PAVING OVER PROBLEM SUBSTRATES FOR ROOF DECK PROJECTS

Mark Smallridge, PE
Mark Smallridge and Associates, Inc.
3524 Cottonwood Springs Drive
The Colony, TX 75056
Tel: 972 624 8817 Fax: 972 624 8818
E-mail: msaimark@cs.com

SUMMARY

Roof deck paving projects frequently involve paving over substrate conditions that can be problematic. These include waterproofing layers, drainage layers and insulation materials that can have a resilient or unstable nature similar to very poor soils. In addition, the thickness of the layers over the structural slab is often minimal as a result of load restrictions, frequently requiring the paving section to contain conduit for utilities, irrigation pipes and snow melt systems. These conditions can create hard points under the paving. Roof decks also experience structural deflections and rebound under loading. This is particularly onerous in conditions where heavy traffic such as buses and other service vehicles will operate on the paving.

This paper discusses the problems related to performance of these components and how they affect the serviceability of the overlying pavers. It draws on the author's experience with the design of successful applications of segmental paving systems on roof decks, and with the investigation of some unfortunate failures. The paper covers specification and detailing issues that have been found to be successful and includes description of some of the failure modes. Where particularly onerous details have been identified the paper includes suggested alternative materials and arrangements.

1. REQUIREMENTS

This paper is written on the assumption that the pavement designer will be part of the team undertaking the development of a new structure that includes a paved roof deck. They may be associated with the civil or structural engineer, the architect or landscape architect, or may be independent of these professionals. Roof deck paving projects considered in this paper may be on the top level of a building, or they can be in tunnels or recesses that pass through the building. They may be at an elevated level or at street level, as long as they have a structural floor under the paving system. Other requirements follow below.

1.1 Structure

The structural floor comprises a structural slab supported on beams, columns and/or walls. The structural slab is invariably portland cement concrete in roof deck applications, but several construction methods are used. The space under the floor may be habitable space with some form of environmental control, or it may be a naturally ventilated area where access is required. The former

frequently includes office space, plant rooms or retail space, while the latter includes car parking, loading docks or general service areas.

The slabs, beams and walls will be designed to carry the imposed dead loading from the paving system, planting and furniture and the imposed live loading from people, vehicles, rain, wind and snow. In addition to the designing for the ultimate loading condition to prevent any member undergoing structural failure, the structural engineer will also consider serviceability criteria for deflections, vibrations and the integrity of finishes.

The pavement designer should work with the structural engineer to ensure that all limitations on the paving are included in the structural design process. In turn, the pavement designer should obtain an understanding of the performance of the structure, particularly in regard to movement joints and structural openings.

1.2 Profiles

The pavement will be exposed to the elements including precipitation in its various forms, and temperature fluctuations. All rainwater needs to be shed from the paving, either to a drainage system, or to planting areas. The surface profiles of the pavement may be designed by a civil engineer or one of the architectural professionals. Unlike paving over the ground, paving on a roof deck typically requires adoption of very flat profiles owing to the restrictions imposed by the structure's load capacity, and the need to keep floor levels and storey heights uniform. For example, a 150 mm (6") curb can add 300 kg/m^2 (60 lb/sq ft) or more to the imposed load.

Generally, maximum gradients of between $1^1/_2$ percent and 2 percent are considered to be applicable to pedestrian pavements in the US. These gradients will provide a reasonable profile for surface drainage and will meet accessibility standards. However, these gradients may be difficult to achieve on some roof deck projects. Gradients on ramps can be up to 8.3 percent for distances of up to 9 m (30 ft) when designing to Americans with Disabilities Act (ADA) requirements. In vehicular areas, gradients of up to 5 percent are common.

1.3 Drainage

Drainage inlets for roof decks frequently consist of area drains that are piped vertically through the structural slab and collected in the building's drainage system. Most of the drainage castings consist of a lower body that is set in the concrete slab and tied into the waterproof membrane in a manner that prevents leaks. An upper body, frame and cover are attached to the lower body with provision for water entry at the joint between the upper and lower bodies.

The alternative is to use a trench drain system. Most trench drain systems on roof decks consist of a channel formed in the structural slab. The frames and covers are mounted on steel angle section that is anchored to the slab. Depending on the details adopted, weep openings can be provided below or through the steel angles.

1.4 Insulation

Where the roof deck pavement is constructed over habitable space with some form of environmental control there is a need to minimize unwanted heat loss or gain through the structure. This is usually achieved by incorporating insulation material between the structure and the pavement surface. In most roof deck applications the insulation material is placed above the waterproof membrane in what is

known as a protected membrane roof. This system provides greater protection to the waterproof membrane, but exposes the insulation to moisture.

1.5 Waterproofing

It is desirable to prevent water entering buildings whether they are habitable space or used for other purposes. The majority of roof deck applications include a waterproof membrane over the top of the structural slab. Either the structural slab will include a nominal fall to drain the water to inlets, or a topping slab will be provided. In most cases the slab drainage falls will be orientated in a similar arrangement to the surface falls, and will use the same inlets. It is therefore important that there is good communication between the design professionals to achieve this.

Waterproof membranes are critical to the maintenance of a dry building interior. Any damage can result in leaks that are frequently difficult to trace and often cause extensive damage and costly repairs. Warranties are frequently required from the waterproof membrane manufacturer to cover many years. As such the membranes need to be properly protected from construction activities and the conditions that will be experienced in service. Many waterproof membranes include a protection layer.

1.6 Snowmelt

Accumulation of snow or the presence of ice on a pavement can be hazardous as well as inconvenient. Snow clearance operations may require heavy equipment or generate heavy stockpiles of snow. De-icing chemicals can cause water quality issues and leave surface staining. An alternative to these measures is the use of a snowmelt system.

In the more common hydronic systems, heated fluid is pumped through a network of tubes so that it raises the temperature of the pavement above freezing. The system is more responsive and more economical to operate the closer to the pavement surface that the tubing located. In light duty paver applications the tubing may be included in the bedding sand layer.

2. COMPONENTS

A roof deck pavement includes many components. Figure 1 depicts a typical cross section.

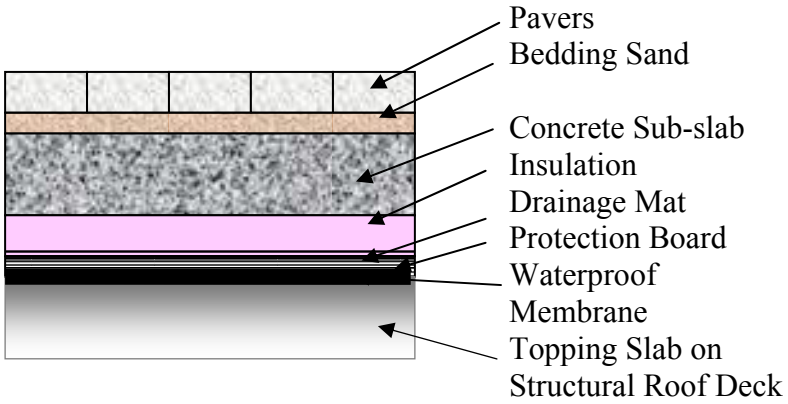


Figure 1. Typical roof deck paving system

2.1 Pavers

The same considerations for paver type should be used for a pavement over a roof deck as would be used for paver type in a ground bearing pavement. Chamfers and spacer bars help to reduce spalling of the pavers where deflections are larger as a result of compressible layers below the pavement.

2.2 Sand

2.2.1 Bedding Sand

The sand may be more frequently saturated than in a ground bearing pavement. The durability of the bedding sand is therefore more critical. Silica based minerals should be favored and carbonate minerals avoided. Naturally occurring sands should be favored over manufactured sands. Using sand with slightly lower fines will increase the permeability and the sand should be provided with positive drainage.

2.2.2 Joint Sand

Similar considerations apply to the selection of the joint sand. The designer may consider using a joint sand stabilizer, as this will reduce the degree of water penetration.

2.3 Hydronic tubing

The tubing and any fixings can create hard points under the pavers that can lead to rocking, sand loss and paver breakage. Adequate cover should be provided to the tubing, and it is beneficial to mix cement with the bottom lift of sand over the tubing and to use pre-compaction. A mixture of 1 part cement to 8 parts of sand is adequate.

2.4 Sub-slab

This layer should be considered critical to provide adequate protection to the insulation and drain mat layers. The stiff layer is necessary to distribute load over these layers and reduce localized deflections.

2.5 Insulation

The most commonly used insulation for roof deck projects is extruded polystyrene boards. Polyisocyanurate foam and expanded polystyrene foam boards are not suitable for use under most paved roof decks. Extruded polystyrene insulation is manufactured by a number of companies. It is available in a range of compressive strengths including 1.4 kg/cm^2, 2.8 kg/cm^2, 4.2 kg/cm^2 and 7.0 kg/cm^2 (20 psi, 40 psi, 60 psi and 100 psi), and thicknesses of 25 mm, 50 mm and 75 mm (1", 2" and 3"), and may have plain or channeled faces.

Insulation is a compressible layer. The test for compressive strength uses a flat plate to apply the load, and the strength is reported at a deflection of 5 percent (10 percent with expanded polystyrene). When equivalent k-values are calculated, the insulation may appear to have a high strength; however, CBR values are comparatively lower. It is preferable to use a sub-slab over the top of insulation to distribute the loads adequately. Insulation should not be placed on drain mat as the three-dimensional core can punch into the foam.

An alternative solution is to use foamed concrete as an insulation layer and sub-slab combined. It is not as thermally efficient as extruded polystyrene, and is considerably heavier. However, it out performs normal weight concrete in both these aspects.

In a few situations it may be possible to use the insulation under the structural slab. However, this position is often considered to be undesirable by the other design professionals. It can lead to internal moisture issues within the building.

2.6 Drainage layer

There are several possible options for this layer, but the more conventional use either a layer of loose drainage rock or a drainage mat. The former was used in the past, but has generally been replaced by the latter option in most, if not all, roof deck applications. An open graded bedding layer for the pavers may also provide some benefits.

Drain mats are available from several manufacturers, and can be found in several product types that use a three-dimensional plastic core and a cover layer of filter fabric. The core may be a dimpled sheet or formed from layers of crossing filaments. Some have a plastic backing sheet for use over waterproof membranes, and others have a geotextile backing to allow water penetration from both faces. The drain mats are available in different thicknesses, load capacities and filter capabilities. In roof deck applications the thicknesses are generally between 6 mm and 12 mm ($^1/_4$" and $^1/_2$") as water flows should not be significant. The quoted load capacities vary from a few thousand pounds per square foot to more than twenty. The apparent opening size of the filter fabrics varies between 212 :m and 425 :m mesh (No. 70 and No. 40 US sieve sizes).

The pavement designer needs to carefully consider the position of the drain mat in the pavement section, particularly in relation to the way it will interact with the layer above it and the layer below. The underside of the mat can damage some waterproof membranes if heavily loaded, and the top can damage insulation. When placed directly under the sand it can experience high deflections leading to creep of the pavers, tearing of the filter cloth and even local collapse of the core.

An alternative to drain mat and topping slab is the use of a permeable concrete slab. Although this material has a fairly closed surface texture it has high permeability. A geotextile may be used over the surface to prevent sand loss, but this is not always necessary. There are also similar asphalt concrete mixes that can be used in thinner lifts, but these are more complex to install.

2.7 Protection board

Protection boards are typically 3 mm to 6 mm ($^1/_8$" to $^1/_4$") thick, bitumen impregnated fiberboard. They can be up to 12 mm ($^1/_2$" thick). They are generally supplied by the waterproof membrane company. They are primarily used over the top of the waterproof membrane to protect it against construction damage. They also provide some protection during the service life of the pavement. Care should be taken to avoid laps that can create localized high points sufficient to collect water, particularly if the bedding sand is to be placed directly on top. These can also create hard spots under the pavers affecting the stability of the affected paver. Butt joints are preferred, but these can allow some membrane materials to exude through them. Where a hot rubber membrane is used, the butt joints should be taped, or a fabric applied to the top of the membrane.

When the boards are delivered to the project site they are often separated by thin plastic sheets. Separation sheets are rarely required to be removed from the boards, but they can cause a lack of bond to the membrane or slippage of the different layers. This can increase the potential for horizontal creep of the pavers.

2.8 Waterproofing

There are three basic types of waterproof membrane that are commonly encountered in roof deck applications. The most popular system is a hot applied rubberized asphalt membrane. Other options are fluid applied elastomeric membranes and less commonly sheet membranes.

Hot rubber remains viscous for many years and this enables the membrane to enter and seal cracks in the underlying concrete. However it may also exude upwards into the paving assembly if there is a possible route. It may also exude laterally under frequent traffic loading and eventually collect at curb lines or clog the drainage system. This membrane requires a protection layer immediately on top of it.

Elastomeric membranes are applied in multiple layers, and proper cleaning is required to ensure an adequate layer to layer bond. The surface is smooth and could create a slip plane unless sand is embedded to create some friction. Several of these systems are manufactured for use as a surface course in car park and similar structures, and therefore do not require a protection layer.

2.9 Topping slab

For the waterproofing consultant and the pavement designer it would be preferable to build the falls in to the structural slab so that drainage falls are provided and the pavement thickness can be consistent. However, most structural slabs are cast level and the profiles are created by using a topping slab. This will normally be a bonded, modified, fine aggregate concrete or mortar mix ranging from 25 mm to 100 mm (1" to 4") in thickness. Care is required to achieve an intimate bond to the structural slab. One item that is frequently overlooked is the finishing tolerances. Too often the topping slab is considered as an unseen product, and rough tolerances are adopted. This can cause significant variations in the thickness of the sand bed. It is recommended that the finished surface of the topping slab should be constructed as if it was the top of the pavement.

2.10 Structural slab

Structural slabs can be supported on beams, walls and columns. For roof deck applications they are normally designed for a live load elastic deflection limited to span/350 to span/500. Over the long term, additional deflection can occur as the result of long term creep. This may have an effect on pavements with minimum grades.

As a structure heats up and cools down, it expands and contracts. It also deflects in relation to different dead and live loads. It is often necessary to include movement joints in a structure to accommodate these differential deflections. Movement joints in the structure must be reflected to the surface. Paving systems are not able to stretch across movement joints, and a header should be fixed to either side. This can be as simple as a pair of steel angles with a backer rod and sealant where the movements are small, as depicted in Figure 2, or may involve the use of proprietary movement joints where larger movement has to be accommodated.

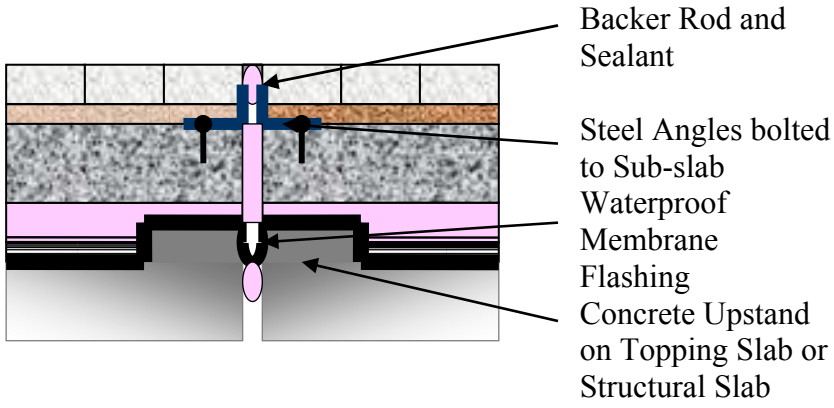


Figure 2 – Typical roof deck movement joint

3. EXAMPLES

3.1 Pedestrian Plaza

3.1.1 Project A

On a pedestrian plaza project the pavement section included pavers, bedding sand, geotextile, insulation, drain mat core, waterproof membrane, topping slab and structural slab. The pavers were square edged without spacer bars and were installed to a grid type pattern using contrasting color bands. The field bond was 90-degree herringbone, with header course bands.

Spalling of the paver edges occurred relatively soon after opening of the project. Investigation of the issues indicated that there were significant deflections of the underlying materials, particularly during mechanical snow clearing operations. The drain mat core had punctured the insulation, which was in itself slightly compressible. The deflections were causing contact at the top of the joints that lead to the spalling condition. Also, the deflections were sufficient to prevent the joint sand from stabilizing and achieving significant interlock.

3.1.2 Project B

On this pedestrian plaza project the pavement section included pavers, bedding sand, drain mat, topping slab, protection board waterproof membrane and structural slab. The pavers had chamfered edges, but no spacer bars. They were installed in a grid pattern with basket weave field pavers and running bond bands.

Movement of the pavers occurred over time requiring some early straightening of the pattern lines and ongoing re-sanding. This was particularly evident where maintenance vehicles undertook sharp turns, causing the pavers to twist. The pavers were on the small size of the tolerance range and the joints were on the wide side of the allowable range. Deflections caused by sagging of the filter fabric over the drain core appeared to be sufficient to prevent the joint sand from stabilizing. This allowed the joints to close and the pavers to creep.

3.2 Residential Access/Parking

3.2.1 Project A

On this residential project the pavement section included pavers, bedding sand, drain mat, protection board, waterproof membrane and structural slab. The pavers were installed in running bond. They were chamfered with spacer bars.

Horizontal movement of the pavers occurred as a result of tight turning maneuvers of the vehicles using the pavement. Packing of the joint sand and consequently interlock were not established owing to the deflection of the drain mat. In some locations bedding sand was lost and the drain mat core crushed.

3.2.2 Project B

On this residential project the pavement section included pavers, bedding sand, waterproof membrane and structural slab. The pavers were shaped units laid in a random ashlar pattern. The pavers were chamfered but did not have spacer bars. There were nominal falls on the structural slab, which also had movement joints around and through it.

The sand became waterlogged and pumped up through the joints in some locations. There was significant movement of the pavers at the structural movement joints, leading to wide joints and loose pavers. Owing to load considerations only a minimal thickness repair was possible. We used a fine asphalt to increase the grades with a porous friction course to act as a drainage layer.

3.3 Retail Parking

3.3.1 Project A

On this retail parking project the pavement section included pavers, bedding sand, filter fabric, drainage ballast, protection board, waterproofing membrane and structural slab. The pavers were installed in 90-degree herringbone bond. The pavers were chamfered but did not have spacer bars. The parking deck was on one level.

The drainage rock base was not sufficiently stable to support the range of loads using the parking deck, and so the joint sand did not pack in some areas. The geotextile sheet was damaged and bedding sand loss occurred.

3.3.2 Project B

On this retail parking project the pavement section included pavers, bedding sand, filter fabric, drainage ballast, protection board, waterproofing membrane and structural slab. The pavers were chamfered with spacer bars. The pavers were installed in 90-degree herringbone bond. The parking deck was on an incline.

The pavers migrated down the ramp, sliding on the geotextile layer. The joints at the bottom became tight, but the joints at the top were wide and interlock was limited. Some sand loss occurred.

3.4 Office Parking

3.4.1 Project A

On this office project the pavement section included pavers, bedding sand, drain mat, protection board, waterproof membrane, topping slab and structural slab. The pavers were installed in a 45 degree

herringbone pattern. They were chamfered with spacer bars. The bedding sand was used to fill the joints between pavers, and dry-mix joint sand stabilizer was added to the final lift of sand.

Large scale movement of the pavers had occurred and the joint sand did not appear to be well packed. This is typically the result of the deflection of the geotextile sheet of the drain mat when the sand is placed directly on top. There was also some localized settlement.

3.4.2 Project B
On this office parking project the pavement section included pavers, bedding sand, waterproof membrane and structural slab. The pavers were chamfered with spacer bars. The pavers were installed in a 90 degree herringbone pattern on an inclined slab. There was a channel drain at the base of the ramp, with geotextile covered weep openings.

Water penetrated the joint sand and soaked to the bottom of the incline. The water built up to the point that it did not all drain through the weep openings, and formed "springs" above the drain. This caused some joint sand loss and movement of the pavers.

3.5 Public Transport
3.5.1 Project A
On this public transportation project the pavement section included pavers, bedding sand, waterproof membrane and structural slab. The joint sand was stabilized. The pavers were chamfered with spacer bars. They were installed in a 45-degree herringbone pattern with multiple colors woven in the pattern. Crosswalk bands were constructed using mortar set granite. The pavement was constructed over a multi level subterranean car park. The pavement is subject to several hundred city buses per day.

Bedding sand loss had occurred where excessive planter watering was ongoing, and there was some paver movement where the stone crosswalk bands had failed. In the location where the sand had been lost, the pavers had eroded the waterproof membrane. These issues have been repaired.

3.5.2 Project B
On this public transportation project the pavement section included pavers, bedding sand, protection board, waterproof membrane and structural slab. The pavers were chamfered with spacer bars. They were installed in a 45-degree herringbone pattern with in-set traffic markings. The pavement was constructed over a subterranean car park. The pavement is subject to several hundred city buses per day.

The pavement had become waterlogged and this lead to degradation of the bedding sand. Localized rutting was present in the bus wheel paths as the fines were pumped to the surface. Where all of the sand had been lost the waterproof membrane was beginning to exude into the paver joints.

4. CONCLUSIONS

The design of a roof deck pavement is complex, and requires consideration of several additional issues to that of a ground bearing pavement. Each component above the structural deck serves a specific function in achieving the design intent for the building. In some cases there are more paver friendly alternatives that can be adopted, but there are always some situations where those components just have to be there. The pavement designer needs to be fully aware of how each component can affect the

performance of the pavement surface, and should involve the other design professionals to select systems that enable the best pavement performance to be achieved.

4.1 Deflections

Several materials used between the structural deck and the pavement surface are compressible or can deflect to the extent that they may compromise the pavement performance. The designer should ensure that the pavement will accommodate the anticipated deflections.

4.2 Utility lines

Utility line tubing or conduit may run in close proximity to the pavement surface. This is particularly the case with snowmelt systems. The designer should ensure that these lines will not cause hard points or affect the support provided to the overlying materials.

4.3 Temperatures

The roof deck pavement may be subject to greater temperature ranges than comparable ground bearing pavements. This can cause a greater range of expansion and contraction of the pavement materials. The designer should ensure that the pavement will accommodate the anticipated movement.

4.4 Moisture

The waterproofing system will prevent vertical dissipation of water so materials may be in a moist condition for extended periods of time. The designer should ensure that the pavement materials are durable under these conditions.