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Malaysia Chapter

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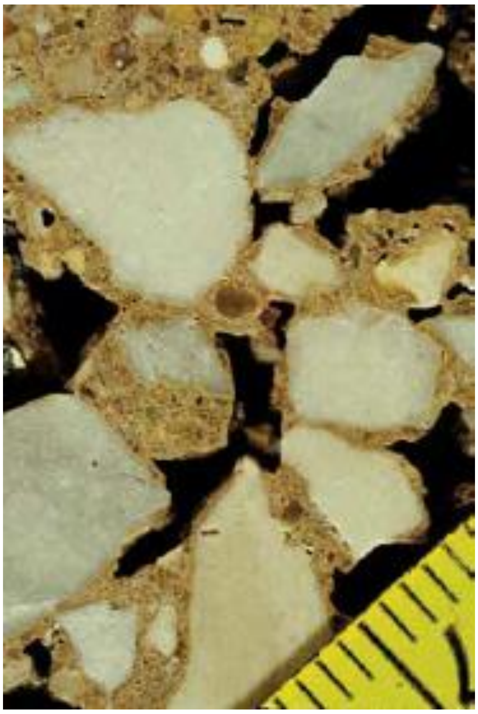


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MyConcrete:
The Bulletin of the American Concrete Institute – Malaysia Chapter

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American Concrete Institute - Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authorities on concrete technology. Our members are not confined to just engineers; in fact, our invitation is extended to educators, architects, consultants, corporate, contractors, suppliers, and leading experts in concrete related field. The purpose of this Chapter is to further the chartered objectives for which the ACI was organized; to further education and technical practice, scientific investigation, and research by organizing the efforts of its members for a non-profit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use and maintenance of concrete products and structures. This Chapter is accordingly organized and shall be operated exclusively for educational and scientific purposes.

Objectives of ACI-Malaysia are:

- ACI is a non-profitable technical and educational society formed with the primary intention of providing more in-depth knowledge and information pertaining to the best possible usage of concrete.

- To be a leader and to be recognized as one of Malaysia's top societies specializing in the field of concrete technology by maintaining a high standard of professional and technical ability supported by committee members comprising of educators, professionals and experts.

- Willingness of each individual member/organization to continually share, train and impart his or her experience and knowledge acquired to the benefit of the public at large.

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ARTICLE

Reprint from CI Magazine, Volume 37, No 3, Page 38-39

Le Corbusier's Love for Concrete

One of the pioneers of modern architecture, Le Corbusier's love affair with concrete, evident in a number of his nearly 75 projects, began early. Having already designed his first house, the Villa Fallet, at the age of just 17, in 1907 the young architect embarked on a series of travels throughout central Europe on a mission of artistic education. In Paris, he apprenticed at the office of Auguste Perret, a structural rationalist and pioneer of reinforced concrete, followed in 1910 by a short stint at Peter Behrens' practice in Berlin. These formative experiences initiated a life-long exploration of concrete in Le Corbusier's work.

Initially, the material was enticing for sheer economic purposes—where the architect desired steel frameworks, reinforced concrete consistently proved cheaper. Working together with Max Dubois and Perret, in 1915 Le Corbusier developed a theoretical study for Maison Dom-ino, a structural frame of reinforced concrete. A pun on the Latin word domus, or house, and the game of dominos, the study intended to find an affordable prefabricated system that could solve the lack of housing left by the brutal destruction of World War I.

He quickly became fascinated, however, with the remark-able adaptability of concrete and with its sculptural and structural potential. Concrete's ability to take any shape and to be enhanced by the surfaces of various molding forms entranced Le Corbusier, and its structural promise was foundational to the formulation of his Five Points for a New Architecture: pilotis (exposed lower-story columns), free façades, open floor plan, ribbon windows, and roof gardens. The most iconic implementation of these ideas was in the Villa Savoye, a pure embodiment of the Five Points.

Among its many qualities, concrete granted Le Corbusier the ability to realize his early design ideals, such as the necessity to link the machine age with classical architecture. However, the mechanized destruction brought by World War II gave him reason to critically rethink his endorsement of the machine, and it was during the postwar era that he truly began to explore the meaningful potential of concrete.

Embracing both the language of the vernacular and the monumentalism of the Classical, and blending romanticism with sensibility, Le Corbusier turned his attention to the tactile expressiveness of concrete, which could evoke both a primitive purity and enable buildings to be built on a much grander scale than before. Concerned with the concept of the architect as "poetic engineer," Le Corbusier's explorations are clearly realized in buildings such as the Convent of La Tourette and the Chapel at Ronchamp.

It was during this process that Le Corbusier inadvertently invented a completely new building method. In a letter to Josep Lluís Sert on May 26, 1962, he writes, "Béton brut was born at the Unite d'Habitation at Marseilles where there were 80 contractors and such a massacre of concrete that one simply could not dream of making useful transitions by means of grouting. I decided: let us leave all that brute. I called it béton brut [bare concrete]. The English immediately jumped on the piece and treated me (Ronchamp and Monastery of La Tourette) as 'brutal'—béton brutal—all things considered, the brute is Corbu. They called that 'the new brutality.' My

Unite d'Habitation at Marseilles (photo courtesy of Simon Glynn, www.galinsky.com)

Villa Savoye (photo *courtesy of Flickr user m-louis*)

Chapel of Notre Dame du Haut at Ronchamp (photo *courtesy of Rory Hyde*)

Convent of La Tourette (photo *courtesy of Jacques Mossot, structurae.net/)*

friends and admirers take me for the brut of the brutal concrete!" The discovery of béton brut may indeed have added to the list of influences Le Corbusier had on the later Brutalist movement, a term coined by Reyner Banham and Peter and Alison Smithson.

The Convent of La Tourette, built concurrently with Le Corbusier's work in Chandigarh throughout the 1950s, is mainly constructed of prefabricated concrete, expressed through the use of béton brut to evoke worn handicraft and natural stone construction. As Nathaniel Coleman explains in his book Utopias and Architecture, "La Tourette reveals a debt, in terms of form and material character, to Le Thoronet," a thirteenth century Cistercian abbey as "although the building is constructed of concrete, it is conceptualized here as an analogue of stone, a new stone, cheaper to use and easier to manipulate, perfect for construction after craft's demise."

Bare and stripped down, some of the idiosyncrasies apparent in the building are the result of Le Corbusier's appreciation of the human fallibility of his craftsmen, and his celebration of the scars of formwork. While his contractors for the convent were well-versed in using concrete for public infrastructure, applying it in architecture was a new step, resulting in concrete skin of variable finish throughout the building.

Some of the exposed mechanical systems were even accidental, although the contrast between the rough and sophisticated is mainly intentional, demonstrated through bare light bulbs set directly into the concrete. The rawness of the material shapes the spiritual nature of the space and works to elevate the mind of the user toward the purpose of the monastery.

The Chapel of Notre Dame du Haut at Ronchamp epitomizes Le Corbusier's experimentation in pushing the limits of the expressive potential of concrete. While the form maintains the appearance of a stereotomic, solid mass, the building is in actuality composed of tectonic shells and suspended planes. What looks like battered, cave-like walls are instead anything but. Three walls are supported by concrete columns nested within rubble, and a fourth is a concrete armature sprayed with gunite. The roof, also made of concrete, departs from this solidity with a draped, fabric-like form, made of two thin concrete membranes supported by internal concrete girders and precast beams. Consistent in this building is the use of concrete to continuously surprise.

TECHNICAL REPORT

Reprint from CI Magazine, Volume 37, No 2, Page 53-57

A Top-Down Approach

Raising the roof and enhancing the floor slab adds volume and utility to existing warehouses

by Edward B. Finkel

To meet the demands of the revolutionary merchandising phenomenon known as Internet retailing, online sales, or e-commerce, new distribution centers are being planned and constructed in strategic locations throughout the United States and Canada. Unlike existing structures lacking the necessary clear heights, these modern facilities feature uncommonly high storage racking systems and often employ wire-guided, swivel-reach materials-handling equipment. Accordingly, landlords holding expiring leases on vintage low-rise buildings are exploring the feasibility, and imple-menting the strategy, of raising the roofs of these buildings to clear heights upwards of 45 ft (13.5 m). This means an increased storage volume of 50% or more. But this maneuver is only part of the strategy. What logically follows is an imperative to evaluate the strength and serviceability charac-teristics of an existing conventional interior concrete slab-on-ground installed in the facility several decades prior to the advent of the laser screed and state-of-the-art construction practices used in floating and finishing operations, reliably reckoned flatness/levelness, slab thickness and subbase tolerances, and high-performance prescriptive low-shrinkage concrete mixtures.

Many modern “big box” distribution facilities now feature towering storage racking units separated by narrow pathways known as defined traffic aisles, traveled repetitiously around the clock by wire-guided, three-wheeled turret forklift trucks with tall masts having extraordinary reach. Needless to say, the floors carrying these vehicles must be exceptionally smooth to manage multidirectional travel while maintaining operational efficiency of the materials handling equipment. Thus, the emergence of F-min numbers prescribed by manu-facturers matching the productivity standards established for their forklift equipment. The F-min is not to be confused with superflat, a term associated with random traffic floors tradi-tionally measured with the F-Meter or other suitable handheld device. Defined traffic aisle tolerances are recorded by a profilograph replicating a three-wheel configuration and the F-min number is reconciled by computer analyses of this data. Meeting these goals requires special placing and finishing techniques by the flatwork contractor followed by local surface grinding, particularly at construction joints.

Meeting the demands associated with increased storage rack post loads and finely tuned flatness/levelness (F-min) values to cope with sophisticated operational strategies, however, begins with research and analyses leading to practical and economic considerations relative to the following options:

1. Bonded concrete topping;
2. Bonded epoxy mortar overlay;
3. Unbonded concrete overlay; and
4. Removal and replacement of the existing floor slab.

Design and construction of bonded and unbonded overlays and high-performance slab-on-ground are covered in ACI 302.1R-041 and ACI 360R-10.2 Bonded and unbonded toppings were also discussed in the August 2013 Concrete International Concrete Q&A feature.3

For decades, existing, predominantly flexible, highway and roadway pavements have been rehabilitated with concrete overlays commonly known as whitetopping. These measures are classified as conventional, thin, and ultrathin, with thick-nesses of more than 8 in. (200 mm), 4 to 8 in. (100 to 200 mm), and 2 to 4 in. (50 to 100 mm), respectively. The ultrathin version, 4 in. (100 mm) thickness preferred, is popular because it is designed to bond compositely with the original pavement. Regarding behavioral characteristics and life-cycle predictions, caution is advised in drawing comparisons between roadway paving and industrial floor rehabilitation protocols, given the disparities in load distribution (large, tandem pneumatic tires versus small, hard polyurethane wheels), serviceability requirements, and construction methodology.

Comparative Features of the Four Options

Before the most suitable choice is selected in connection with conversion of an existing facility to Internet-era function, the original floor slab-on-ground installation must be thoroughly investigated. Studies pertinent to forming judgments about the bonded, unbonded, and replacement options include:

- Flatness/levelness and impulse radar (slab thickness) measurements;
- Petrographic and environmental studies;
- Moisture emission tests; and
- Compressive and flexural strength evaluations of in-place concrete test specimens.

The subbase materials also need to be examined for evidence of latent adverse chemical activity and, perhaps, prior leakage of stored toxic liquids or intrusion of contami-nated floor cleaning solutions. This information is essential to evolving structural section properties, finishing and detailing characteristics, moisture mitigation techniques, construction practices, and comparative costs commensurate with antici-pated usage criteria and serviceability standards. Historically, the thickness of an industrial concrete floor slab has been derived manually from empirical data embodied in design charts published by the Portland Cement Association (PCA) in several editions dating back to 1967. The essentials of this method, also appearing in the appendixes of ACI 360R-10,2 are rooted in the pioneering work of H.M. Westergaard4 and others early in the twentieth century. In theory, the floor slab is assumed to behave as a flexible mat, relying on such criteria as modulus of subgrade reaction, in lieu of bearing capacity applicable to rigid foundations, and modulus of rupture (flexural strength) assigned to the subbase soil and plain concrete slab, respectively. Early on, the determinations were bloated with rather sizeable safety factors. It is also notable that the allowable unit stress for flexural tension, for example, stipulated in the ACI 318-56 Building Code,5 hovered around 100 psi (700 kPa). Estimates of flexural strength can be determined conservatively from the popular compressive strength test on cylinders commonly cast at construction sites. Actually, flexural beam specimens drawn from modern concrete floor slabs made up of uniformly graded and well-proportioned concrete mixtures have yielded upwards of 10 times the flexural capacity of plain concrete contemplated generations ago. Nowadays, safety factors are being streamlined and slab thickness analyses are relegated to the computer in a futile search for greater accuracy, despite the fact that software programs also ask for modulus of subgrade reaction input. No matter how you figure it, the concrete floor slab-on-ground is demonstrably stronger than it looks on paper.

Nonetheless, judicious estimates need to be made about loading expectations consistent with enlarged storage volume. The building adaptation may be undertaken on a speculative basis or with particular new tenant occupancy in mind. Manufacturer’s rated rack post load data are not normally available until the equipment is ordered, so the product should be “weighed” or the loading otherwise rationally determined statistically.

Option 1: Bonded concrete topping

Structural capacity of an existing industrial floor slab can, theoretically, be substantially enhanced by a relatively thin, reliably bonded overlay minimally 2 in. (50 mm) thick, but this option requires invasive preparation involving rehabilitation of intrusive random drying shrinkage cracks and curled joint edges as well as sealant replacement. Surface contaminants, dirt, and debris are removed by blast-tracking (a minimally intrusive dust-free process in which a hand-operated apparatus spews a metal abrasive by means of a rotating blast wheel) to render a uniformly bondable texture. This is followed by grinding at repair locations, using equipment fitted with high-efficiency air filters to protect workers and others from accumulated dust. It is critically important to install this topping immediately after application of a proper, uniformly distributed bonding agent. To facilitate placement and finishing of a thin topping, the concrete mixture must uniquely incorporate a single coarse aggregate with a nominal maximum top size of 3/8 in. (9.5 mm), commonly referred to as pea gravel. Such a mixture, tending to be highly shrinkage-prone, requires especially judicious proportioning of the mixture ingredients and rigorous water control management. The finished topping slab is to be moist cured and provided with full-depth early entry saw cuts at precisely matched, existing, closely spaced contraction joints.

Option 2: Bonded epoxy mortar overlay

Contrasted with the other options, an oversized epoxy mortar/fine aggregate blended material, 1/2 to 3/4 in. (13 to 19 mm) thick, provides a dependable bonded topping capable of increasing the geometric section properties of a nominal 6 in. (152 mm) existing industrial concrete floor as much as 20 to 30%—sufficient to sustain correspondingly elevated rack post loads. The finished surface is notably strong, with superior abrasion and impact resistance, and may preclude dock leveler adjustments. This method entails a multistep epoxy installation entrusted to an experienced coating contractor with demonstrated expertise in this particular specialty.6

Option 3: Unbonded concrete overlay

The minimum thickness of this plain concrete installation must be 4 in. (102 mm). Considerably thicker than a bonded topping, it is much less invasive. Surface preparation comprises only power-washing the existing slab and placement of a puncture-resistant plastic membrane spread evenly over the entire floor area (to mask existing slab abnormalities such as cracks, curled joint edges, and repairs) and lapped upward to form a flashing continuously at the perimeter. Slab anchorages, embedments, and steel reinforcing bars tending to restrain or otherwise inhibit slab movement are to be scrupulously avoided. Obtrusive cracking and slab edge curling are directly related to restrained drying shrinkage. The smooth membrane acting as a slip sheet directly beneath the overlay dramatically reduces subgrade drag, thereby permitting the new slab to shrink freely.

The overlay concrete is to be proportioned for the lowest shrinkage characteristics attainable with locally available materials. This formulation typically embodies at least two coarse aggregates, beginning with a reasonably well-graded No. 57 ASTM C33/C33M blend, 1 in. (25.0 mm) top size, and an added No. 8, a 3/8 in. (9.5 mm) intermediate size. It is also strongly recommended that the mixture includes monofilament synthetic fibers for control of plastic shrinkage cracking and properly configured ASTM A820/820M Type II steel fibers, 1 in. (25 mm) long and continuously deformed, at dosage rates prescribed by the manufacturer and consistent with contractor experience, proportioned according to slab thickness, and meeting targeted widely spaced contraction jointing. Needless to say, minimization of contraction joints in a finely tuned floor slab, with embedded wire guidance and meeting critical surface tolerances, is a high priority. Achieving crucial F-min readings at construction joints may require special localized grinding, particularly at those that are armored. Expectations of extending joint spacing boundaries to column lines and beyond, enclosing two full bays in each direction, are not unreasonable in a floor slab constructed by an experi-enced and enlightened flatwork contractor.

ACI 302.1R-041 has traditionally advocated limiting joint spacing in feet as a function of 2 to 3 times slab thickness (expressed in inches). This, of course, is a capitulation to the inevitability of excessive drying shrinkage in generic floor slabs made up of unworthy concrete mixtures. Chapter 6 of this guide delves thoroughly into the fundamentals of pre-scriptive, low-shrinkage concrete mixture proportioning which, when combined with judgment and experience, will dramatically reduce drying shrinkage. Yet, inexplicably, a recent trend favors limiting this outmoded ratio to 2 to 2.5 times the slab thickness. After all, a sawn joint is also a crack, albeit aesthetically more pleasing than a random drying shrinkage crack but more likely to curl.

Option 4: Removal and replacement of existing slab

This option virtually precludes investigative study of the existing slab. Only the subbase will require rehabilitation. Industrial floors and the subbase strata below them, constructed before 1990, in general, are known to vary considerably in thickness and are not notably flat or leveled. Demolished recyclable crushed concrete retrieved from the existing slab can be used to improve subbase properties and, through re-grading adjustments, restore a level profile and allow space within the original subbase to accommodate increased slab thickness. Recycling trucks are designed to selectively root out reinforcing steel and other unwanted embedments and equipped to minimize dispersion of dust, while reducing the concrete to a suitably well-graded and compactible subbase material. The new floor slab can then be designed to meet anticipated forklift truck wheel and rack post loading criteria and usage and serviceability requirements. The concrete mixture, with an added ASTM C33/C33M No. 4, 1-1/2 in. (37.5 mm) top size coarse aggregate, will fundamentally mirror Option 3, focusing on a low-shrinkage mixture with optimized aggregate grading, minimal mixing water and paste contents, and steel fibers; likewise affording the opportunity for extended contraction joint spacing boundaries.7 Under special circumstances, depending upon contractor skill and experience in managing paste content, placement of a membrane slip-sheet between bottom of slab and the subbase will drastically reduce subgrade drag.8 Naturally, Option 4 has additional benefits that accrue from beginning anew.

Discussion

The surge in Internet commerce underlying the discussion of floor Options 3 and 4 lends a sense of urgency to challenges facing a concrete industry overwhelmingly reluctant to change course with respect to the traditional strength-driven perfor-mance mixture design strategy. These formulations are usually gap graded and offer little prospect for shrinkage curtailment, which is vital to modern industrial floors. Surely, the substantial expenditure involved in reaching historic heights in new and adapted buildings outfitted with sophisticated materials handling equipment is not to be squandered due to neglect of the important role played by slab-on-ground under these circumstances. Unfortunately, it often is.

Understandably, the idea of prescriptive lowest shrinkage concrete mixtures is not about to become universal overnight but personal experience, during the past two decades with hundreds of floors, has proven that the prescriptive mixture is easy to do and quality control managers in ready mixed concrete plants throughout the country are eager for the opportunity. Meanwhile, added to the usual list of suspects enlisted in the battle against excessive random cracking and joint edge curling in the generically formulated concrete floor is the notion that a chemical additive will magically lower the shrinkage threshold to a prescribed limit confirmed by standardized test. It should be noted that a 4 x 4 x 11 in. (102 x 102 x 279 mm) specimen, tested in a controlled laboratory environment per ASTM C157/C157M, "Standard Test Method for Length Change of Hardened Hydraulic- Cement Mortar and Concrete," does not replicate acres of slab-on-ground cast in the field under variable climatic conditions, moist at the bottom while drying out at the top. Larger-size test specimens have been suggested to overcome this disparity dating back, at least, to 1984, but there is little in the way of reported statistical data to support this alternative.

The concrete floor slab-on-ground, operational heart of an industrial facility is much less expensive than the roof that hovers above it. Consider the following fundamental truths about plain concrete: it is a nonhomogenous material that, unlike structural steel, is inconsistent in manufacture and behaviorally unpredictable, especially when formulated generically in accordance with mythical rules limited to a single quality marker, compressive strength, often accompanied by a targeted water-cement ratio (w/c) bearing no known relationship to it. Compressive strength is not normally influential in the design of concrete subjected to flexure, notably slabs-on-ground, and w/c is evolved at the jobsite to suit optimum paste content consistent with hard-trowel finishability. The historic fascination with vapor retarder positioning relative to the "blotter effect" of the subbase

Raising the Roof

The proprietary E-Z Riser process can be used to lift an existing roof to two or more times its original height. Interior columns are enclosed within steel sleeves that allow the original columns to rise as they lift the roof. The original columns remain attached to the roof structure, and the sleeves remain in place to provide new and stronger lower support. Perimeter columns are fitted with additional telescoping columns that remain as integral parts of the lifted, strengthened structure. The condition and pitch of the existing roof are main-tained, and the existing foundation system continues to support the roof. While additional cladding is required and the floor slab may require modification, raising the roof is an economical and sustainable way to modernize a facility. Additional information can be found at www.rooflift.com.

An example of capturing unused air space to enlarge an industrial facility (photo courtesy of John J. Bernauer, EZ Riser Roof Raising Services)

centers upon bleed water management, profoundly important in the “window of finishability” period during the floating and finishing processes. The debate persists because excessive initial slump has predominated slab-on-ground discourse since time immemorial. Judgment of the finisher regarding “set time” is guided by skill honed through prior experience. This skill can be successfully adapted to managing low slump in concrete mixtures cast directly upon a membrane slip-sheet.

In the strictest sense, concrete is not an elastic material. It is, nevertheless, blessed with an ill-defined modulus of elasticity (E) that varies with time and stress gradient. Concrete is an exceptional material, when treated with respect. Blended to its full potential, the results are uniformity of strength and shrinkage properties. No other remedies are necessary. A proper, well-blended formulation negotiated with the local ready mixed concrete supplier is as good as it gets and no one need bear the onus of a target shrinkage limit governed by an indeterminate standard of measurement. The concrete industry, languishing in a perpetual state of inertia, is burdened with an archaic method of formulating concrete mixtures, notably those dedicated to slab-on-ground usage. Most building materials are manufactured under strict quality control protocols aimed at product quality and consistency. An industrial floor constructed of a worthy plain concrete and treated to a superior hard trowel finish will surely suffice. The performance concept applied to concrete manufactured universally under the aegis of the concrete industry is a good idea. Why not merge it with the lowest attainable shrinkage characteristics of the prescriptive formula and make them one and the same? This is inevitable; simply a matter of time.

Summary

The slabs covered in Options 1 through 3 will reside upon an impervious, virtually inflexible, concrete substrate (rather than directly against a proper moisture absorbent granular subbase). All of the options provide aesthetic improvement and refined surface tolerances. Options 3 and 4 also offer substantially reduced subgrade drag, allowing the new slab increased shrinkage freedom, thereby dramatically reducing the incidence of random restrained drying shrinkage cracking and perceptible joint edge curling. Both options will necessitate rearrangement of embedded steel load dock leveler apparatus to meet the newly raised floor elevation.

While roof and floor adaptations may be implemented in footprint segments as small as 100,000 ft2 (9290 m2), it is likely that buildings selected for high-rise conversion will be considerably larger. Floor slab upgrades in a vacant space may begin at once, await arrival of a prospective tenant with specific usage requirements, or may not be done at all depending on investigative findings and economic considerations.

Options 1, 3, and 4 contemplate uniquely blended plain concrete mixtures with lowest attainable shrinkage character-istics, conventionally deposited and appropriately flowable for laser placement without benefit of excess mixing water; adding a first-generation high-range water-reducing admixture (Super P) in the field to insure control of initial “water slump.” It is not necessary or beneficial to perform shrinkage tests to quantify shrinkage limits in such concrete formulations. Shrinkage test prism specimens in the laboratory do not replicate the behavior of a slab-on-ground in the field, and adding a shrinkage-reducing admixture to an unworthy concrete is an unacceptable alternative.

Option 1 not only requires less concrete volume than Option 3, it adds theoretically reliable composite geometric section properties and increases flexural capacity of the floor. However, there is insufficient evidence to engender full confidence in the long-term survivability of a thin concrete topping bonded to a generic industrial floor that is destined, in the modern era under perennial 24/7 continuous operations, to endure hard-wheeled forklift traffic abuse. While the degree of risk associated with debonding may not be fully known, the consequences of operational interruption are all but unthinkable.

Option 2 combines reliably with an existing floor slab to effect composite structural enhancement at a threshold meeting the needs of many prospective tenants. Absent the specter of major adaptations, it lends an attractive, nonslip, durable finish to a worn and outmoded floor, significantly prolonging its serviceable life and limiting maintenance costs.

Favoring the low-shrinkage approach, Option 3 involves twice as much concrete volume as Option 1. Extensive rehabilitation of the existing floor slab is avoided and the opportunity to broaden joint spacing boundaries is available. Unlike Option 1, the independent overlay does not unite with the existing slab in creating composite geometric section characteristics essential to enhanced structural behavior. But, the thickened overlay does improve the surface profile as it introduces a stratum of broadened influence over which concentrated loads are distributed through the existing slab to the subbase.

Option 4 requires minimal study and will not usually involve extensive reworking of the subbase or membrane vapor emission protection (except in relatively small areas destined for office occupancy). It offers the best attributes of the other options, fulfilling modern usage requirements, serviceability standards, and minimal future maintenance expectations, while curtailing investigative efforts and rehabilitation protocols.

Nevertheless, it is prudent to compare and contrast the expectations and costs associated with all of the options on a project-specific tenant usage basis. Depending on building size, scope of façade work, and extent of utility, mechanical, and electrical adaptations, the expenditure for a floor slab upgrade is estimated to be somewhat less than the cost of the roof conversion. The roof transformation adds substantially to the property value and is also environmentally friendly; adding little new material to the building, it simply moves things around. But, the floor does not just lie there covering the earth. It deserves more than a sprucing up with a surface hardener or deep-penetrating chemical densifier to meet the demands of modern commerce. The total adaptation expenditure can be expected to reach many millions of dollars. The urgent need for higher space accommodating vastly expanded storage volume is often accompanied by the yearning for larger floor area. Major Internet-commerce companies are currently building facilities more than 1,000,000 ft2 (92,900 m2) in area throughout the Northern Hemisphere. Landlords holding smaller, low-rise buildings with expiring leases may opt to hold out for a tenant whose needs suit the space. Inevitably, contemplation of adapting a building trumps the thought of replacing it.

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Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

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CASE STUDY

Reprint from CI Magazine, Volume 37, No 3, Page 49-53

Reinforcing Steel in Pervious Concrete

The case of the Rosehill Cemetery walls

by George W. Seegebrecht

While pervious concrete (also known as no-fines, porous, or popcorn concrete) has recently received much attention as a pavement material, this type of concrete is not new and its applications haven't been limited to pavements. In fact, records show that walls constructed using no-fines concrete (two houses and a seawall in the United Kingdom) date as early as 1852.1 Further, no-fines concrete has been used in construction of single and multi-story buildings in the United Kingdom and other European countries since 1930.

Pervious concrete has also been used to construct walls in the United States, including concrete walls and various building elements at the 63rd Street Beach House and the perimeter boundary walls of the Rosehill (Fig. 1) and St. Boniface Cemeteries (Fig. 2) in Chicago, IL. Over the past 18 years, periodic observations were made of the condition of these walls. When possible, concrete samples from spalled locations were examined. This article summarizes the obser-vations and discusses the surprising performance of this reinforced pervious concrete.

History

The Rosehill Cemetery was chartered in 1859, and the first plat comprised about 60 acres (24 ha).2 From time to time, the Rosehill Cemetery company acquired additional land and the cemetery grew to about 320 acres (130 ha). According to court records regarding a disputed further expansion of the cemetery in the 1930s, the concrete wall was constructed in about 1928.3

In recent years, some of the wall segments and pilasters on the Rosehill Cemetery wall have been replaced or removed due to damage or changes in use. The walls on the western boundary of the cemetery, for example, were replaced with wrought iron fencing around 1990, mainly because the cap stones on the wall's pilasters were falling (information provided by the late Albert Litvin, while at CTLGroup, Skokie, IL). During one of the replacement projects, square twisted reinforcing bars, such as the one shown in Fig. 3, were exposed. This type of bar was patented by E.L. Ransome in 1884 and produced by Carnegie Steel in Pittsburgh, PA, and Ryerson Steel in Chicago, IL.4 This bar type would be expected to be used in a wall constructed in 1928.

The St. Boniface Cemetery, which was consecrated in 1863, is just a few blocks southeast of Rosehill Cemetery. While the construction date for the pervious concrete walls at the St. Boniface Cemetery is unknown, the walls are quite

Fig. 1: Overall view of the Rosehill Cemetery, Chicago, IL, perimeter wall, which comprises porous concrete. The coping (top cap) is similar porous concrete but is covered with a mortar coating and exhibits occasional damage due to freezing-and-thawing. The wall exhibits corrosion-related distress, particularly near the base, where the pervious concrete is supported by a foundation made of similar porous concrete covered with a mortar coating approximately 1/8 in. (3 mm) thick

Fig. 2: Perimeter walls at St. Boniface Cemetery, Chicago, IL: (a) a general view; and (b) close-up of the deterioration of the 1/8 in. (3 mm) thick mortar coating on the porous concrete foundation

Fig. 3: An example of a square twisted reinforcing bar in the pervious concrete wall at the Rosehill Cemetery, Chicago, IL. Spalling damage can be seen at the interface between the pervious wall beyond and top of the bearing surface of the foundation. The foundation is composed of similar porous concrete covered with a mortar coating approximately 1/8 in. (3 mm) thick

similar to those at Rosehill. Although significant portions of the St. Boniface walls were demolished and replaced with fencing in 2012 and 2013, many sections of the original walls remain.

Decades of Service

Pervious concrete has been shown to perform well under freezing-and-thawing cycles,5 largely because it drains rapidly and therefore can't become saturated. Placing reinforcing steel in pervious concrete would, however, seem to present durabil-ity issues. An advancing carbonation front would be expected to quickly reach the steel, resulting in relatively early depassiv-ation and initiation of the corrosion process (with sufficient moisture conditions). Expansive pressure exerted by the formation of corrosion products could then be expected to eventually cause visible corrosion related damage (spalling). Yet, despite these seemingly negative characteristics, signifi-cant damage of the walls at Rosehill Cemetery occurred only after many years of service. Why have the walls performed well for over eight decades? We begin to answer this question simply by examining the potential corrosion mechanisms for steel embedded in pervious concrete.

Concrete Qualities

During one of the recent replacement projects at the Rosehill Cemetery, samples of the pervious concrete were obtained. The concrete contains 5/8 in. (15.9 mm) crushed limestone (Fig. 4), but it is not strictly a no-fines mixture. Based on laboratory examinations, approximately 5% of the total mass of the mixture comprised fine aggregate (Fig. 5).

The pervious concrete walls drained water well and exhibited no widespread freezing-and-thawing deterioration except in isolated areas where drainage appeared restricted.

Fig. 4: Texture of exterior face of pervious wall. The mixture contains 5/8 in. (15.9 mm) crushed aggregate and a small amount of sand. Form board impressions are occasionally evident, but very few lift lines are visible, suggesting thorough mixing, efficient placement, and methodical consolidation (probably by tamping)

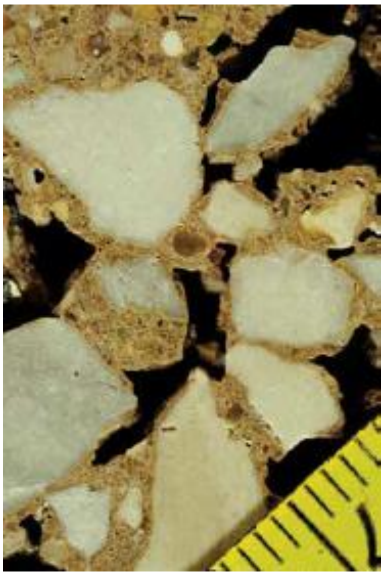

Fig. 5: A cut and polished cross section of the pervious wall concrete. The graduations on the scale in the lower right corner are in millimeters (photo courtesy of CTLGroup)

Fig. 6: The frequency and severity of distress is predominately greater at the base of the pervious wall, where the pervious concrete bears on the closed surface of the mortar-covered concrete foundation

The vertical orientation of the walls, the mostly unobstructed exposure to air flow on both wall faces, and the interconnected void system of the mixture almost certainly helped to avoid critical saturation, thereby reducing the probable damage due to freezing and thawing.

Over the past 18 years, increasing incidences of visible distress have been noted. The distress commonly occurs above the interface of the pervious concrete wall and the mortar-coated porous concrete foundation (Fig. 6).

While the majority of the visible sections of newly exposed steel bars were in excellent condition with almost clean bar surfaces, those located in zones with reduced drainage near the wall/foundation interface (where repairs have been made using conventional mortar) exhibited heavy corrosion or complete section loss.

It can be difficult to match repair materials with existing concrete, but aesthetic and durability requirements frequently call for repair mixtures similar to the base material. The mortar repairs observed on the pervious concrete wall, however, don't meet that simple objective (Fig. 7). The relatively nonpervious mortar used in the wall repairs would be expected to clog the pervious concrete void structure, trapping moisture within the member and impeding drainage from the wall. This can be expected to contribute to both corrosion and freezing-and-thawing damage. To restore appearance and improve performance, it would be prudent to conduct trial mixtures as Gaudette and Stanton did for the 63rd Street Beach House evaluation.6

Carbonation

The high alkaline environment of concrete normally protects steel against corrosion through passivation,7 but this protection breaks down as chlorides reach the steel level or the

Fig. 7: Repairs made using a nonpervious mortar mixture are unattractive, and they could be accelerating corrosion damage by clogging the open textured matrix and reducing drainage of any accumulated water within the wall

pH of the concrete drops below about 11.5, often as the result of carbonation of the concrete. According to Detwiler and Taylor,8 the reaction of atmospheric carbon dioxide (CO_2) with calcium hydroxide tends to reduce permeability in conventional concrete as the reaction products make the concrete somewhat denser. This densification subsequently retards the reaction at greater depths, slowing the advancement of the carbonation front through the cover protecting the steel. Conversely, the porous void structure of pervious concrete would be expected to offer much less resistance to slow rates of carbonation, and this has been verified by research on no-fines concrete specimens produced with a water-cement ratio (w/c) of 0.39. Cube specimens were exposed to air at a nominal 3% CO_2 content, 21°C (70°F) temperature, and 60% relatively humidity. After only 10 and 30 days of exposure, the specimens were split and the fractured surfaces were treated with phenolphthalein. Due to the nature of carbonation process in no-fines concrete, carbonation depth measurements were not possible but image processing software was used to estimate the percentage of carbonated surface. The fractured surfaces were found to be carbonated over more than 50 and 70% of the treated area, respectively.9

With uniform pervious mixture proportions and cover, carbonation and subsequent depassivation of steel could occur relatively quickly over the length of any embedded reinforcing bars, assuming a uniform cover depth. While this would make the steel more susceptible to corrosion, carbonation represents only one component necessary for the corrosion process to take place.

Moisture

The cemetery walls are exposed to atmosphere on both faces. Wind-driven rain can therefore be expected to enter the no-fines concrete and increase the relative humidity within the wall. However, air movement also allows relatively quick drying of the walls. Long periods of dry weather could lower interior relative humidity levels, resulting in an inefficient electrolyte at the concrete-steel interface, with the net effect of reduced rates of corrosion until the next rainstorm.

This has been confirmed by research on no-fines concrete exposed to carbonation and wetting and drying cycles.10 The results indicate that while the time to corrosion initiation may take only a few weeks, the material dries quickly, leading to negligible corrosion of embedded steel. That is, the corrosion rate is high only when the material is exposed to wetting.

The lack of capillary passages in the pervious concrete11 would also be expected to limit or prevent the upward transmission of water (rising damp) from the foundation into the wall. However, the bearing surface of the foundation would be expected to interrupt the downward percolation of water draining from the wall from a rain event. Until that water drains and/or evaporates from the upper surface of the foundation, an efficient electrolyte would exist at the interface of the wall and the foundation. A corrosion cell would be maintained at this level of the wall longer than any corrosion cells that might develop higher up in the wall. This interface also is near the zones of most severe reinforcement corrosion as well as complete disintegration of the steel within 1 ft (0.30 m) above the top of the foundation.

Because the foundation concrete actually consists of the same porous concrete but covered with a uniform mortar coating approximately 1/8 in. (3 mm) thick, this coating resists rain penetration and capillary rise from below quite well until the mortar coating is breached.

Chlorides

Chlorides in concrete generally increase corrosion rates in the presence of sufficient moisture and oxygen. While the pervious concrete samples from the cemetery walls were not evaluated for the presence of chlorides, a discussion of the potential sources of chlorides is warranted. There are usually three sources of chlorides in concrete: aggregates, accelerating admixtures, and deicing chemicals. The aggregates in the Chicago area are generally not a source of chlorides. Also, it's highly unlikely that accelerating admixtures were used in the construction of the cemetery walls. The somewhat "dry" mixture needed to produce pervious concrete would normally allow only a relatively short time frame for proper tamped wall placement. It's likely that the concrete for the walls was mixed in the field and placed in shallow lifts, so the use of an accelerating admixture in this construction would have been quite counterproductive. Some of the walls are, however, located near busy city streets. It's possible that road salt would not have affected the pervious walls for at least the first two decades of their existence. Deicing chemicals, particularly rock salt, did not come into heavy use on U.S. streets and highways until the 1950s.12 When road salt did become more common in the 1960s and 1970s, however, spray from passing vehicles would have transferred chlorides to the walls, and the pervious concrete would have allowed the chlorides to penetrate and possibly reach the reinforcing bars. While rain water would be expected to remove some of those chlorides, poor drainage in the lower portions of walls would be expected to result in increasingly higher chloride concentrations at the interface with the conventional concrete foundation.

Decades of Success

The pervious concrete walls at the perimeter of Chicago's Rosehill Cemetery have been in place for at least 85 years. While the embedded reinforcing steel has exhibited corrosion in recent years, the walls have performed surprisingly well. Corrosion has been predomi-nantly limited to the zone near the interface between the pervious concrete wall panels and the mortar-coated porous concrete foundation.

On the one hand, the voids in the pervious concrete would be expected to promote rapid carbonation of the concrete and allow regular wetting of the reinforcing bars as well as exposure to chlorides from nearby streets. On the other hand, the voids should and probably have allowed rapid drying of the concrete near the reinforcing bars, effectively impairing conditions for maintaining the electrolyte necessary for ongoing rapid corrosion rates. Even in locations where corrosion has initiated, it's possible that the voids in the concrete provide zones for corrosion products to expand without immediate develop-ment of cracking or spalling and thereby extending the time until actual damage is exhibited.13

Unfortunately, distress suggests that drying has apparently been prevented at the interface between the pervious concrete wall and the mortar coated pervious concrete footing. The footing may also be allowing an accumulation of chlorides from road salts used on nearby streets. Corrosion damage is causing spalling near the base of the pervious concrete wall panels while inappropriate selection of repair materials may be compounding the problem.

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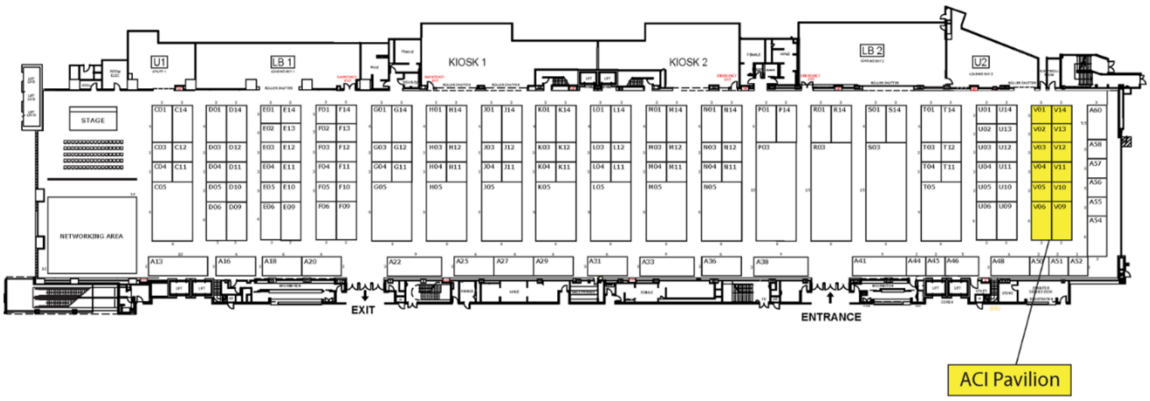

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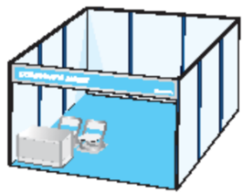

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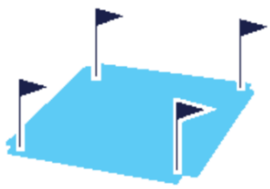

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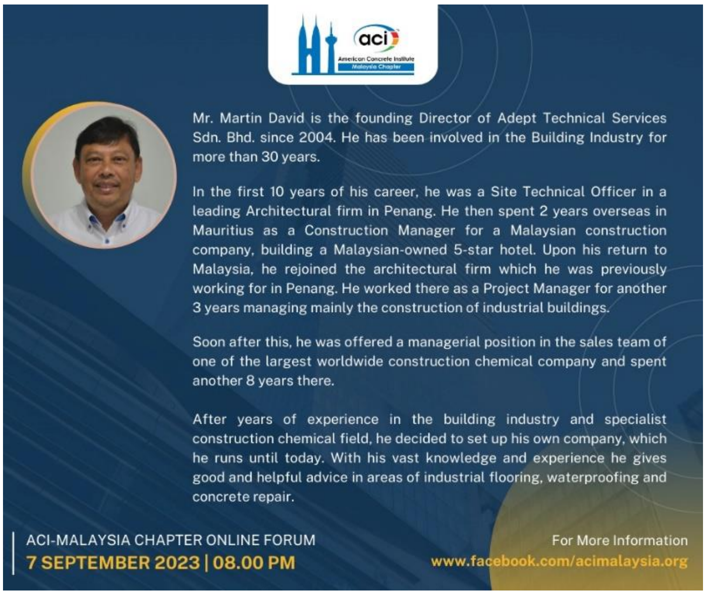
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America Concrete Institute-Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authority in concrete technology.
Our membership is not only limited to engineers, in fact it includes educators, architects, consultants, corporate bodies, contractors, suppliers and experts in cement and concrete related fields.
Contact Us
www.acimalaysia.org
70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC) 46150 Selangor, Malaysia.
+60 (3) 7782 2996 (Admin-1)
+60 (14) 2207 138 (Admin-2)
Email: info@acimalaysia.org

REGISTER NOW

WHY CHOOSE US?

We look forward to your kind support and, more importantly, to your participation and registration as a member of ACI-Malaysia Chapter. It is our firm belief your involvement and together with your commitments will go a long way in our quest to uphold all our objectives to mutually benefits for all members.

Open for Registration

JOIN US

+6014 220 7138
http://www.acimalaysia.org
admin@acimalaysia.org

American Concrete Institute - Malaysia Chapter
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Petaling Jaya Commercial City (PJCC),
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Website: **www.acimalaysia.org** eMail: **info@acimalaysia.org**

Membership Application Form

Type of Membership (please tick "☑" one option only)

	Joining Fees (Total)(RM)	(Entrance Fee +	Subscription Fee per annum)
❒ Organizational Member:	A Firm, Corporation, Society, Government Agency or other organizations. **RM800.00**	(RM500.00 +	RM300.00)
❒ Associate Member:	An individual who is not a member of **ACI International** but American Concrete Institute – Malaysia Chapter only. **RM200.00**	(RM100.00 +	RM100.00)
❒ Student Member:	**RM30.00**	(RM30.00 +	RM0.00)

To be admitted as a **Chapter Member**(*), return this form together with **Crossed-cheque** (any outstation cheque to include Bank Commission)/ **Online Bank Transfer/ Cash Deposit** made payable to:

Account Holder Name: **American Concrete Institute – Malaysia Chapter**
Bank: **Hong Leong Bank Berhad (HLB)**
Account Number: **291.0002.0936**

*Once payment has been made, it is important to send **Remittance Slip/ Deposit Advice/ Bank Transfer Receipt** to our Administrative Office for confirmation, via these channels:*

WhatsApp: **+60 (14) 2207.138** (*ACI.my Administrative-2*); or
eMail: **admin@acimalaysia.org**

(*) Benefits provided by **ACI International** for Chapter Members:

1. Digital subscription to Concrete International magazine;
2. Access to the ACI Membership Directory; and
3. 3-Tokens to ACI University Courses;
4. Printable ACI Membership Certificate

Important Notes:

- ❖ Benefits will be accessible via Temporary Password sent to your email account either in the month of **June** or **December**, depend on time slot of **Chapter Member List** update to **ACI International**;
- ❖ All benefits are subject to change without prior notice.

Personal Particulars:

Are you a Member of **American Concrete Institute International** (ACI International)?
❒ No.
❒ Yes. (Please provide your ACI Int'l Membership Number: ________ Since (Year): ________)

Name: ____________ (First) ____________ (Last)
Salutation / Title: ________ (Mr./ Ms./ Mdm./ Ir./ Ar./ Dr./ Prof./) Other: ________
NRIC/ Passport No: ____________ Nationality: ________
Mobile Number: +60 (1) - ________ Email: ________
Company / Organization: ____________ Designation: ________
Postal Address: ______________________________
____
Postal code: ________ State: ________
Tel.: ________ Fax: ________ Email: ________
I am introduced to ACI-Malaysia Chapter by: ________________

Applicant Signature ________ Date ________

For Office Use Only

Membership No: [| - | | | |] Receipt No.: ________ Date: ________
Verified by: ________ (Name: ________) Date: ________
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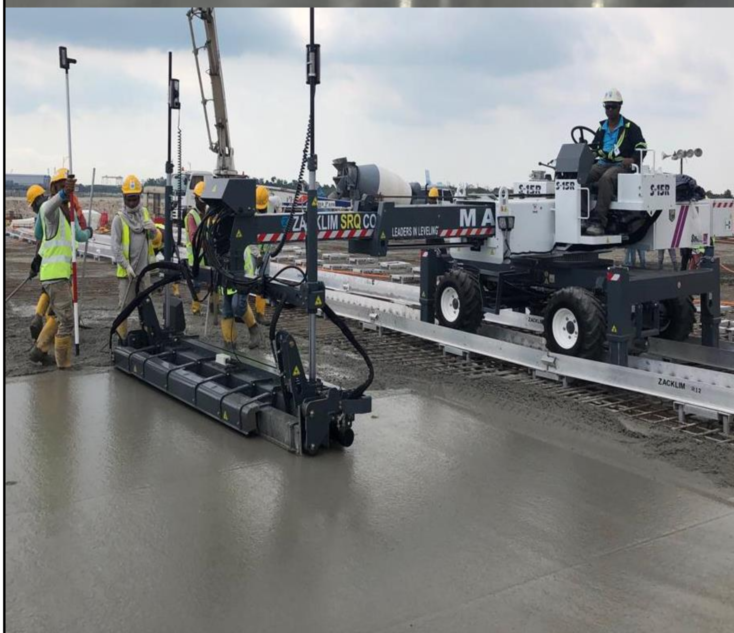

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