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JOINT DESIGN AND MANAGEMENT IN INDUSTRIAL FLOORS

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ABSTRACT

When considering joint design and management in industrial floors, current global practices consider the most prominent design methods as a best practice which include the following standards and guidelines;

- ACI360R-10 - Design of Slabs on Ground – US Standard
- TR34 – Fourth Edition - Concrete Industrial Ground Floors – UK Standard
- CCAA T48 – Guide to industrial floors and pavement – AUS Standard
- CCANZ – Slab on Grade (Industrial) – NZ Guide

Each standard provides a variety of solutions for the design of industrial floor slabs. You will find some standards address certain considerations, such as the size of an industrial floor slab, differently to the others. As this is the case, it is imperative that the designers are aware of the differences in the standards to provide the most appropriate solution.

Joint design for industrial floors needs to consider the planned use of the floor from the asset owner.

Typically, industrial floors are subject to the wear and tear of materials handling equipment such as forklifts and cherry pickers, and as such, joints are vulnerable to damage from such equipment. As this is the case, the designer needs to factor this into their joint design, using the most applicable standard, to ensure the most appropriate desired outcome for the asset owner. Common industrial floor characteristics which are considered during the design stages include dowel spacing, edge protection, concrete curling and reinforcement, all of which are subject matter listed in the available standards.

Once the joint design is established, it is imperative that the contractors of industrial floor slabs follow the best practice for joints formation during the construction phase. This will include, correct placement of dowels (i.e. in accordance with manufacturer's installation procedures), correct reinforcement placement and saw cutting technique and process.

When combining good sound design with best practice construction, the likely outcome will be flatter concrete floors with minimal cracks leading to a longer lasting, more versatile industrial facility.

Keywords: Joint design, curling, dowels, saw cutting, cracks, edge protection, load transfer, TR34, ACI, T48.

INTRODUCTION

It is important for Industrial floors to be appropriately designed with the goal of achieving flat and crack free slabs. The various design methods around the globe address this using joint design in many different ways. Regardless of the design method, joints for slab-on-ground construction are essentially used to control the crack when it occurs. Not only do they limit the frequency and width of random cracks occurring, but they can also be used to cater for pour-breaks in the construction process.

Further to this, the management of joints is just as important. Their design will need to allow for the in service requirements of the slab and address issues such as load transfer, slab curling, shrinkage, edge protection and of course crack control. An example of how a joint controls a crack, is depicted in Figure 1. Additionally, concrete placement is also implicated affecting areas such as time, labour, equipment and supply of product.

Essentially, a joint can be categorized as either a construction joint, contraction joint or an isolation joint. A construction joint shown in Figure 2, is typically positioned at the border of a pour (pour break) and allows panels to float independently. Construction joints are located at planned locations and between slab panel free edges. A contraction joint shown in Figure 3, also referred to as a saw cut or soffcut joint, is used to control cracking within the individual slab panels. An isolation joint is used when vertical and horizontal movement is required between the concrete floor slab and adjacent elements and should be used around potential points of restraint such as columns and drains as shown in Figure 4.

A crack is an Uncontrolled Joint   A Joint is a Controlled Crack (soffcut)

Figure 1. Example of joint controlling cracks

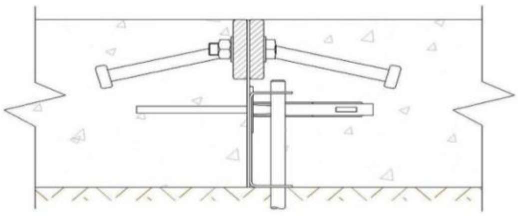


Figure 2. Typical construction joint detail

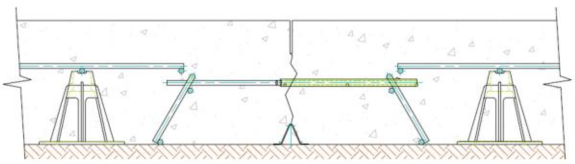


Figure 3. Typical contraction joint detail

Figure 4. Typical isolation joint

ASSET PROTECTION

The Role of the Floor Slab

For industrial facilities, the floor system is one of the most important parts of the building as it is the area of where all activities occur. It requires to perform 24 hours a day by providing a smooth running surface to maximize materials handling speed and efficiency. Correctly designed floor slabs will address the type of material handling equipment used to minimize potential damage which can occur. For example, hard wheeled, high point load forklifts such as reach lift-truck, stock picker lift-trucks and stand-up lift-truck can cause expensive damage on inappropriately designed joints as depicted in Figure 5. Furthermore, not only can this cause damage requiring joint repair to the floor but it will also cause other serviceability issues such as tire replacement maintenance of the hard urethane wheels for the material handling equipment.

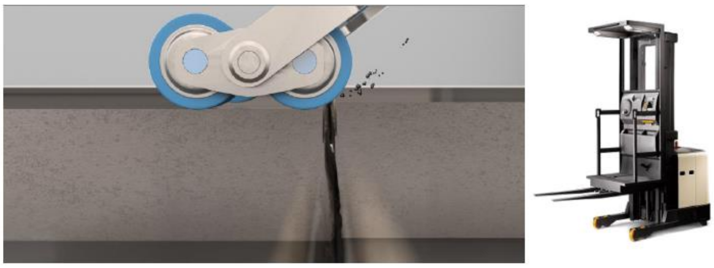


Figure 5. Joints damaged by hard wheeled, high point load forklifts detail

Future Proofing

To ensure the asset owner gets the best possible value for the investment, it is vital that the value proposition takes into consideration the longevity, flexibility and cost of the asset. The extension of the floor lifecycle equates to an increased return on investment and this is only possible when focusing on the serviceability of the floor. This can be addressed by designing appropriate load transfer control, edge protection at construction joints, adequate crack control and proper isolation of services.

INDUSTRY STANDARDS AND GUIDELINES

General

Globally there are a number of standards which provide guidance to design floor slabs whilst addressing serviceability. These standards are either European based, American based or Australian based. From this, the two most widely used and well accepted standards are TR34 Fourth Edition (European based) and ACI360-R10 (USA based).

<u>TR34 Fourth Edition</u>

TR34 Fourth Edition – Concrete industrial ground floors a guide to design and construction, is a European publication (UK based) which is widely adopted in Australia and New Zealand. It provides guidelines to load capacity requirements for load transfer systems in joint widths of up to 20mm.

<u>ACI360R-10</u>

ACI360R-10 – Guide to design of slabs-on-ground, is an American publication (USA based) which addresses the planning, design and detailing of industrial slabs. It details a variety of load transfer mechanism and prescribes joint stability recommendation of deflection ≤0.25mm.

<u>TR34 Fourth Edition vs. ACI360-R10 Design Methodology</u>

When comparing the two most widely used standards for floor slab design, it is evident that TR34 is more formula based design calculations whereas ACI360R-10 is more tables and graphs based design calculations. Furthermore, other evident differences include the slab size and number of joints. TR34 bases its designs on larger & maximized slab size with fewer joints and ACI360R-10 considers smaller slab size and more joints with smaller gaps. Another obvious difference is that ACI360R-10 entails extensive detail on the topic of curling and shrinkage whereas TR34 has very little on the topic.

When applying the above standards, it is important to appreciate the regions they were written for and understand whether the conditions are applicable for New Zealand or Australia. For example, in the UK region, the industrial floors are thicker, with lower concrete strength (25-32MPa) and therefore curling is not a prominent issue. On the other hand, in New Zealand and Australia, curling definitely needs to be considered given the slab thicknesses are thinner with higher concrete strength (40 MPa). Also, in the UK the slab is built on stabilized bases including piers where as in New Zealand and Australia, the slabs are built on a sand based and /or reactive soils.

Joint Design Considerations

As mentioned earlier in the paper, the joint type can either be a construction joint, contraction joint or isolation joint. Following this, where applicable, the joint design needs to consider dowel spacing, edge protection, concrete curling, drying shrinkage and reinforcement. Furthermore, where load transfer is required, the design also needs to assess the performance of the dowel. This includes performance for concrete shear cone, punching shear, steel yield, steel shear, steel bearing and bending.

<u>Load Transfer</u>

Load transfer is best described as the transfer of concentrated loads across a joint to an adjacent (abutting) floor slab. To prevent vertical displacement of adjacent slabs at a joint, some form of load transfer control is necessary. This ensures the top surface of the slab remains at the same level even though it may be subjected to uneven loads.

These loads may be due to vehicular traffic, or more commonly, as a result of the ground swelling and or shrinkage. If the (joint) opening is greater than 1mm, load transfer by aggregate interlock cannot be relied upon and an effective load transfer device should be installed.

When construction joints are spaced at large intervals, load transfer mechanisms such as dowels are required to control vertical deflection of the slabs. For an effective load transfer device addressing serviceability of the joint refer to Figure 6. Without an appropriate load transfer system, potential issues such as differential height between adjacent slabs may occur. Excessive differential heights in slabs cause operator fatigue, vehicle damage and are considered a safety hazard. Figure 7 illustrates what differential height commonly looks like.

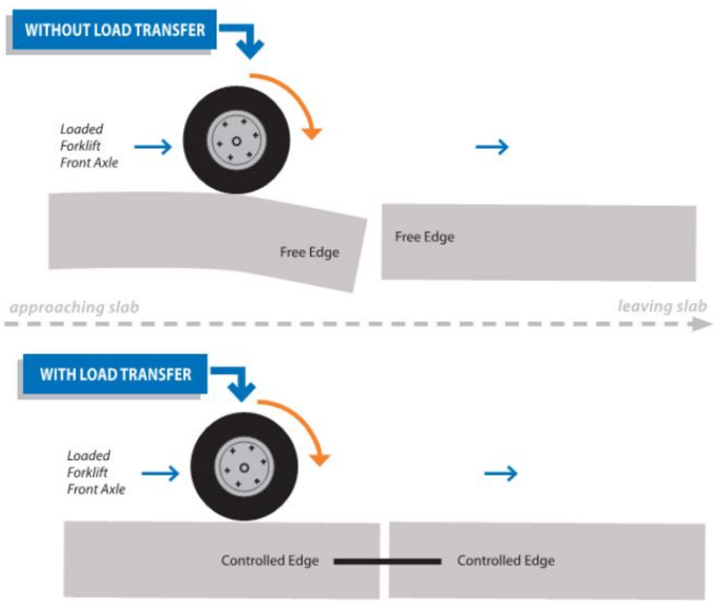


Figure 6. Effective load transfer device maintaining serviceability of the joint

Figure 7. Differential height

<u>Types of load transfer systems</u>

Both ACI360R-10 and TR34 Fourth Edition, mention a variety of load transfer systems such as round dowels, square dowels, plate dowels, keyjoint, aggregate interlock and steel fabric. The most effective load transfer systems will allow for bilateral movement (i.e. allow horizontal slab movement perpendicular to the joint and horizontal slab movement parallel to the joint). At the same time, they also minimize vertical differential movement between adjacent slabs. Examples of effective dowel systems include both plate dowels and square dowel. Research carried out at the Queensland University of Technology (QUT) has indicated that plate dowels perform more efficiently than the traditional round and square dowels. Examples of plate dowel systems are listed below;

1. Plate or PD3™ dowels (typically for contraction joints – refer to Figure 16)
2. Diamond™ dowels (typically for construction joints – refer to Figure 8)

Both the plate dowels are reasonably effective if used with sleeves that allow movement both perpendicular and parallel to the joint. They both have a higher joint capacity and have the load supported uniformly across the dowel

Figure 8. Diamond™ Dowels

Traditional round dowel systems do not allow for lateral movement and are quite often poorly or incorrectly placed. As such, they can induce higher stresses and therefore behave more inefficient when compared to other dowel systems. An example of incorrectly placed round dowels is demonstrated in Figure 9.

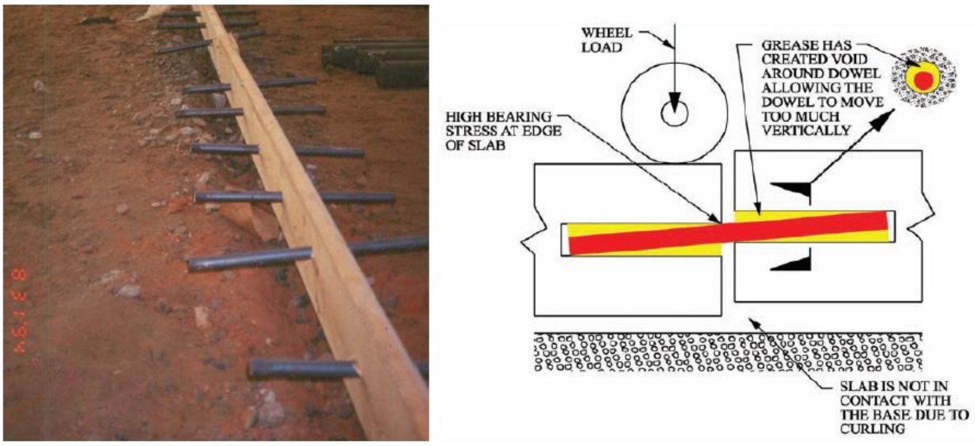


Figure 9. Round dowels incorrect placement

Other less effective load transfer systems include the keyjoint system which is suitable for lightly loaded application only where height differential between slabs is of little importance. There is risk of cracking under heavy loading with this system as shown in Figure 10.

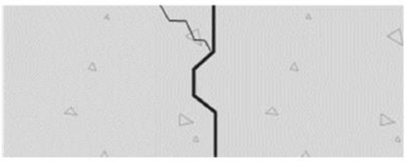


Figure 10. Keyjoint – risk of cracking under heavy loads

If relying on aggregate interlock only, the joint becomes ineffective when opening up more than 10% of the largest aggregate size used in the concrete mix. Furthermore, the saw cut reduces the area available for aggregate interlock to develop.

When relying on steel fabric, this system typically provides 10% load transfer capacity for a joint opening of 2mm and therefore considered as an ineffective solution as mentioned in the TR34 standard series.

<u>Concrete Slab Curling</u>

As mentioned in ACI360R-10 section 14.3, curling occurs because of differential shrinkage. This means the top of the concrete slab will always shrink faster than the bottom no matter what the climate. In most situations today, the inside humidity and temperature is controlled and, no matter what the environment is, within 3 months of placing a slab, the humidity at the bottom of the slab will be between 80-100%.

Figure 11, shows the dark area as the part of the slab that is typically in intimate contact with the sub-grade. What's notable is that the corners curl up the most, so the curling effect is more exaggerated at the corners where the slab meets other floor panels as shown in Figure 12. This explains why we see so many corner crack-offs. An example of corner crack-offs is shown in Figure 13. The longest point between where the concrete is in contact with the sub-grade in a typical 4.5 metre x 4.5 metre panel can be 2.1 metres.

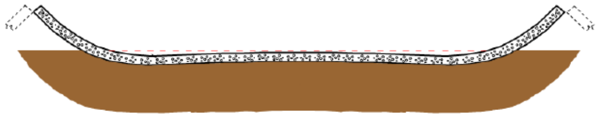


Figure 11. Curling more exaggerated at the corners

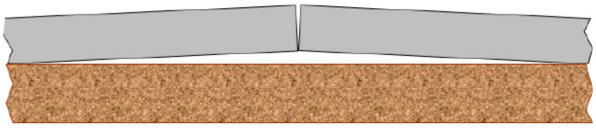


Figure 12. Curling at corners where slab meets other floor panels

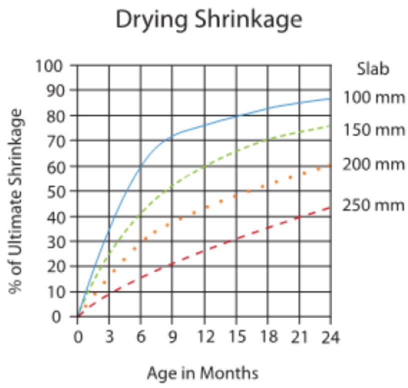
Figure 13. Corner crack-off repaired with temporary repair using asphalt

Concrete Shrinkage

Rapid drying shrinkage begins immediately after concrete placement, particularly in thin slabs. For example, in a 150mm thick concrete slab of standard weight concrete, nearly 30% of the drying shrinkage occurs in the first 90 days and approx. 60% in the first year as depicted in Graph 1. For normal concrete with characteristic strengths between 30 and 40 MPa, the drying shrinkage value is approximately 500 to 700 microstrain. This means that a concrete slab 6 m long would shrink approx. 3 to 5 mm during its life. This may also be increased by thermal effects and lower relative humidity.

Drying shrinkage cause stresses in the concrete slab immediately after concrete has been placed.
The effect of this includes cracking of the concrete slab and a way to minimize or eliminate this would be by the use of contraction joints. The most efficient way of forming a contraction joint is with an early-entry saw cut (i.e. within 2-3 hours of the last pass of the power trowel and a saw cut depth of approx. 1/4 of the slab thickness).

In large areas of concrete, drying shrinkage is controlled by the use of construction joints, contraction joints and isolation joints.



Graph 1. Percentage of ultimate shrinkage Vs. age in months

Construction Joints

Construction joints are commonly used where the concrete pour is interrupted either planned or unplanned. If the joint is in a high traffic area and/or subjected to heavy loads, it is imperative that the construction joint design allows for a load transfer propriety system with published capacities as depicted in Table 1, or is designed using TR34 Fourth Edition section 6 which allows you to calculate capacities for the various modes of dowel performance. This will ensure the appropriate dowel is used to sustain the design's applied loads. For high traffic areas in particular, the joints would need to have steel armouring as depicted in Figure 15. This will minimize or eliminate potential damage caused by material handling equipment such as forklifts and their hard wheel point loads as demonstrated in Figure 5. Further to this, consideration also needs to be given for allowing independent movement between slab panels. Typical round dowels provide load transfer and allow longitudinal movement only. If both longitudinal and lateral movement is required due to drying shrinkage described earlier, there are various propriety plate dowel systems in the market which provide solutions for this requirement (e.g. Diamond™ Dowels and plastic sleeve square dowels). Figure 14 provides an example of where both longitudinal and lateral movement are required due to drying shrinkage.

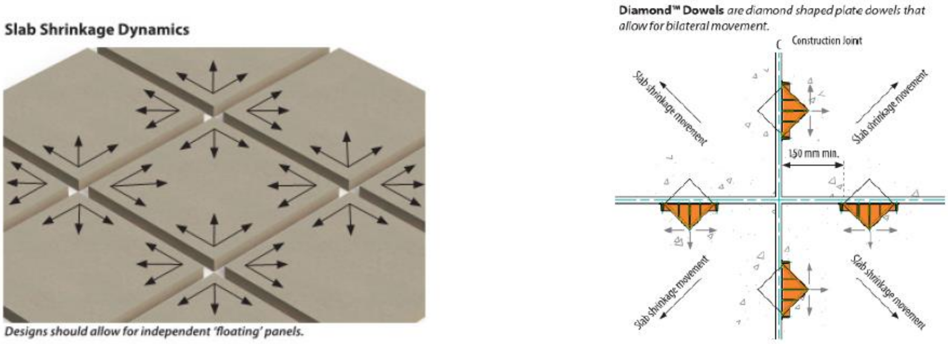
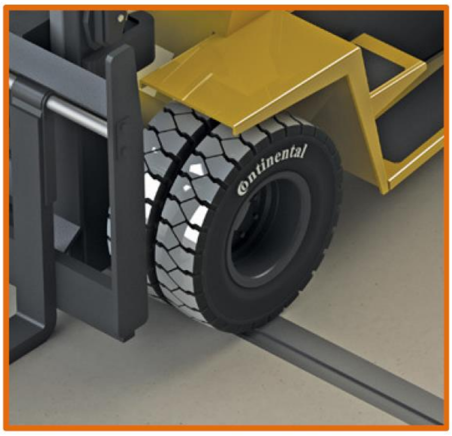


Figure 14. Bilateral movement is required

Single Dowel Limiting Load Capacity							Joint Width Efficiency, %
Concrete Design Capacities, kN							
Slab Thickness mm	Dowel Thickness mm	Joint Opening mm	Concrete Compressive Strength, Mpa				
			25	32	40	45	
			Shear Cone Capacity, kN				
125	6	10	11.3	12.8	14.3	15.1	
150	6	10	15.4	17.5	19.5	20.7	
150	10	10	14.7	16.7	18.6	19.8	95.2%
150	10	20	14.0	15.8	17.7	18.8	
175	10	10	19.4	22.0	24.5	26.0	95.5%
175	10	20	18.5	21.0	23.4	24.9	
200	10	10	24.7	28.0	31.3	33.1	95.8%
200	10	20	23.7	26.8	30.0	31.8	

Note: Joint Width Efficiency percentage taken from the 40Mpa column.
Concrete shear cone capacity is the limiting factor in typical slab-on-ground designs.

Table 1. Capacity chart for **Diamond™ Dowel system** based on TR34 section 6



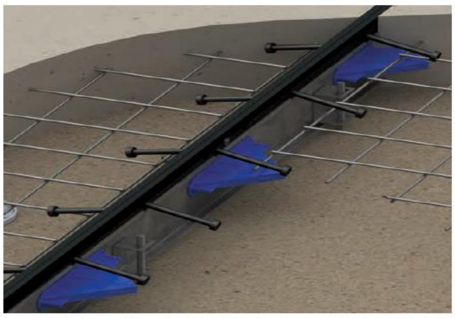


Figure 15. Steel armouring of construction joints

Contraction Joints

Contraction Joints are used to control potential stray cracks caused by shrinkage via actuating the cracks only at the predetermine joint positions. They are typically formed by saw cutting the concrete slab as soon as it is hard enough to support the saw and operator. The saw cut needs to be performed within 2-3 hours of the last pass of the power trowel and the saw cut depth should be approximately 1/4 of the slab thickness.

TR34 Fourth Edition classifies contraction joints as either free-movement or restrained movement.

For restrained movement joints, the fabric reinforcement is extended across the joint. As such, this limits the horizontal movement perpendicular to the joint restricting its opening and therefore causing additional stresses across the joint. Although this method may help with crack control due to shrinkage, it has limited load transfer capability and heavily relies on aggregate interlock.

For free-movement joints, the contraction joint also provides load transfer by locating de-bonded dowels across the joint before the concrete is poured. The de-bonded dowels are typically fabricated in cradles (also referred to as cages or baskets) to ensure correct alignment and positioning prior to concrete placement. Free movement contraction joints typically require bilateral movement and as such, similarly to construction joints, there are various propriety plate dowel systems in the market which provide solutions for this requirement (e.g. PD3 – tapered plate dowel cradle system and Plastic sleeve plate dowel cradle systems). Figure 16, depicts a contraction joint with free-movement including the image of a PD3 - tapered plate dowel cradle system positioned before concrete placement.

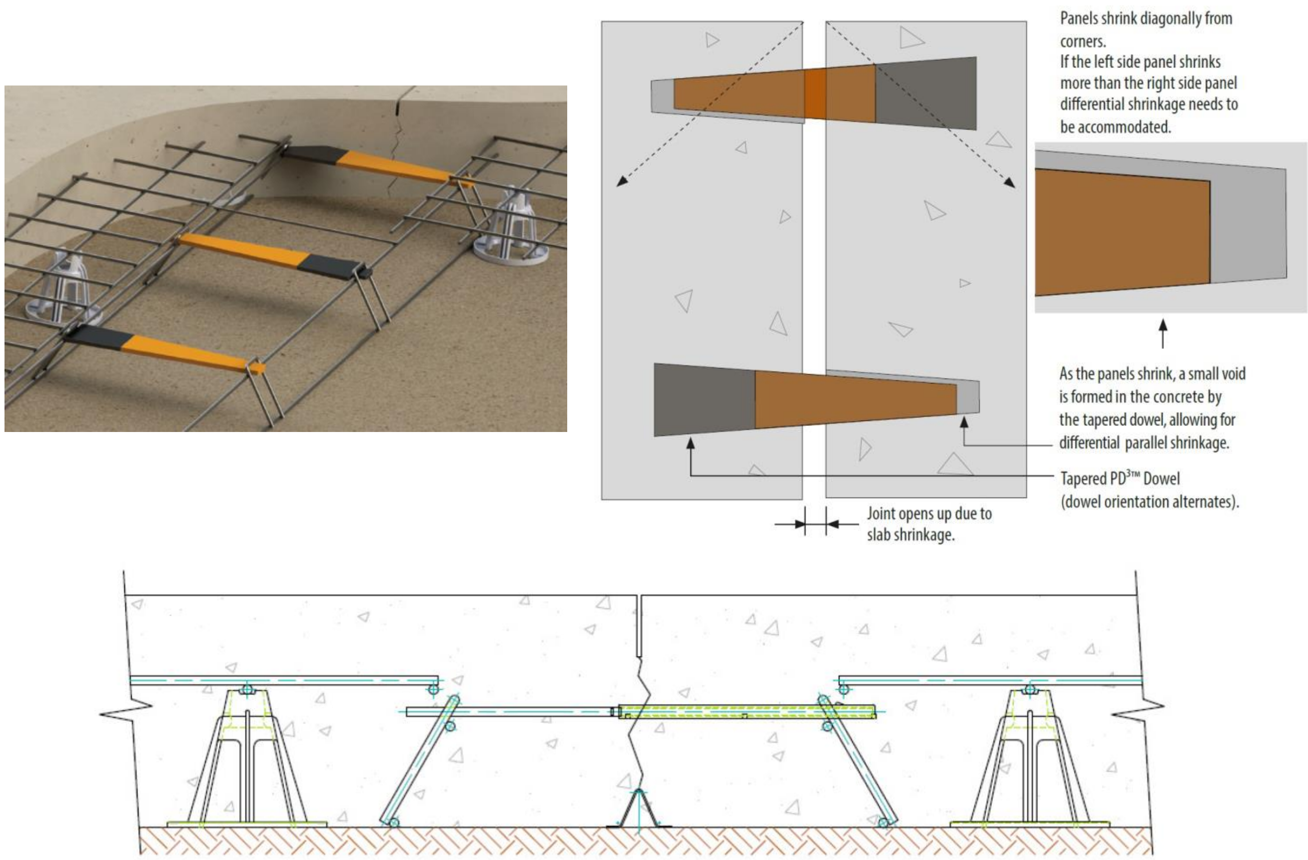


Figure 16. Contraction joint detail, PD3 dowel cradle and plan view of free-movement

Isolation Joints

Isolation Joints ensure there are no restraints between the floor slab and adjacent elements such as columns and walls. Typically, for these applications, there is no load transfer required and the solution detail is consistent for both TR34 Fourth Edition and ACI360R-10. Typical details from these standards prescribe a compressible filler material used to create the isolation between the slab and the column or wall. Refer to Figure 17 for typical details and Figure 4 for images of real examples.

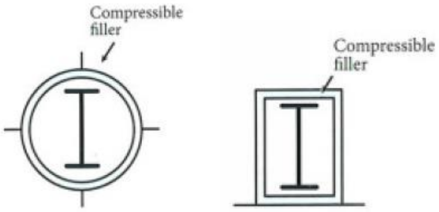


Figure 17. Isolation joint with compressible filler material

Dowel Size and Spacing for construction and contraction joints

For square and round dowels, ACI360R-10 Table 6.1 provides guidance for centre to centre dowel spacing. For plate dowel's the guidance from ACI360R-10 is to refer to manufacturers recommendations given the various plate geometries and installation devices available. It also advises to consult with the dowel manufacturers for their recommended plate dowel size.

In general, TR34 Fourth Edition makes reference to Eurocode 2 with respect to calculating concrete punching shear and concrete bursting forces. For concrete punching shear calculations shown in section 6.4 of TR34 Fourth Edition, the optimal dowel spacing can be derived from the critical perimeter calculation. For concrete bursting forces detailed in section 6.5.3 of TR34 Fourth Edition, the optimal dowel spacing can also be derived in a similar manner.

Joint Management

Regardless of the joint type, it is essential that when it comes to forming the joint, the correct installation procedure is adhered to. This means that for proprietary joint systems, the manufacturer's installation instructions are followed and/or for designed joint systems, the correct associated standard is followed (i.e. ACI360R-10 or TR34 Fourth Edition).

Correct placement of dowels

When it comes to dowel placement for load transfer, the installation process can vary depending on the joint type. Construction joints without armouring will heavily depend on the contractor to correctly position each dowel with special attention to spacing and vertical alignment. Figure 18 describes the most effective location in the concrete to maximize shear load transfer. Failure to follow this can cause under performance of the dowel and result in unsightly bursting and spalling at the joints. An example of vertical alignment tolerances is depicted in Figure 19. Misalignment outside these tolerances will cause restraint of the slab which will lead to cracking at the joints.

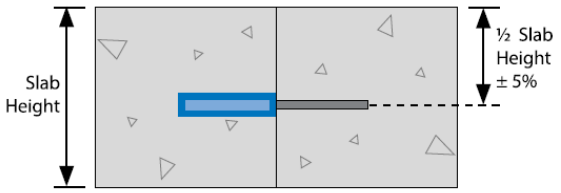


Figure 18. Effective location in concrete to maximize shear load transfer

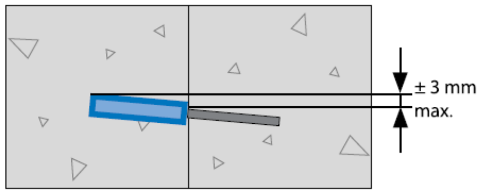
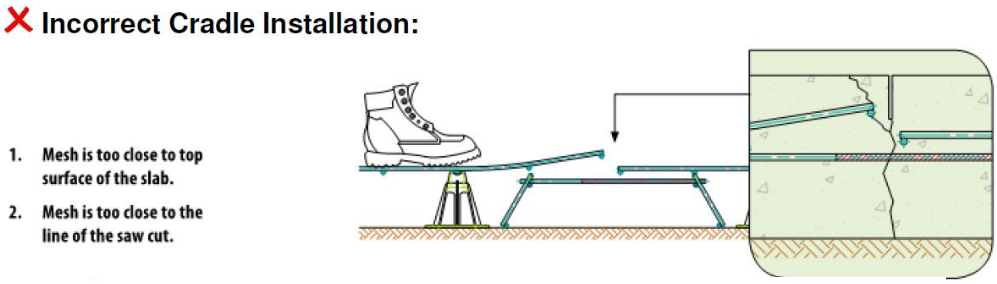


Figure 19. Vertical alignment tolerances to minimize restraint of the slab

For construction joints with armouring, the prefabricated nature of the doweling systems eliminates positioning errors however special attention is needed on the adjacent reinforcement placement and how it interacts with the dowel system. Furthermore, consideration needs to be given to the type of slab and whether it is a PT slab or not. This will help determine what the most appropriate armouring is required for the joint. Figure 20 demonstrates the different types of armouring based on the different concrete slab types.

Figure 20. Edge protection – plate system Vs. rail system

For contraction joints where dowel cradle systems are used, although installation error is minimized due to the dowels being already prefabricated in the cradle system, special attention is still needed on the adjacent reinforcement placement. An example of manufacturer's installation instructions depicting incorrect cradle installation is shown in Figure 21. Similarly, correct cradle installation is shown in Figure 22.



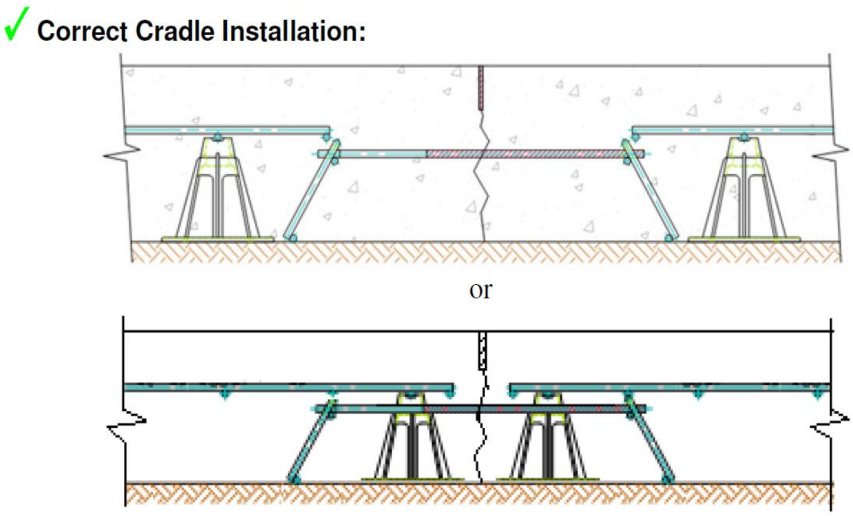


Figure 22. Correct cradle installation

Saw cutting techniques and processes

With contraction joint, it is just as important that the saw-cut is performed at the correct time and at the correct depth. As mentioned earlier in the paper, the saw cut needs to be performed within 2-3 hours of the last pass of the power trowel and the saw cut depth should be approximately ¼ of the slab thickness. Figure 23 shows a typical saw-cut being carried out and Figure 24 depicts incorrect saw-cut dept˙

Figure 23. Saw-cutting process

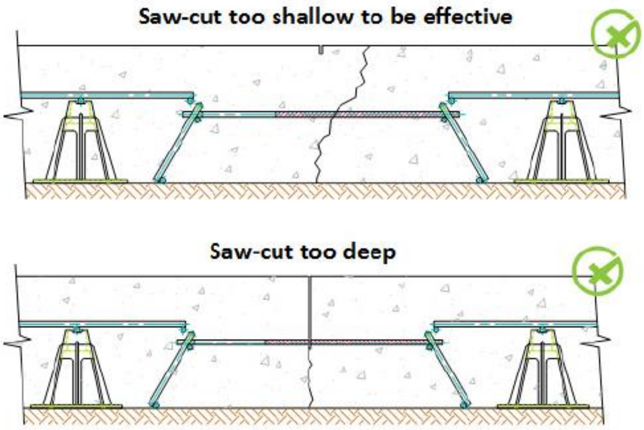


Figure 24. Incorrect saw-cut depth

CONCLUSION

In summary, when designing joints for industrial concrete slabs, the following points need to be considered;

- The asset owner's needs
- The role of the slab
- Future proofing the asset through maximizing the use of the slab
- Appropriate load transfer systems based on the use of the slab
- Appropriate edge protection or armouring of the joint
- Consideration of curling and drying shrinkage
- Ascertaining best saw-cut location
- Saw-cutting at the correct time and correct depth
- Placing isolation joints where necessary (eg. around columns)
- Installing dowels in the correct location
- Placing reinforcement correctly to ensure you do not compromise the joint's functionality

This paper has addressed the above points for joint design and management of industrial floors based on the most current best practice and utilizing the most recent global standards, namely TR34 Fourth Edition and ACI360R-10.

ACKNOWLEDGEMENT

ramsetreid® Concrete Structures Laboratory.

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   b) Diamond™ Dowel Load Transfer System Industrial Slab on Ground
   c) PD3™ Dowel Cradle Industrial Slab on Ground