Concrete Slabs and Blocks for Car Park Paving

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Car park pavement design and construction did not receive much attention in Singapore until the early 1970s, when special landscape and public policy regulations requiring planting trees and growing grass within and around car parks were enforced. This rendered the conventional method of flexible or rigid pavement construction unsuitable for certain areas of a car park, parking lots in particular. The evolution is described of several innovative forms of parking lot pavement construction implemented by local pavement engineers in their decade-long search for a workable engineering solution to the problem. The features and performance of three satisfactory forms of construction are discussed and compared.

Singapore is a city state with a population of 2.5 million. More than 80 percent of Singapore's population are housed in multistory residential flats. Public housing estates consisting of hundreds of blocks of multistory buildings have become a landmark of Singapore. Above-ground car parks form an important element of these housing estates, which are situated mainly in suburban locations. Within the city area, parking facilities are always in great demand. More above-ground car parks are being constructed as urban renewal development projects continue in the older sections of the city.

The shortage of car parks is most acute in the public-housing sector. In terms of dwelling units, more than 500,000 flats had been constructed by the end of 1984 *(1)*. The number is expected to reach 600,000 in the 1990s. In 1984 the number of passenger cars and pickups owned by residential flat dwellers was estimated to be 160,000 *(2)*, amounting to approximately one car per three dwelling units. On the basis of the past year's record, the number of cars owned by flat dwellers is expected to rise by more than 8 percent per year. Many existing car parks have had to be expanded in order to cope with the constantly increasing demand.

Construction and maintenance of public car parks represents an important expenditure item in the annual budget of Singapore road agencies. In public housing estates alone, on the basis of the expected 600,000 flats in the 1990s and assuming 150 parking spaces for an average car park, more than 1,300 car parks in total would be required. Like any large engineering project, the search for the most cost-effective construction materials, construction method, and maintenance procedure for car parks under local conditions presents a challenge to the road engineers in Singapore.

It is interesting that in Singapore car park construction is not a straightforward engineering problem. The impacts of car parks on the landscape of housing estates has been a major concern since large-scale construction of multistory residential flats began in the early 1970s. In line with the then-existing public policy of keeping the city green, it was introduced as a standard practice in Singapore to plant trees and grass in all public car parks. In a typical public car park, as shown schematically in Figure 1, two neighboring rows of parking spaces are usually separated by a median on which grass and trees are planted. Efforts have also been made to plant grass on part or all of the parking areas.

Certain engineering problems were encountered during the early phase of implementing the policy of planting of trees and grass within car parks. A number of car park pavement designs and constructions have been introduced and tried by engineers of various local highway agencies with varying degrees of success. In this paper the local experience involved and problems faced in providing car park pavements that are both structurally sound and aesthetically compatible with the adjacent landscape are discussed. A review on the development of various designs and types of construction in Singapore since the early 1970s is also presented.

EARLY FORMS OF CAR PARK PAVEMENTS

Traditionally, public roads in Singapore have been constructed of bituminous materials. One of the reasons that concrete roads are uncommon in Singapore is the lower capital costs of constructing bituminous pavement. The early phase of Singapore road network development in the 1950s and 1960s was involved mainly with construction and improvements of urban streets and rural roads. The need for frequent maintenance and upgrading of utility services beneath roadway pavements in urban areas was another factor contributing to the continuing use of asphalt pavements for urban streets. However, the concept of asphalt pavement stage construction, which allowed for strengthening as the need arose, was adopted as the practice for developing rural roads.

As a logical extension of roadway construction, car parks as well as bus terminals constructed during this period were also the flexible-pavement type. The combined effects of fuel spillage, oil leakage, and heat in the tropics that cause softening of asphalt binder make bituminous materials particularly vulnerable as bus terminal and car parking lot pavements in Singapore's climate. By the mid-1970s, although most bus terminal pavements had been converted into concrete slabs, concrete construction for car parks was still not regarded as an attractive alternative because the distresses found on parking lot pavements were less severe and less objectionable under the lighter traffic of automobiles.

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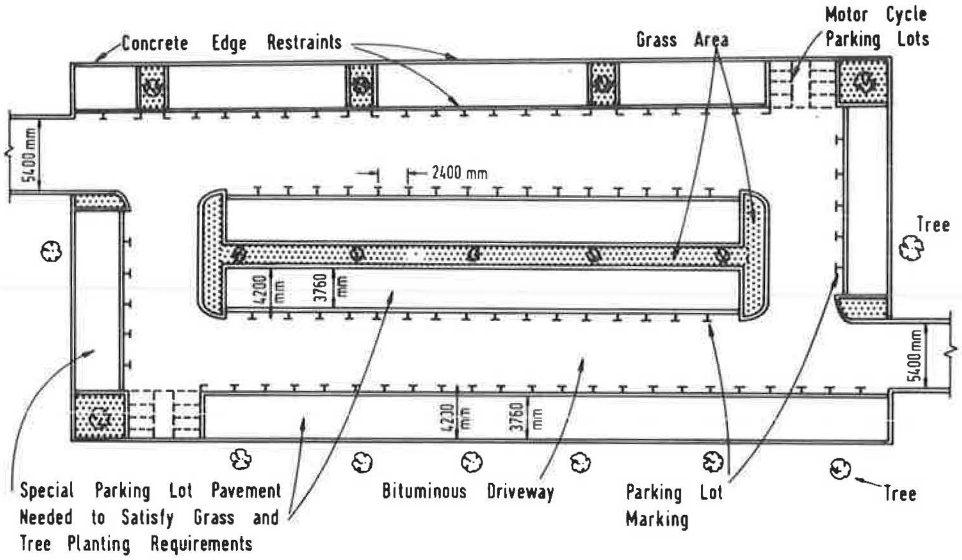

FIGURE 1 Typical layout of a public car park.

The continued use of bituminous pavements for parking areas was questioned when problems began to surface as the tree-planting policy was implemented. The adverse impacts of planting trees within a bituminous car park area were highly noticeable in the form of heaving and cracking of the bituminous pavement (Figure 2), which is caused by upward growth of tree roots. This is a direct consequence of the presence of the impervious bituminous pavement, which cuts off the surface water supply to the tree roots.

FIGURE 2 Asphalt pavement damaged by tree-root heaving.

The use of concrete construction for a part of each parking area became unavoidable subsequently when it was further required that a patch of grass wider than the ordinary grass median be provided so as to produce a more pleasant landscape. In other words, the shaded areas in Figure 1 are required to be sufficiently strong all-weather load-bearing surfaces with the appearance of natural grass. Neither the ordinary bituminous pavement nor the conventional concrete slab construction could satisfy this requirement. A new form of pavement construction was needed.

STUDDED-SLAB PAVEMENT

The versatility of concrete that allows it to be cast into different shapes and its durability under exposed environmental conditions make it a logical choice of material for the problem at hand. A studded-concrete-slab paving method (Figure 3) was a popular form of construction during the 1970s.

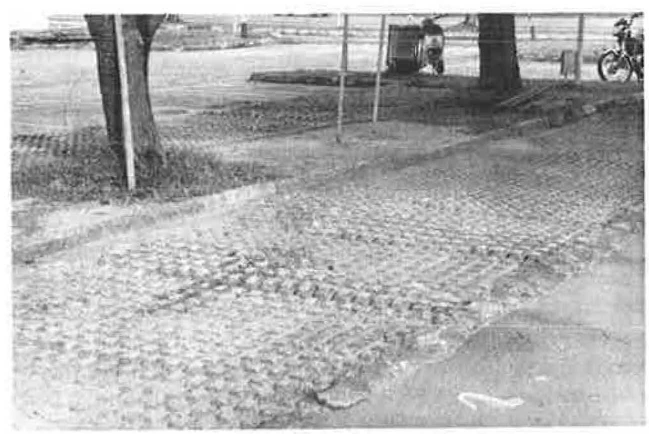

FIGURE 3 Studded-concrete-slab pavement construction for parking areas.

Two structural components of a studded slab can be differentiated, although in actual construction the two components are always cast together monolithically. The main component is the base slab from which the rigidity of the pavement is derived. The base slab acts to distribute vehicular loads to underlying base and subbase layers in the same way that a conventional concrete pavement does. It is the component that provides structural resistance to applied loads and temperature stresses. As such, the structural design of the base slab of a studded concrete pavement and the underlying base and subbase layers is the same as that of conventional concrete pavement.

Vertical concrete studs protruding from the base slab are the second component of a studded slab. The main functions of

these studs are to provide a stable contact surface for vehicular wheels and to transmit the wheel loads to the base slab below. The spacing of the studs has to be sufficiently close so that vehicles can maneuver smoothly in and out of a parking area, but it must be wide enough to provide space for grass to grow.

The studded-slab construction in Figure 3 separates the surface grass-growing soil from the load-bearing base and subbase materials by means of a base slab. This is desirable from an engineering point of view because fines and organic soils could be harmful to the structural properties of load-bearing layers. Field applications in the 1970s showed that grass could grow well on studded concrete parking areas, and structural failures of the base slab due to vehicular loads were rare. Unfortunately, just as a bituminous pavement seals off surface water, studded slabs also prevent surface runoff from entering the subsoil. Tree-root heaving remains a problem to be solved. Figure 4 shows a studded concrete pavement that was damaged by tree-root heaving.

FIGURE 4 Studded-slab pavement damage by tree-root heaving.

A modified construction process utilizing precast studded-slab units was subsequently tried. Each precast slab unit shown in Figure 5 is 585 mm (23 in.) long and 370 mm (14.5 in.) wide, with a base thickness of 100 mm (4 in.). The main purpose of using the precast-slab paving construction was to maintain joints between slab units through which surface water could enter the subsoil. The construction method also had the advantage of easy repair or replacement of individual damaged slab units and easy installation and maintenance of underground utilities. This modified construction process, unfortunately, did not produce the expected improvement in pavement performance problems with tree-root heaving. Heaving of slab units continued to occur even when a joint as wide as 50 mm (2 in.) was used.

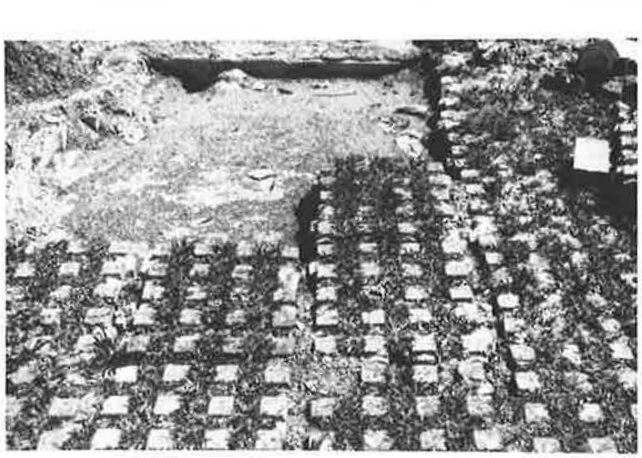

FIGURE 5 Precast studded-slab construction.

The experience with studded-slab pavements in Singapore also showed that they did not offer a comfortable surface for car owners and pedestrians to walk on. These pavements were found to be particularly inconvenient, if not hazardous, to female motorists wearing high-heeled shoes. Because of their unsatisfactory performance with tree-root heaving and the inconvenience caused to users, studded slabs are now rarely used for paving car parks in Singapore.

THE CONCEPT OF THE PERFORATED SLAB

The failure of precast studded slabs with joints to eliminate tree-root heaving led to several more in-depth research studies by pavement engineers of local road agencies. An early conclusion common to these studies was that a sufficiently large open space was necessary around a tree to alleviate the phenomenon of tree-root heaving.

The area of open space required around a tree varies with the type of tree planted. For those commonly planted in public car parks in Singapore, studies have found that an open area with a radius of 3.0 m (9 ft 10 in.) or more is desirable under the local climatic conditions *(3)*. With the standard car park layout shown in Figure 1, this means a loss of at least four parking spaces for every tree planted in a traditional bituminous pavement car park if tree-root heaving problems are to be avoided. This is not a desirable solution in either public housing estates or city areas where parking spaces are in great demand.

To provide as many parking spaces as possible in a car park without tree-root heaving problems, the parking spaces around a tree have to satisfy the following two conditions: (a) sufficient surface water must be able to enter the underlying soil and reach tree roots; and (b) the pavement surface must have sufficient strength and durability to support vehicular loads. In addition, a pavement surface with an appearance of high aesthetic value, such as a natural grass surface, is highly desirable.

The search for a suitable paving surface eventually led to the use of concrete perforated slabs. A perforated slab has openings to facilitate water passage into the underlying soil. A number of different designs have been tried in Singapore. The key issue, as far as tree-root heaving is concerned, is to determine the perforation area required that would allow sufficient surface water into subgrade soil.

There exist two variables in the design of slab perforations: (a) average perforation area per unit slab surface area and (b) size and distribution of perforations. On the basis of the performance of various perforated-slab designs, it appears that the average perforation per unit slab area is the controlling factor for preventing tree-root heaving problems. Distribution of perforations does not appear to affect the performance of the pavement much as long as it is fairly uniform over the pavement area concerned.

Perforation sizes are related to the perforation area required per unit slab area. In general, an opening should not be so small as to become clogged up easily. Openings smaller than 25 mm in diameter are undesirable. However, an opening wider than the imprint of a normal vehicle tire would not offer a stable contact surface to support vehicular loadings. Similarly, grass would not grow well in too small an opening. When the opening sizes are too big, grass tends to get damaged by repetitive moving wheel loads. From the car owner's or passenger's point of view, perforated slabs with small openings are preferable because they provide a smoother drive and a more comfortable walking surface.

Figure 6 shows the major types of precast perforated-slab units that are available in Singapore. Types A and B are the most commonly used for public housing estate car parks. On the basis of field performance, it has been found that Types D and E, with 20.4 and 16.6 percent openings, respectively, in surface area, were still adversely affected by upward growth of tree roots. In general, assuming that openings are uniformly distributed over the entire slab area, it may be said that slabs providing openings in excess of 30 percent in total surface area have been successful in eliminating tree-root-related heaving problems. Job specifications for car park perforated slabs in Singapore usually require a perforation area of 35 percent or more of the entire covered surface.

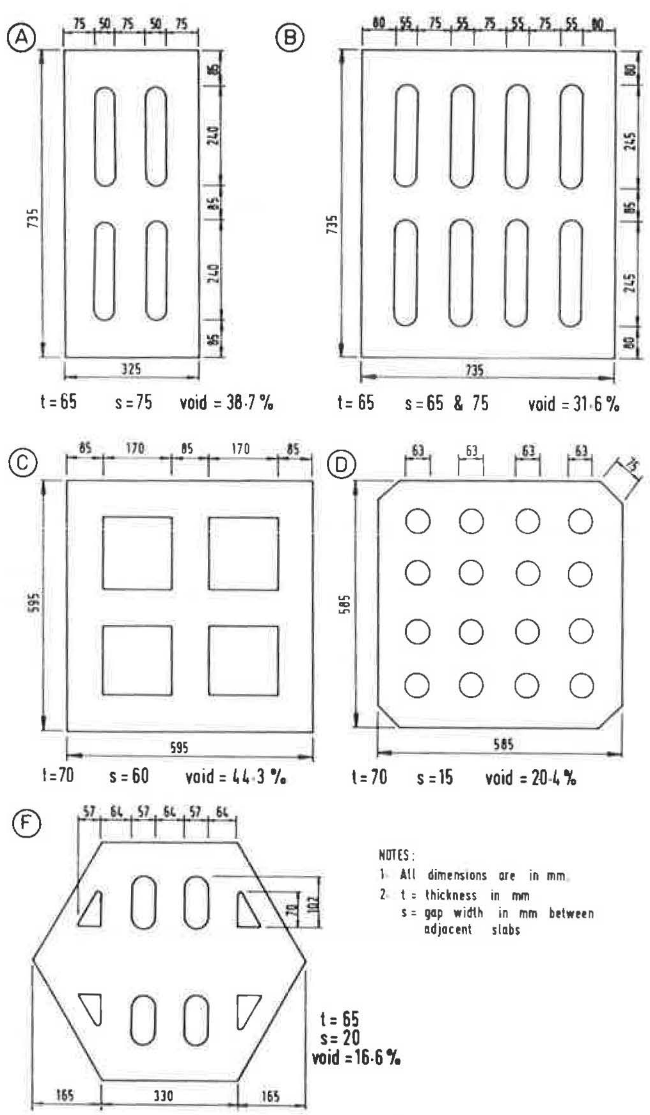

FIGURE 6 Types of precast perforated slabs.

PERFORMANCE OF PRECAST PERFORATED SLABS

The overall performance of a pavement constructed of precast perforated slab units may be evaluated by considering the following aspects: functional serviceability, structural stability, and aesthetic requirements. Functional serviceability refers to the perforation design of a perforated slab. As discussed earlier, small-width openings would provide a smoother ride and a relatively more comfortable walking surface.

The results of a survey to compare the functional serviceability of Types A and C slabs are as follows. The survey was conducted at a Type C perforated-slab car park by direct interview with the drivers who used the car park during lunch hour on a working weekday. A Type C perforated-slab car park was selected because it was believed that most motorists in Singapore were familiar with Type A slabs, whereas relatively few were familiar with Type C slabs.

	Response (N=132)					
	Yes		*No*		*No Difference*	
Question	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Does Type A provide smoother drive?	91	68.9	5	3.8	36	27.3
Is Type A more comfortable to walk on?	74	56.1	23	17.4	35	26.5
Is Type A aesthetically more pleasing?	49	37.1	37	28.0	46	34.9

On the basis of the foregoing survey, it appears that Type A slabs have better functional serviceability than Type C slabs. The functional serviceability of a perforated-slab pavement is a function of (a) percentage of perforation area, (b) distribution pattern of slab perforation, and (c) size of individual openings. In general, better functional serviceability can be achieved with a lower percentage of perforation area, more uniform distribution of slab openings, and smaller or narrower openings. No quantitative relationship, however, has been developed between functional serviceability and the three variables.

Landscape aesthetic value was the consideration that led to tree planting within car parks and the use of perforated slabs for parking areas. Two components of slab aesthetics are of interest to a landscape planner. These are the perforation pattern of the slab and whether grass could grow in these openings to give the pleasing appearance of a natural grass surface. Grass growing within perforated slab pavements has been a constant problem confronting car park maintenance agencies. Parking movements of automobiles are especially destructive to the growing grass.

In lightly used car parks, grass could grow well with most designs of perforated-slab pavement. In a heavily used car park such as the one in which the foregoing survey took place, the design of slab openings becomes important. For example, Type

A slabs with narrow oblong openings provide more protection against vehicular movement than Type C slabs with big square openings. Experience, however, has shown that even Type A slabs would not be able to produce a desired grass surface appearance when the frequency of parking movements is high. In comparison, studded-slab pavements are more satisfactory for growing grass in car parks with frequent vehicular movements.

Structural stability is perhaps the most important factor in the engineering design of perforated slab pavements. Beside the tree-root-heaving problems described earlier, two other common types of instability can be identified. One is structural cracking of slabs due to the action of wheel loads; another is movement of slabs, also caused by vehicular loadings. There are two general forms of slab movements, namely, tilting and rocking. Tilting occurs mostly on slabs that are subjected to edge loadings, whereas rocking is usually restricted to slabs centrally located on a wheelpath.

Table 1 summarizes the findings of a recent survey of several public car parks in Singapore that were affected by various forms of structural instability. This survey covered only Type A slabs because the number of car parks constructed with Type A slabs far exceeds the combined number of car parks using other slab types. Tilting and rocking together accounted for more than 90 percent of instability occurrences. Structural cracking was the next most frequent form of instability. It was common to find tilted or rocking slabs and cracked slabs both within one parking space. The results confirmed that the use of perforated slabs was effective in arresting tree-root heaving problems.

Figure 7 shows some cracked slabs. Typically cracks are found across longitudinal ribs adjacent to slab openings. In a number of cases, slab cracking was found to be related to upside-down placement of slabs. The reinforcement layout of Type A slabs is such that an upside-down slab could have its bending capacity reduced by more than 60 percent. It is therefore of importance to mark the top face when the slabs are cast in a fabrication yard to avoid placement mistakes in the field. Another frequent cause of slab cracking is nonuniform supporting conditions due to uneven compaction of underlying layers.

Most of the slab tilting and rocking problems were believed to be caused by unsound base materials and lack of interlocking between slab units. A standard layout of perforated slabs for a parking area is shown in Figure 8. The essential elements of perforated slab construction consist of a 200-mm (8-in.) crusher run granite base course and a 50-mm (2-in.) thick sand bedding. Subsequent to placement of slab units, all joints and slab openings are filled with organic soil and then close-turfed with grass. Although insufficient or uneven compaction may

FIGURE 7 Cracked precast perforated slabs.

lead to slab tilting and rocking, it is unlikely that the foregoing construction procedure might be partially responsible for the instability problem. First, the use of compressible soils in the joints would not provide effective interlocking between slab units. Second, the top organic soils and impurities may work their way into the underlying bedding sand, thereby impairing the latter's load-bearing capacity.

A study is now under way to seek a compromise solution so that both load-bearing and grass-planting requirements can be met. In this study sand is used for both slab bedding and joints, and grass planting is restricted to interior slab openings only. In addition, a filter blanket is also suggested to prevent contamination of bedding sand from the overlying organic soils. The aim of the study is to determine whether these measures would significantly reduce the occurrences of slab tilting and rocking.

In another recent effort to arrest the problem of slab tilting and rocking, all new public housing estate parking spaces are now laid with Type B instead of Type A slabs. These two types of slabs are similar in most design features, but the Type B slab is much wider and has a surface area more than twice that of the Type A slab. In terms of load bearing, there is a clear advantage in using a larger slab unit. For a given magnitude of wheel load applied at the center of each of the two slab types, the bearing pressure beneath a Type B slab will be only about 45 percent of the pressure under a Type A slab. Reductions of the same order are also obtained in cases of edge loadings. Given the same construction materials and procedure and the same vehicular loading conditions, it is therefore logical to expect that slab tilting and rocking would be less likely to occur with a Type B perforated-slab pavement.

TABLE 1 TYPE A PERFORATED-SLAB INSTABILITY

Car Park Location	No. of Defective Car Park Spaces	No. of Spaces by Instability			
		Cracking	Tilting	Rocking	Tree-Root Heaving
Geyland East	65	14	65	31	0
Toa Payoh Centre	47	31	44	19	0
Telok Blangah IIt	41	3	36	15	1
Ang Mo Kio West	36	8	35	7	0
Clementi Central	33	6	33	9	0

NOTE: A defective parking space may contain one or more than one type of slab instability.

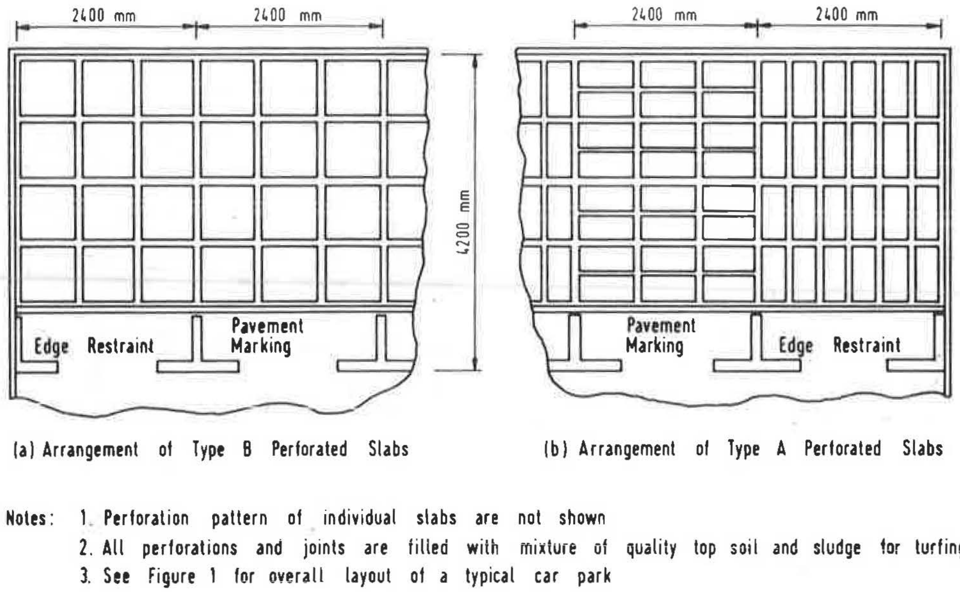

FIGURE 8 Layout of Types A and B perforated-slab pavements.

Another merit of using Type B slabs is that they would help to reduce the occurrences of edge loading along longitudinal joints. As with Type A slabs, the structural performance of Type B slabs depends very much on the soundness of the foundation construction. Furthermore, the problems of interlocking between slabs and possible contamination of bedding sands that affect Type A slabs are also present with Type B slabs. Figures 9 and 10 reveal that instabilities similar to those experienced with Type A slabs are also found in Type B slab pavements. The long-term field performance of Type B slabs is being monitored, and relevant data are being collected to determine whether occurrences of slab tilting and rocking will decrease.

FIGURE 10 Rocking and cracked Type B perforated slabs.

PERFORATED INTERLOCKING PAVING BLOCKS

Interlocking concrete block paving is not commonly used for road pavements in Singapore. Its use has been limited to car parks and driveways of private properties and hotels where aesthetic appeal of colored block units is an important architectural consideration. Although interlocking blocks are ideal for car park driveways, they are not suitable for paving parking areas, where openings must be allowed to prevent tree-root heaving. The joint spaces in a standard interlocking-block pavement do not allow for sufficient surface water to drain downward into the subsoil. Very often these joints are covered with dirt and become quite impervious after the pavement is opened to traffic.

FIGURE 9 Tilted Type B perforated slabs.

A patented design, known as Turf-Pave *(4)*, was used in Singapore in 1984 in a private housing estate to pave parking areas. It combines the concept of the perforated concrete slab with interlocking-block paving construction. Each Turf-Pave block is 470 by 470 mm (18.5 by 18.5 in.) and 120 mm (4 in.) thick. They are much bigger and heavier than ordinary interlocking paving blocks. They weigh 30 kg (66 lb) each, whereas an ordinary paving block weighs about 5 kg (11 lb). As shown in Figure 11, each Turf-Pave block has a 35 percent perforation area to cater to tree planting. The blocks are constructed of 35-MPa grade concrete and no steel reinforcements are used.

FIGURE 11 Interlocking-perforated-block pavement.

The construction of a perforated interlocking block pavement is similar to that for normal interlocking blocks. As with installation of other forms of perforated slabs, the subgrade must be compacted, leveled, and adequately drained and protected from inundation. The subbase usually consists of two or three layers of crusher run with a total thickness of 200 mm (8 in.) or more. A sand bedding layer is then laid and compacted to a thickness of about 30 mm (1.18 in.). The bedding sand used is well-graded sand passing a 4.75-mm sieve. The next step involves laying perforated interlocking blocks in the pattern shown in Figures 11 and 12. These blocks are vibrated to a uniform level with two or three passes of a powered vibrating plate. After this final compaction, dry angular sands are brushed over the surface of the blocks to fill the joints between paving blocks. All the interior perforations are then filled with loamy soil and turfed.

It is important that edge restraints be provided along the entire perimeter of an interlocking-block pavement to ensure effective interlocking. Such edge restraints are usually effected by constructing concrete edge strips or side curbs. It is hoped that the interlocking effect will help eliminate or reduce the slab rocking and tilting problems encountered in ordinary perforated-slab pavements. The perforated interlocking block parking lot pavement constructed was relatively small in area and subjected to very low frequency of vehicular movement by lightweight automobiles. More field applications will be required before sufficient data can be collected for a detailed evaluation of the performance of perforated interlocking-block pavements.

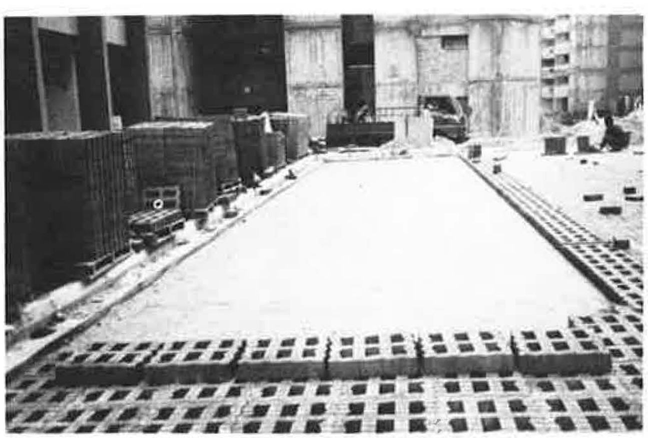

FIGURE 12 Construction of interlocking-perforated-block pavement.

The main deterrent to widespread use of perforated interlocking blocks for parking areas is cost. The unit cost for each square meter of paving (not including gravel subbase and sand bedding) is about 35 Singapore dollars, which is nearly twice the cost of the Type A or B perforated-slab pavement described in the preceding section. This construction, with higher initial cost, may be more economical in the long run because of the expected lower maintenance cost due to the reduced number of rocking and tilted slabs. Unfortunately, there are insufficient maintenance and cost data at the present time to enable such a cost analysis to be conducted.

CAST-IN-SITU JOINTED PERFORATED CONCRETE SLAB

Another patented form of perforated-concrete-slab construction recently introduced in Singapore is known as Grasscrete *(5)*. The construction is similar to that for conventional jointed-concrete-slab construction except that special polystyrene formers are used to make the required perforation pattern (Figure 13). Steel mesh reinforcements are laid in position on preformed spaces provided within each former. Concrete is then poured around the formers and screed level with the top of the formers. After gaining its initial set, the concrete is brushed to leave the tops of the formers exposed. The exposed former tops are burned away after 48 hr. The voids that remain are then filled with good-quality friable topsoil and turfed.

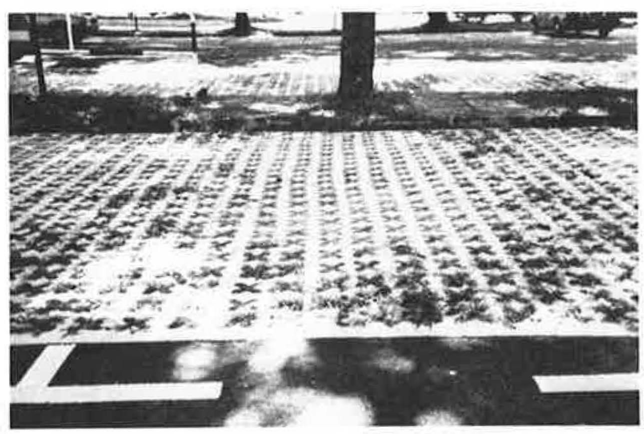

FIGURE 13 Cast-in-situ perforated concrete slab.

Expansion joints are usually provided at 9800-mm (12-ft) intervals so that each span will cover exactly the width of four parking spaces. The construction gives a 37 percent perforation area, which should be sufficient to avoid tree-root heaving problems. The cast-in-situ construction does not produce a surface as smooth as those of either precast slabs or blocks. The perforation edges tend to be rather sharp. As a result, the ride is relatively rough, even for vehicular parking movements. The discomfort can also be easily felt by pedestrians walking on the surface.

TABLE 2 COMPARISON OF VARIOUS FORMS OF PARKING LOT PAVEMENT CONSTRUCTION

Item	Precast Perforated Slab	Interlocking Perforated Block	Cast-in-Situ Jointed Perforated Slab
Installation	Easy	Moderately easy	Labor intensive and time consuming
Construction cost	Low	High	High
Need for maintenance	Relatively high	Moderate	Low
Repair of defects	Easy	Moderately easy	Tends to be more elaborate
Structural stability	Satisfactory	Good	Good
Ride quality	Satisfactory	Comparatively most satisfactory	Comparatively least satisfactory
Pedestrian comfort	Satisfactory	Comparatively most satisfactory	Comparatively least satisfactory
Aesthetics	Satisfactory	Good	Satisfactory
Grass growing	Satisfactory	Satisfactory	Satisfactory
Underground utilities	Easy to accommodate	Moderately easy to accommodate	Not suitable

It is believed that concrete-slab construction provides the benefits of rigid pavement such as low maintenance and long service life. It is also expected that the pavement will be less prone to rocking and tilting as compared with individual smaller precast units of Type A or B perforated slabs (Figure 8). The cast-in-situ construction, however, tends to be more labor intensive and time consuming. In terms of construction cost, the jointed-perforated-slab pavement is nearly 40 percent more expensive than the precast-perforated-slab system. Table 2 presents a comparison of this construction with the other two forms of perforated pavement construction described in this paper.

CONCLUSION

Special landscaping and public policy requirements for car parks in Singapore have made it necessary for pavement engineers to search for innovative designs for parking area pavements. In addition to its primary function of providing a stable and durable surface for vehicular movement, the parking area pavement must also allow sufficient open spaces for turfing and tree planting.

After several years of trial and error and field experimentation, a pavement system consisting of discrete precast perforated-concrete-slab units was found to offer a reasonably satisfactory solution. It gained approval from leading car park construction authorities in Singapore in the mid-1970s and was the only form of parking lot pavement construction for many years in Singapore.

The experience of more than 10 years of field application has revealed that the discrete precast perforated-slab pavement is not a problem-free system. The belief that some other form of construction exists that might be more cost-effective in the long run has led to the introduction in the last 2 years of two new forms of parking area construction, namely, the interlocking-perforated-concrete-block pavement and the cast-in-situ jointed-perforated-concrete-slab pavement. Although both innovations have led to higher construction costs, their superior structural stability and lower maintenance requirements may justify their use on the basis of life-cycle cost considerations.

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