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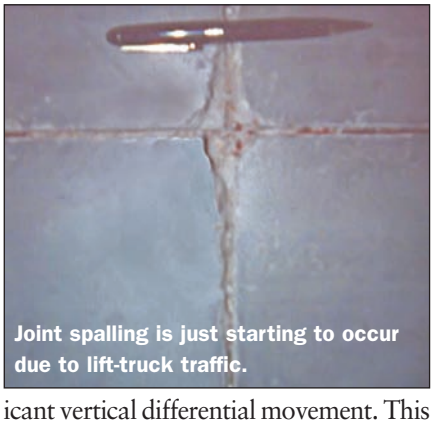
The Hidden Cost of Aggregate Interlock

Using dowels will reduce long-term cost for slabs on ground

By Wayne W. Walker and Jerry A. Holland

Of the many forensic investigations of warehouse and industrial slabs on ground we have conducted throughout the years, the majority of the problems have involved joint deterioration, including edge spalling due to lift-truck traffic. This problem is commonly a result of the slab designer having relied on aggregate interlock to transfer the wheel shear load across the joint. This practice is ineffective because the aggregate interlock is nearly always lost over time due to horizontal shrinkage and curling of the slab.

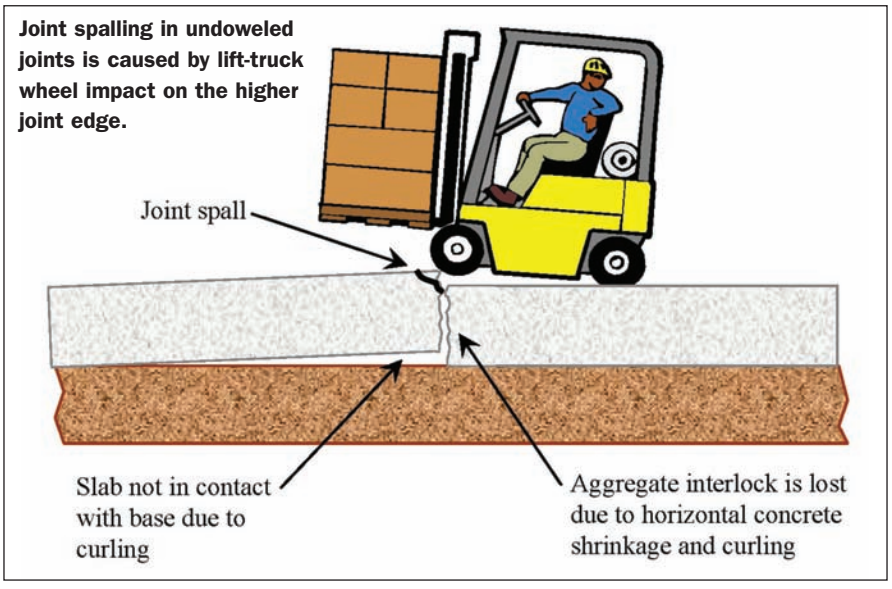
When aggregate interlock is lost, the slab edges on either side of the joint become free edges. Free edges have significant vertical differential movement. This movement is made worse by the slab losing base contact at the joint due to curling. When a lift-truck's wheels travel across the joint, the unloaded slab panel edge is exposed and damaged by the lift-truck wheels (see drawing on page 2).



Joint spalling is just starting to occur due to lift-truck traffic.

Once the edge spalls, the lift-truck wheels can be damaged when the vehicle travels repetitively over the spalled area. If the joint spall is not quickly repaired, this repetitive traffic often causes the spall to become wider, with a corresponding increase in damage to lift trucks.

As we discussed in a previous article (Ref. 1), the trend in lift trucks to use harder, smaller wheels has made this problem worse. Joint spalling often begins only after most of the concrete shrinkage and curling has occurred—typically 12 to 18 months after slab construction and the owner has taken possession of the facility. The cost for the repairs, therefore, is hidden often in the facility owner's maintenance budget, or as we will discuss, the contractor pays. We have collected data



Joint spalling in undoweled joints is caused by lift-truck wheel impact on the higher joint edge.

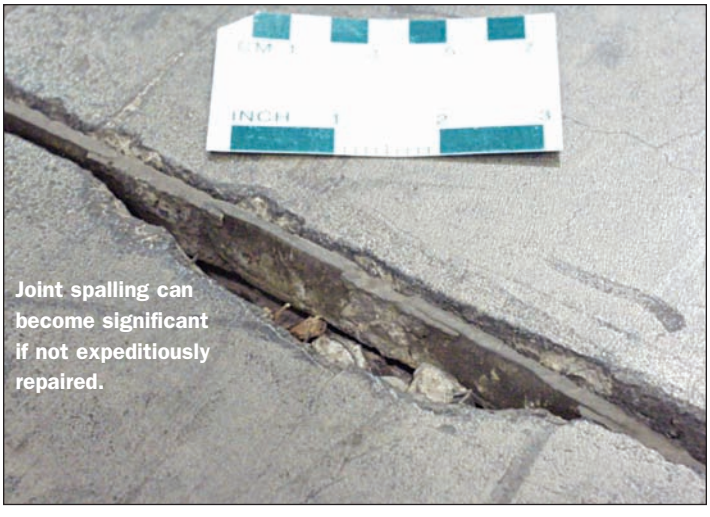
that shows it to be cost effective to use a small portion of these "hidden maintenance costs" to provide dowels in the initial construction to minimize the joint deterioration and equipment repair costs. The payback period for this investment in dowels is as short as 18 months.

Should aggregate interlock be used?

Many slab designers rely on aggregate interlock even though American Concrete Institute (ACI) publications for many years have cautioned against this practice and have recommended doweled joints when load transfer is required. ACI 302.1R-04 "Guide for Concrete Floor and Slab Construction" states that "Doweled construction and contraction joints are recommended when load transfer is required ..." The 1996 edition of ACI 302R.1 had similar wording regarding dowels.

ACI 360-06 "Design of Slabs on Ground" states "if the designer cannot be sure of positive long-term shear transfer at the joints through aggregate interlock, then positive load-transfer devices should be used at all joints subject to wheeled traffic." We have shown in previous articles (Refs. 2 and 3), that it is impractical to rely on aggregate interlock for long-term load transfer at the contraction joints for floor slabs subjected to lift-truck traffic. Even as early as 1956, ACI Committee 325 on concrete pavements cautioned against relying on aggregate interlock: "Experience indicates that aggregate interlock may be satisfactory as a means of load transfer only under unusually favorable conditions of joint opening and foundation support. It is not satisfactory under a large volume of heavy commercial traffic." (Ref. 4)

Another potential problem in relying on aggregate interlock is what we call the "dominant joint" issue. Saw-cut contraction joints are intended to control the location and width of shrinkage cracks. Hopefully, if done properly, the shrinkage cracks will occur below these saw-cuts. But due to uneven base restraint below the slab and differences in slab thickness, not all saw-cut joints actually crack or "activate." Because some joints do not activate, or activate very little, this causes those joints that do activate to open much wider, since the shrinkage is concentrated at these "dominant joints." These dominant joints are the first to lose aggregate interlock, and if they occur in traffic areas, are the first to spall.



Joint spalling can become significant if not expeditiously repaired.

Many times the slab panels on either side of these dominant joints will curl differentially, producing a differential elevation between the panels and creating tripping hazards and potential lawsuits. This dominant joint behavior is made worse by the ever-increasing use of vapor barriers/retarders, which reduce base friction and make the dominant joints more noticeable and problematic in exposed concrete floors.

Given the cautionary statements in the ACI documents, other published information, and our experience with the problems inherent in relying on aggregate interlock, we recommend against it. To rely on aggregate interlock for slabs with wheeled traffic, slab designers would need to have great confidence in their knowledge of the local long-term shrinkage potential of the concrete, the slab base restraint, the anticipated construction tolerances, the corresponding joint spacing, and other factors. If the slab designer cannot be sure of positive long-term shear transfer at the joints through aggregate interlock, then the prudent and cost-effective approach is to specify dowels in the contraction and construction joints.

Passing on the hidden costs

In building and operating a large warehouse or retail store that will have lift-truck traffic, there are typically two teams involved. The first is the design/construction team whose responsibility is to design and build the best facility for the given budget and to minimize initial cost. The second is the maintenance team whose responsibility is to maintain the floor and the lift trucks during operation.

Spalled joints can result in expensive damage to lift-truck wheels.

Our experience is that the design/construction team often makes design decisions without input from the maintenance team, which could provide valuable information on the long-term performance of the design/construction system. The construction team typically does not like to ask the maintenance team for input, fearing that they would ask for quality items that would increase the initial cost. The design/construction team gets no benefit or reward for initial cost increases and may be penalized for the increase. Therefore, there is a disconnect between these two teams' objectives, even though they may work for the same company.

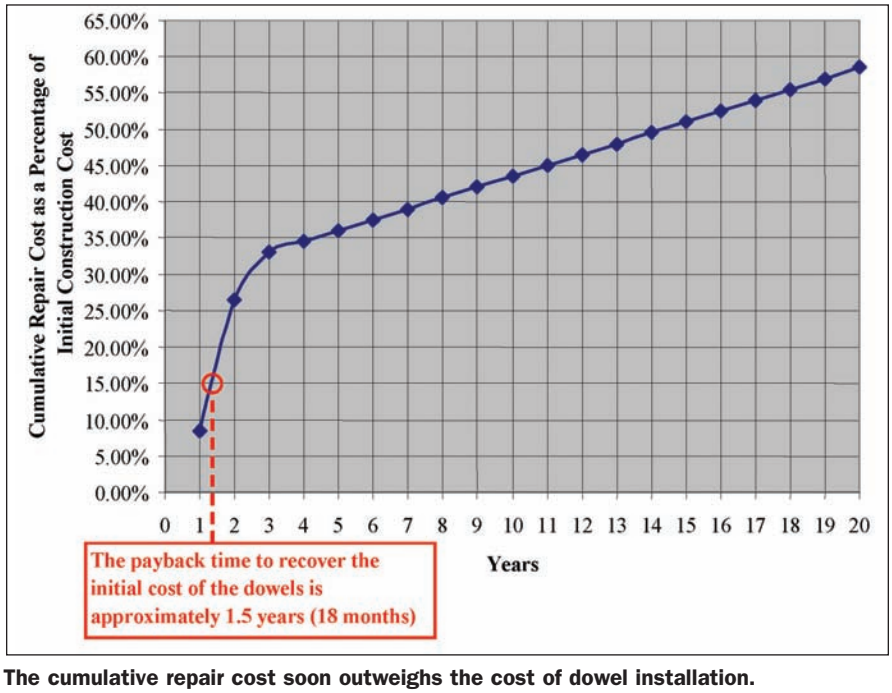
To lower initial cost, the design/construction team often eliminates the dowels in the contraction joints or does not even consider using dowels to minimize the long-term cost of joints and equipment repairs because they have no responsibility for the maintenance budget. The slab designer who is unaware of the joint problems on previous projects may even agree with the decision to not require dowels. When we have asked the construction team and slab designer why they did not require dowels, they often reply that they have never heard of any problems on previous projects. This is probably true because, as we noted, the problem is often only obvious after 12 to 18 months when most of the concrete shrinkage and curling has occurred and also after the one-year warranty has expired.

Another typical response from slab designers is that aggregate interlock is assured because the joints are filled with joint filler. Even when the joints are initially filled according to the joint filler manufacturer's specifications, the joint filler will eventually fail over time if there is significant vertical differential joint movement. We know of facility owners that did not properly repair spalling joints but simply continued to refill the joints. This improper repair can significantly increase the "hidden cost."

Because these problems usually occur after the warranty has expired, the owner ends up paying for the repairs and often does not even notify the contractor or slab designer, who never learns of this latent problem. Other times, though, the owner will contact the contractor, assuming that the joint deterioration is due to poor construction. The contractor is faced with three options, none of them desirable. The first is to pay for the repairs, even though the contractor is not at fault, to keep the owner happy, who may be a long-term client. The second is to claim that the problem occurred after the one-year warranty and that the contractor is not obligated to pay; however, the contractor may never be able to work for that owner again and might get sued anyway. The third option is for the contractor (or possibly the owner) to sue the slab designer to pay for the repairs because, as noted above, this is a design issue and not a construction issue. As you can probably guess, this situation often ends up in court, which greatly escalates the "hidden" costs.

The solution

The economical solution is to use properly designed and installed dowels in the contraction joints (Ref. 1 and 5). We have collected joint and lift-truck repair cost data on typical projects to show the economic feasibility of using dowels. The repair costs that we have used for this analysis are for slabs with only minor to medium repair costs. If the repair costs are major, or if a lawsuit occurs, then the



The cumulative repair cost soon outweighs the cost of dowel installation.

Maintenance costs for a slab with undoweled joints as a percentage of initial slab cost

Year	Joint Repair Cost, %	Equipment Repair Cost, %	Total, %
1	5.5%	3.0%	8.5%
2	12.0%	6.0%	18.0%
3	3.5%	3.0%	6.5%
4 to 20	0.5%	1.0%	1.5%

costs will be substantially greater, which will even more significantly favor the dowel solution.

For undoweled floors, problems and costs typically begin to be seen near the end of the first year (although we have seen significant damage and costs within four months of the start of owner operations). Most of the cost, though, is in the second year, since the majority of shrinkage and curling has occurred and many of the joints in the traffic areas become damaged and must be repaired. Near the end of the third year, the repair costs begin to stabilize because most of the joints in the traffic areas have been repaired.

A proper repair is critical. We have seen many poor repairs that then need to be redone, further increasing the hidden cost.

For the remaining years of this analysis (we have assumed a 20-year life for the floor), there will be some small additional costs for undoweled floors. These result from things such as new floor areas being opened to traffic due to rack configuration changes or to repair joints needing follow-up repairs.

We have indexed the annual maintenance costs to a percentage of the initial slab construction cost (see table). The initial slab cost consists of:

1. Concrete

2. Labor, materials, and equipment to place, finish, and cure the concrete

3. Labor, materials, and equipment to saw-cut joints (at 15-foot maximum spacing) and to fill the joints full depth with a proper joint filler

4. Materials and labor to install dowels at ACI recommended size and spacing.

For a floor slab with doweled joints, the initial cost for the dowels could be as much as 15% of the initial cost of the slab, but often is less. As can be seen from the cumulative repair cost figure, the payback time conservatively would only be 18 months. If a life-cycle cost analysis is done, these "hidden" costs are even more significant. Using 5% interest, the owner would need to initially budget approximately 45% of the initial cost of the slab for repairs. In other words, the owner would potentially save approximately 30% (45% minus 15%) of the initial cost of the slab if dowels are used.

Relying on aggregate interlock for shear transfer of wheel loads is problematic. The repair costs for the joints that have lost aggregate interlock, and the damage to the equipment caused by the spalled joints, are significant. Unfortunately, the design/construction team, which is motivated only to minimize the construction budget, many times makes the choice to eliminate or not require dowels at contraction joints. This choice significantly increases the maintenance cost for repairs that are "hidden" in the yearly maintenance budget over the life of the facility.

Facility owners often become unhappy with spalled joints and the damage they cause to lift trucks. The contractor may then be asked to repair the joints because the owner erroneously assumes that the problem is a result of poor construction. The cause of the problem, however, may be because the slab designer chose to rely on aggregate interlock instead of specifying dowels for the contraction joints; in that case, the slab designer would be at risk for these repairs. Only a small portion of the maintenance costs incurred as a result of not specifying dowels would be needed to pay for initial dowel cost. The payback period conservatively would only be 18 months. Because of the very short payback period, and to minimize the potential of this problem escalating to more significant costs, the prudent approach is to use dowels in the contraction joints when there will be lift-truck traffic. ■

References

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