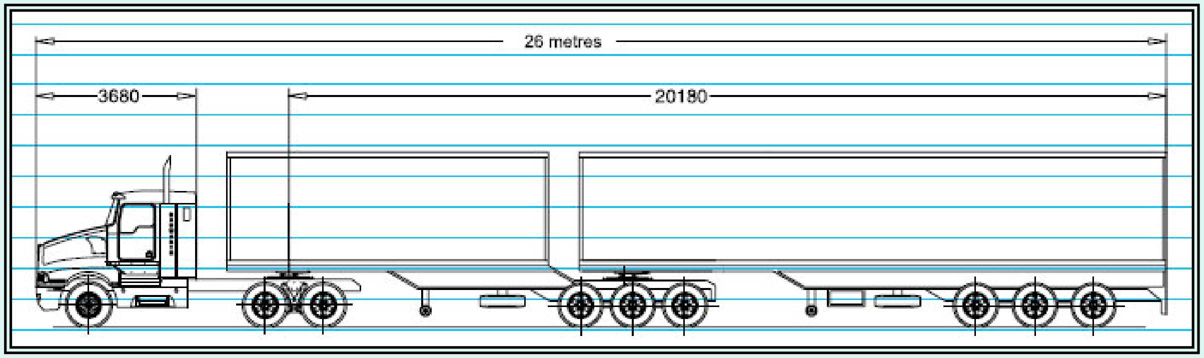
- Magnitude of loading
- Percentage of load to be transferred across the joint
  [must be 100% for loads rolling across joints]
- Load repetitions
- Design concrete strength
- Reinforcing in the slab [unreinforced, steel fibres, bar mats, etc]
- Slab thickness
- Projected joint width [anticipated slab shrinkage]
- Capacity of the concrete at the load transfer device
- Capacity of the load transfer device [dowel steel capacity]
- Supplemental reinforcement at dowels
- Vertical differential movement that can be tolerated
- Joint type – construction, contraction, expansion

What are the loads?

While the uniform loads from stacked material may be high, the wheel loads on the material handling equipment may be more severe on the load transfer dowels in the joints

It's not always the size that matters …

Legal loads on B-doubles



6.0 t on steer axle

17.0 t on tandem axle group

22.5 t on tri-axle group

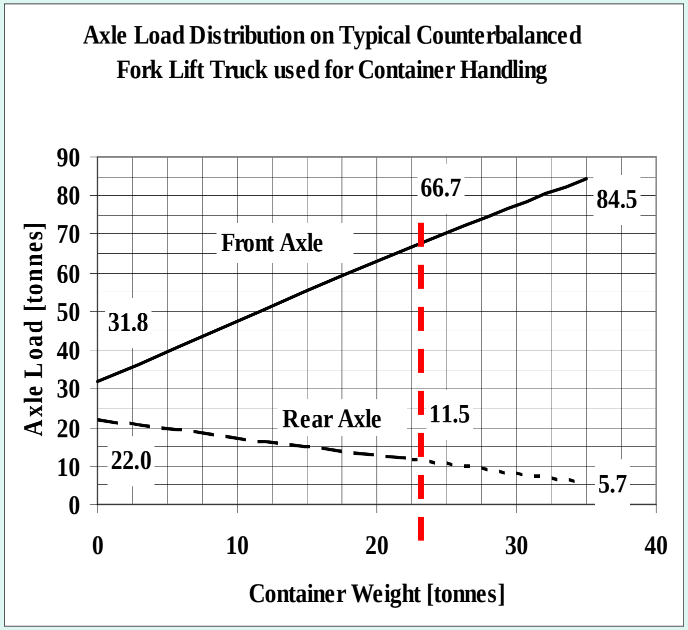
So for B-doubles, load per axle ranges from 6.0 to 8.5 t

But even the humble delivery truck with dual wheel single axles may legally have 10.0 tonne axle loads, and the dowels in concrete pavement joints need to be able to accommodate these loads

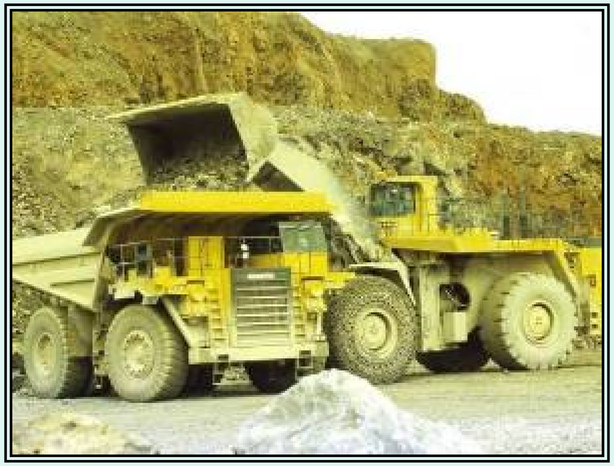
Container handling terminals

The forklift [left] lifting a 23 tonne gross weight container has a front axle load of nearly 67 tonnes; the reach stacker [centre] can have drive axle loads up to 96 tonne; while the straddle carrier could have wheel loads of only 15 tonne

And stacked loaded containers 4 high x 30 tonne each impart a load of 30 tonne on a 162 x 178 mm contact area

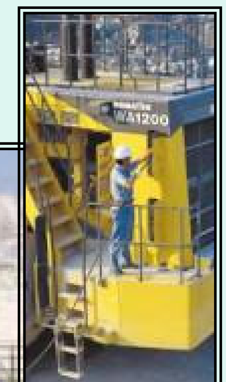


Even in repair facilities at mines



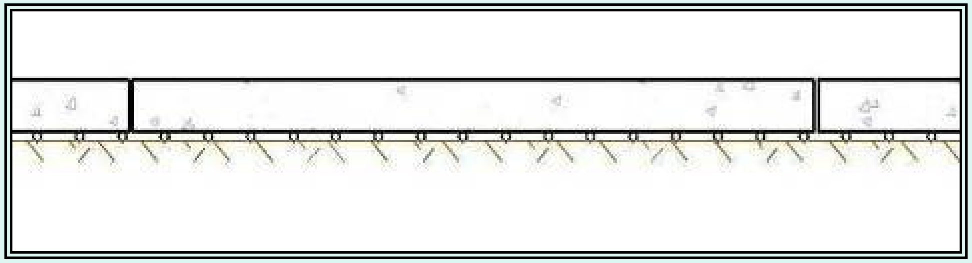
With equipment getting larger and larger, design of dowelled joints for mine maintenance facilities requires close attention

For example, the Komatsu WA1200 “Mountain Mover” wheel loader [below] can load 250 tonnes into the dump truck in just 6 scoops, and is 213 tonnes unladen, and the dump truck 200 tonnes unladen



Don’t forget the details

Slabs curl, [and sub-grade may be “pumped” out] so edges and corners may not be supported



Slabs should be free to move on a well-compacted sub-base, as if on rollers

Recommend using poly sheet as a slip sheet to reduce friction

Poly sheet also reduces moisture loss into the sub-grade, ensuring improved curing

Make sure appropriate dowels are specified for the transition between the exterior pavement and the interior slab

Load factors

As a minimum, recommend use of AustRoads rigid pavement factor of 1.2 on the load side of the equation

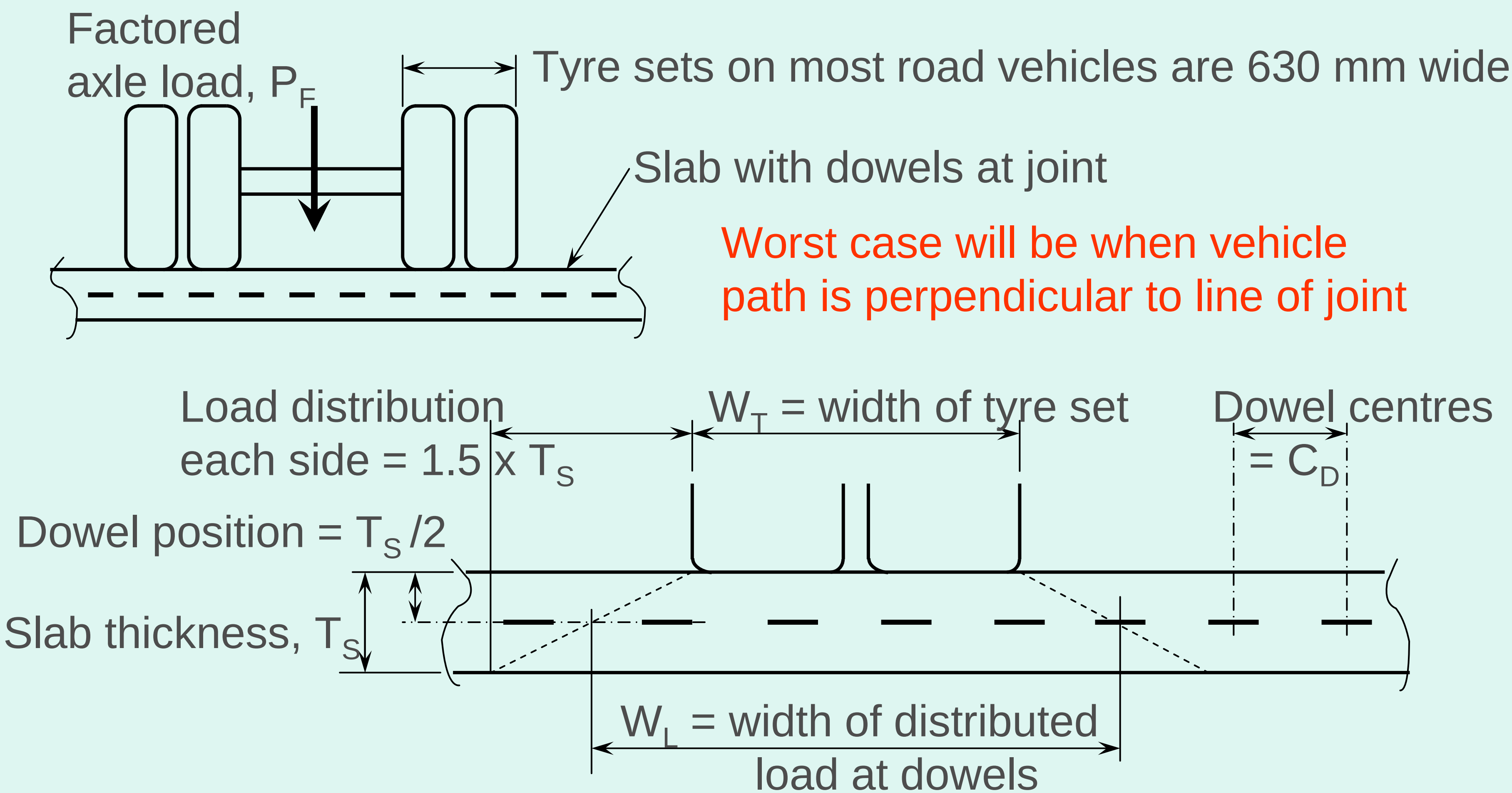
This value does not include any dynamic load factor

While the typical dynamic load factor for highway conditions may be 0.6 or higher, most industrial conditions will only need to cater for low speed applications, in addition to braking and turning effects at low speeds

So recommend use of additive dynamic load factor of 0.2 on the load side of the equation for industrial applications where loaded moving vehicles are present

- So for uniform load conditions and racking, use load factor of 1.2
- And for moving vehicle loads, use load factor of [1.2 + 0.2] = 1.4

Load distribution from vehicle wheels



$W_L = W_T + 1.5\ T_S$

So load per dowel, $P_D = 0.5\ P_F \times [\ C_D / W_L\ ]$

Load resistance and repetition factors

Strength reduction factors should be included in the design charts provided by manufacturers. For loads controlled by concrete strength, use ♐ = 0.6 for fixings in accordance with AS 3600 Table 2.3.(j); or ♐ = 0.9 in accordance with AS 4100 Table 3.4 for loads controlled by steel strength

For light duty industrial applications, it is generally not necessary to use a load repetition factor. However, at the discretion of the engineer, a load repetition factor may be applied to the resistance side of the equation

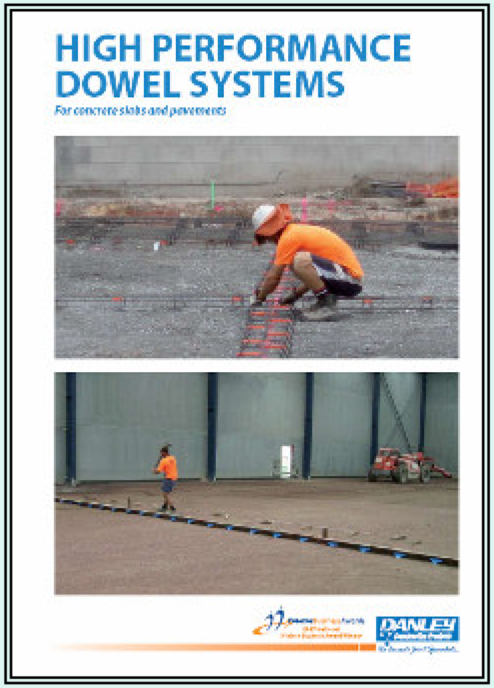
In these situations where frequent heavy load repetitions will be imposed on the joints and dowels, perhaps use of a modified factor of $\sqrt{k_2}$ where the k_2 factor is derived from Table 1.18 of the CCAA T48 *Industrial Floors and Pavements* manual.

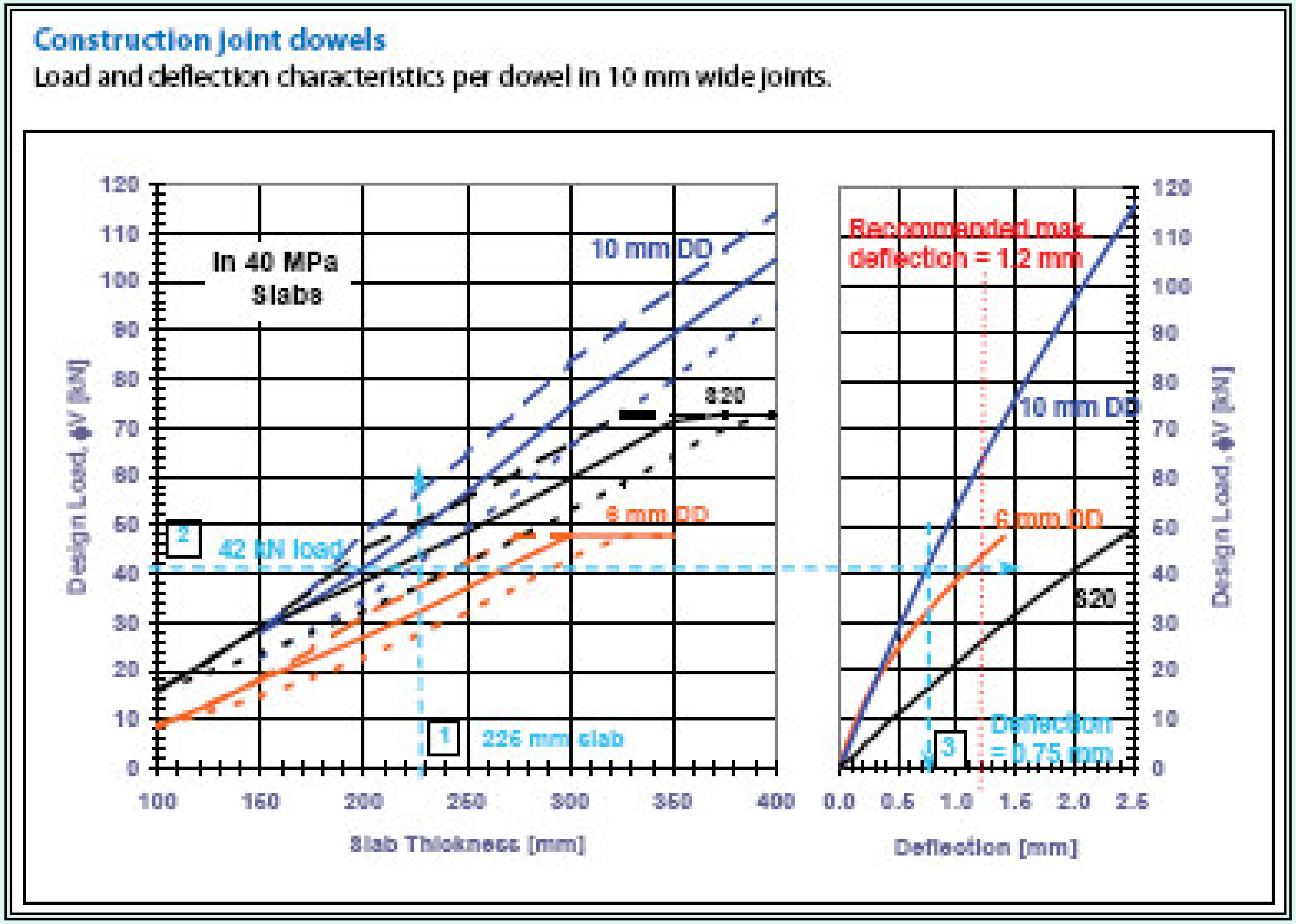
[Note that Table 1.18 of T48 is taken from the AustRoads *Pavement Design Guide* and is appropriate for vehicles at highway speeds, so for low speed traverses and impacts that would be encountered in industrial applications, a reduced factor could be considered appropriate]

Dowel design capacities

Dowel capacity charts such as those contained in the Danley® *High Performance Dowel Systems* brochure should be used.

These selection charts address eight variables



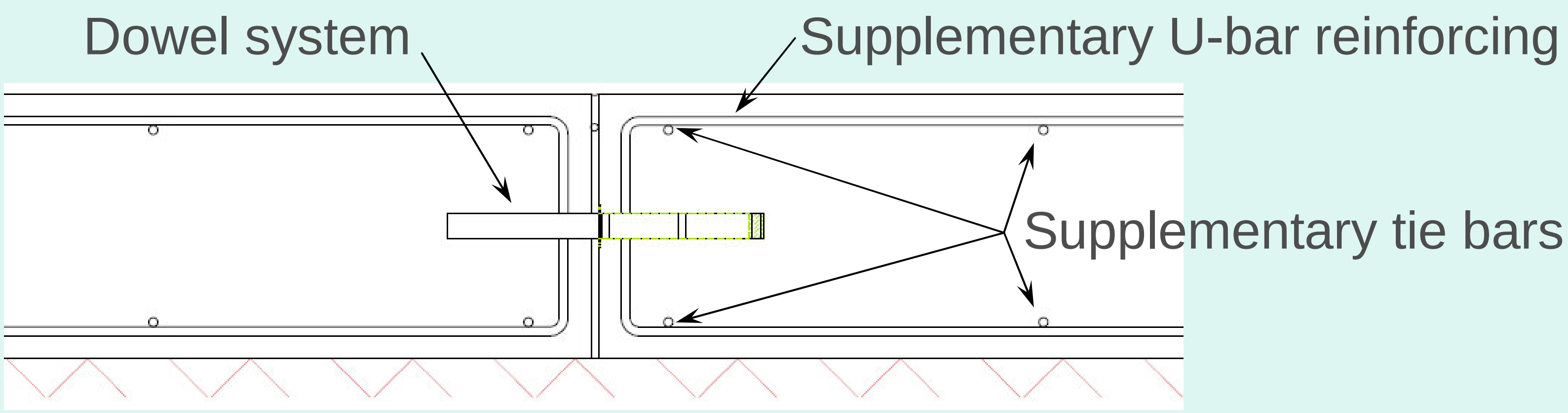


Supplementary reinforcement

Either of two methods of adding supplementary reinforcement may be used if the concrete surrounding the dowels is not sufficient to develop adequate resistance to the applied loads

- Steel fibre reinforcing has been shown in tests [when compared to unreinforced concrete] to increase concrete capacity adjacent to dowels by approximately 30%, even with dosages as low as 20 kg/m^3,
- For some loading conditions, where slab thickness allows, supplementary U-bar reinforcement may be appropriate

Area of steel required = P_D x 10^3 / [0.6 x 500], where P_D is load per dowel



Worked examples

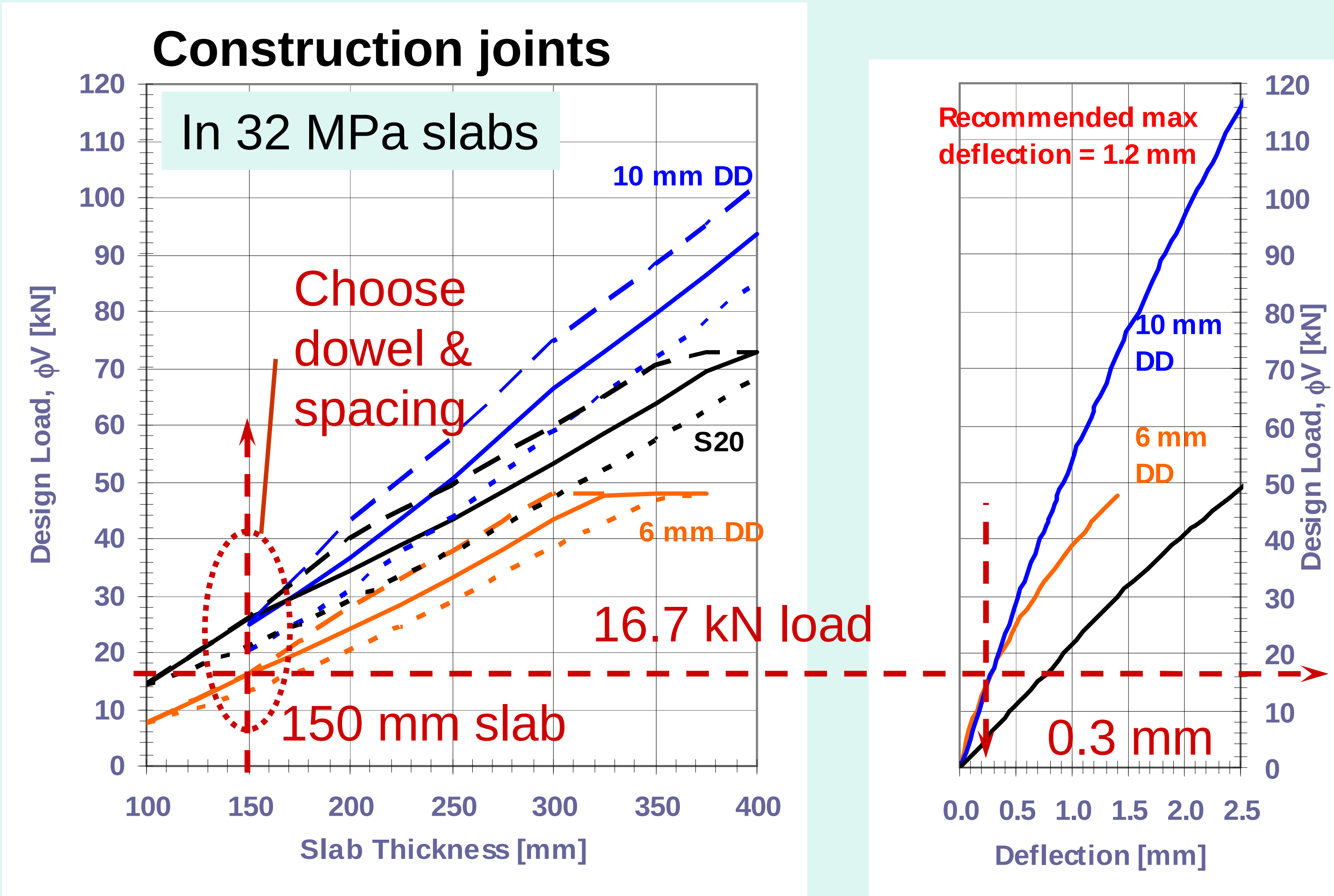
- **Example 1** - Light industrial facility
- **Example 2** – Distribution facility pavement
- **Example 3** - Industrial pavement with wide joints
- **Example 4** - Container handling facility

Example 1 – Light industrial facility

Design parameters:
Slab: 150 mm thick 32 MPa unreinforced normal weight concrete
Anticipated joint width < 10 mm
Live load = 10 kPa
Forklift: Nominal 2 tonne capacity, with laden front axle load = 4850 kg
Forklift wheels 250 mm wide

Determine appropriate dowels:
Because of slab curling, approx 1.2 m wide perimeter of slab will be unsupported, so factored live load supported by dowels
= 1.2 x [0.5 x 1.2 m] x 10.0 kPa = 7.2 kN / m
Try dowels at 450 centres
Live factored live load per dowel = 7.2 kN/m x 0.45 m = 3.24 kN per dowel
For wheels, load width at dowels, W_L = 250 + 1.5 x 150 = 475 mm
But, practically, at least two dowels will resist wheel load
So factored wheel load = [1.2+0.2] x [0.5 x 4850 x 9.81 x 10-3] /2
= 16.7 kN per dowel

Example 1, continued



From the design chart, 6 mm Diamond® Dowels at 450 mm centres are appropriate at construction joints, with differential deflection approx 0.3 mm

Similarly, for contraction joints, 6 mm Plate Dowel Cradles™ with dowels at 450 mm centres are appropriate, with approx 0.6 mm differential deflection

Example 2 – Distribution facility pavement

Design parameters:
Slab: 180 mm thick 40 MPa unreinforced normal weight concrete pavement
Anticipated joint width < 10 mm
Design for B-doubles, semi-trailers and delivery vehicles
So design axle load = 10 tonne max
Dual wheel set width = 630 mm

Determine factored loads:
Factored wheel set load = [1.2 + 0.2] x 10 x 9.81 / 2 = 68.7 kN per wheel set

Determine appropriate dowels:
Tributary load width at dowels = 630 + 1.5 x 180 = 900 mm
Try dowels at say 450 mm centres
Load per dowel = 68.7 x [450 / 900] = 34.4 kN
From the design charts, S20 dowels have design capacity, ϕV = 35 kN

So S20 Square dowels at 450 mm centres are appropriate at construction joints [and expansion joints]; and, S20 Square Dowel Cradles with dowels at 450 mm centres are appropriate for sawn contraction joints

Example 3 – Industrial pavement with wide joints

Design parameters:
Slab: 200 mm thick 50 MPa post tensioned slab
Anticipated joint width = 25 mm
Rack post load = 40 kN on 125 mm square plate [worst case beside joint]
Wheel load = 25 kN , from cushioned tyre forklift
Forklift wheels 200 mm wide

Determine factored loads:
Factored rack post load = 1.2 x 40 = 48 kN per contact area
Factored wheel load = [1.2 + 0.2] x 25 = 35 kN per wheel

Determine appropriate dowels:
Worst case condition can be when rack post is adjacent to joint and wheel of forklift passes close by the post, say with 100 mm clearance
So compound load = 48 + 35 = 83 kN
Post base tributary width of load at dowels = 125 + 1.5 x 200 = 425 mm
Wheel tributary width of load at dowels = 200 + 1.5 x 200 = 500 mm
So tributary width = 425/2 + 125 + 100 + 200 + 500/2 = 887 mm

Example 3, continued

Try S25 [25 mm] Square Dowels with Flanged Dowel Boxes at say 450 mm centres
Load per dowel = 83 x [450 / 887] = 42.1 kN
Design capacity of steel dowel in combined shear plus bending for 25 mm joints, ♐V_S = 76.3 kN > required 42.1 kN, so steel OK
Design capacity of concrete adjacent to S25 dowel will be same as S20 dowel, ♐V_C = [50/40]^0.5 x 38 = 42.5 kN > 42.1 kN so concrete OK

NOTE: From the design charts, it could be shown that a S20 dowel may be and the adjacent concrete may be just capable of resisting the load. However, for joint width of 25 mm, it would be prudent to use the stiffer S25 dowel to reduce dowel deflection, or even increase dowel size to S32 Square Dowels with Flanged Dowel Boxes

Example 4 – Container handling facility

Design parameters:
Slab: 350 mm thick 40 MPa unreinforced normal weight concrete
Anticipated joint width < 10 mm
Containers max 25 tonne each stacked 3 high
Reach stacker, with laden front axle load = 76 tonne
Reach stacker wheel set 1100 mm wide

Determine factored loads:
Container factored load = 1.2 x 3 x 25 x 9.81 / 4 = 220.7 kN per contact area
Stacker factored load = [1.2 + 0.2] x 76 x 9.81 / 2 = 521.9 kN per wheel set

Determine loads per dowel:
Try dowels at say 400 mm centres
Stacked containers – each container has a corner block approx 170 mm square
Container tributary width of load at dowels = 170 + 1.5 x 350 = 695 mm
Load per dowel = 220.7 x [400 / 695] = 127.0 kN for containers
Stacker tributary width of load at dowels = 1100 + 1.5 x 350 = 1625 mm
Load per dowel = 521.9 x [400 / 1625] = 128.5 kN for stacker < 127.0 kN controls

Example 4, continued

Determine appropriate dowel:

Dowel capacity must be examined from two distinct views – dowel body capacity and ability of surrounding concrete to absorb the applied loads

For a S32 [32 mm square dowel] of AS / NZS 3679.1 Grade 300, design capacity in combined shear plus bending for 10 mm joints, ϕV = 165.3 kN > required 127.0 kN, so steel OK

But concrete capacity ≈ 60 kN, so supplementary reinforcing required

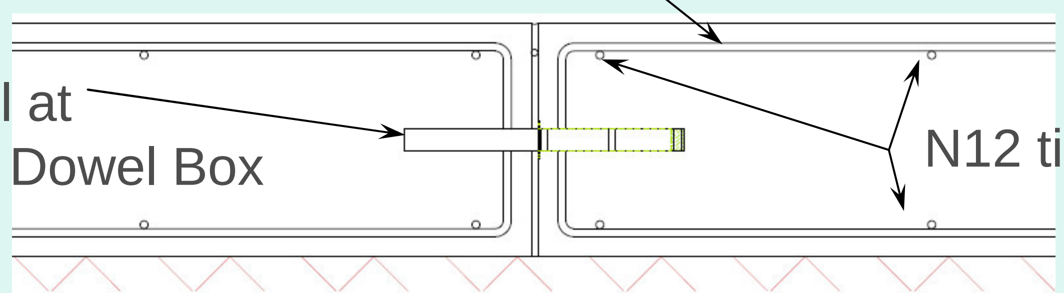
Supplementary reinforcement:

Required reinforcement area = [127.0 x 10^3] / [0.6 x 500] = 436 mm^2

Use 2 x N12 U-bars [bundled] 100 mm each side of dowel [As = 423 mm^2]

Use U-bars with say 750 mm long legs

Use minimum 2 x N12 bars tie bars top and bottom, inside U-bars



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"High Performance Dowel Systems" brochure; Danley Construction Products Pty Ltd

"Square Dowels and Flange Dowel Boxes" brochure, Danley Construction Products