PRINCIPLES OF DESIGNING PLAZA WATERPROOFING SYSTEMS

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ABSTRACT

Plaza waterproofing differs from that of roofing systems because of the severe conditions under which it must perform. The waterproofing membrane is inaccessible for repairs, and its primary performance criteria are to resist the passage of water under continuous exposure to moisture. A plaza waterproofing system is covered by a wearing surface that can impede drainage at the membrane level. This makes any investigation and repair extremely difficult and expensive. Therefore, the anticipated service life of the membrane must approximate the predicted life of the building.

This paper will present design and installation fundamentals for plaza waterproofing systems. It will discuss drainage, insulation, waterproofing, and flashing details.

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INTRODUCTION

The design of a plaza over occupied space must create a system that waterproofs and insulates the structural building deck while supporting pedestrian and/or vehicle traffic, including landscaping elements (Figure 1). Its design entails multiple component layers, including a waterproofing membrane, protection layer, drainage course, insulation, and wearing surface.

Earlier plaza designs did not incorporate a drainage layer within the system components. As a result, water that was trapped between the membrane and wearing surface caused them to deteriorate from freeze/thaw cycling or saturation. Since publication of Charles Parise’s seminal paper in 1981, the accepted ASTM and industry standard requires the incorporation of a drainage course. The system must allow for the flow of water from the plaza wearing surface through the various components at the drains and sides. There are two basic categories of overburden on plazas over occupied spaces:
- Hardscaping with wearing surfaces,
- Landscaping or softscaping with planting, fountains, etc.

Systems can be further divided into categories where the membrane is either accessible or inaccessible.

Accessible systems are those in which the wearing course is removable. Pavers that are installed on insulation, pedestals, or sand beds are classified as accessible systems. Landscaping or planting is considered to be an accessible system.

Inaccessible plaza systems are those in which the membrane is covered with a concrete protection slab or where the wearing surface units are installed in a solid, mortar-setting bed. Fountains and most vehicular wearing surfaces also fall into this category. These systems require demolition of the concrete protection slab or solidly grouted units for access to the membrane.

A waterproofed plaza system that
includes a separate wearing course contains some or all the following components (Figure 2):

- Structural deck
- Membrane
- Protection board or protection membrane
- Drainage layer or course
- Thermal insulation
- Concrete protection slab (optional)
- Flashing,
- Wearing surface

An earth-covered system consists of essentially the same, with the exception of the wearing surface, where the earth takes its place (Figure 3).

There are three ASTM International Standards that cover waterproofing under hardscaping:

- C981 — Standard Guide for Design of Built-Up Bituminous Membrane Waterproofing Systems for Building Decks
- C898 — Standard Guide for Use of High-Solids Content, Cold, Liquid-Applied Elastomeric Waterproofing Membrane with Separate Wearing Course
- C1127 — Standard Guide for Use of High-Solids Content, Cold, Liquid-Applied Elastomeric Waterproofing Membrane with an Integral Wearing Course

Designers are advised to consult these standards when designing waterproofed plaza decks because they constitute the current body of knowledge on the subject.

**STRUCTURAL BUILDING DECK**

A structural plaza deck typically consists of reinforced concrete slabs, concrete topping over precast units, post-tensioned slabs, or composite concrete-and-steel decking. Reinforced structural concrete slabs are the most common and consist of framed or flat slabs. However, monolithic concrete slabs make a better substrate for waterproofing.

Joints between and at the ends of precast units and at
their ends may not be in the same plane, and therefore they require a concrete topping to even out lippage and cover lifting rings and welded plates. However, the topping is prone to cracking along joints and, in particular, at the end joints, which may rotate between precast elements at supporting girders.

Post-tensioned slabs offer better control of deflection and cracking within the plaza deck. However, careful analysis of the deck deflection pattern and post-tensioning design is critical to achieve proper slope-to-drains after the plaza overburden has been placed.

Composite decking comprised of concrete-on-steel centering is more commonly used for terraces at higher floor levels than for plaza design near grade level. Provisions for venting moisture from the concrete must be made if a liquid membrane is applied to the concrete surface. This is typically achieved by using a slotted steel deck or additional curing time, which can be reduced by a low cement/water ratio.

Whichever structural system is selected, the waterproofing designer should assure himself that the structural engineer is informed as to the need for positive slope-to-drain. These discussions should include coordination among the waterproofing designer, landscape architect, and structural engineer to assure adequate load-bearing capacity and slab slope.

**MEMBRANES**

Membranes for waterproofed deck systems include:

- Conventional built-up bituminous
- Multi-ply modified bitumen sheets
- Single-ply sheets
- Liquid or fluid-applied elastomers

A built-up bituminous membrane consists of alternating multiple plies of saturated felts between applications of bitumen applied on-site (Figure 4). The plies include organic felt, glass mats or fabrics, and polyester mats or fabrics as reinforcement.

Organic felts are preferred over glass. The bitumen can be asphalt or coal tar pitch. The bitumen of choice for waterproofing is coal tar pitch (ASTM D-450, Type I or II) because of its self-healing properties. Asphalt (ASTM D-449) has greater water absorption than coal tar pitch and is not suitable.

The felt plies can be shingled or phased (ply-on-ply). In a phased-type application, moisture that penetrates through a lap leads only to the next ply and not through the entire membrane.

Except for tarred felts, membranes constructed of organic felt have not performed well when exposed to standing water. Glass fiber felts are less absorbent than organic felt, but they tend to float or sink in coal tar pitch.

**Modified bitumen sheets** are modified with polymers to improve the sheets’ flexibility and elasticity, as well as the cohesive strength of the bitumen. Some are self-adhering sheets, laminated to a high-density, polyethylene backing, and are often called “peel-and-stick” or rubberized asphalt (Figure 5). The sheets can be applied as a single- or multi-ply waterproofing membrane system. They must be protected from ultraviolet exposure within a few weeks of application.

Modified bitumen sheets used for roofing do not perform as well when used for waterproofing membranes because of the potential for wicking of the reinforcing as end-laps. These systems are fully adhered to the concrete substrate and are sensitive to site conditions, moisture, and deck surface quality.

**Single-ply sheets** include EPDM, butyl...
rubber, KEE, and PVC. Butyl rubber sheets have an advantage over EPDM sheets because of their lower moisture absorption. This benefit is more important for a waterproofing membrane than EPDM’s greater resistance to ultraviolet resistance. PVC sheets offer improved puncture resistance and heat-welded seams.

These sheets are either fully adhered or loose laid. When loose laid, they should be compartmentalized by adhering the sheet in a 3-meter (10-foot) grid. This forms compartments that confine water migration if a leak occurs and also helps facilitate leak detection (Figure 6).

Liquid-applied membranes include hot and cold:
- Polymer-modified asphalt
- Single-blown asphalt
- Coal tar modified urethane
- Two-component urethanes
- Aliphatic polyurethanes
- Reinforced liquid polyester
- Two-component synthetic rubber
- Polymer-modified asphaltic emulsion.

Proper performance of solvated or emulsion-type membrane systems requires that they contain a minimum of 65 percent solids to reduce pinholing. Problems associated with reflective cracking from the deck below can be addressed by proper dry mil thickness of the membrane (which is normally a minimum 60-dry-mil film thickness) and by reinforcement.

The advantage of adhered membrane systems is the localization of leaks. A disadvantage is the need for rigorous surface preparation of the substrate, which must be dry and dust-free, with a lightly broomed texture. Cracks must be detailed. Liquid-applied membranes should never be used to fill or level surface irregularities.

Moisture is the adversary of these systems. It causes urethanes to foam and hot-applied systems to froth. Dust can cause pinholing or entrained air bubbles in the coating film (Figure 7). Unsuitable curing agents such as waterglass can inhibit adhesion.

Hot-applied liquid systems are often reinforced with polyester or woven glass (Figure 8). This process requires two applications in order to prevent coincident pinholing and thin spots in the membrane.

Cold-applied liquid membranes are applied over concrete substrates by spray, squeegee, roller, brush, trowel, or other
method acceptable to the membrane manufacturer (Figure 9). Manufacturers claim that these products are sufficiently elastic to bridge cracks that occur in the concrete after the coating is in place. Reflected cracking is reduced by increased thickness.

The reinforced liquid polyester systems require exposure to ultraviolet light to cure. PMMA cures from contact with moisture in the air.

ASTM International Standard C-836, which was first published in 1976, is a non-generic performance specification that describes the required properties and test methods for cold-applied, elastomeric-type waterproofing membranes for both one- and two-component systems.

PROTECTION BOARD

Waterproofing membranes all require protection during construction as well as from ultraviolet radiation. This protection should be applied as soon as possible after the membrane is installed and flood testing is concluded.

The industry’s most common material is an asphalt-core, laminated panel with polyethylene film on one side that prevents sticking. The panel or board is produced in 1.5-mm (1/16-inch), 3.1-mm (1/8-inch), or 6-mm (1/4-inch) thicknesses. One manufacturer produces a 2-mm (.085-inch), synthetic, fiber-reinforced, rubberized, asphalt-protection sheet in roll form for use with its waterproofing system.

Protection of the horizontal waterproofing membrane is mandatory after the membrane is installed and water testing is completed. The sequencing of these steps – membrane application, flood testing, and protection-board installation – must continue without interruption. If the protection-board installation is delayed, damage to the waterproofing membrane can occur from some of the following construction activities (Figure 10):

- Pipe scaffolding without proper protection
- Stockpiled masonry
- Reinforcing bars
- Welding rods
- Fasteners
- Loose aggregate

Any of the above items are hazards to the membrane’s service life. A membrane is worthless after it is damaged or destroyed by careless construction operations. That is why it is important to have a qualified per-
son inspect the membrane and to ensure that the protection board is installed after the flood testing is completed. If the membrane fails the flood test, the protection application must be held until the membrane is repaired and re-tested.

**DRAINAGE DESIGN**

When a membrane waterproofing system is applied directly to the structural deck and then covered with a wearing surface or overburden, it is assumed that water will reach the membrane. If this were not the case, there would be no need for the membrane.

According to ASTM C-981, drainage of the waterproofed deck system should include all components, from the wearing surface down to the membrane. The structural deck and the supporting columns and walls should be properly designed to provide positive slope. Inadequate slope-to-drain is a common deficiency in plaza design.

Drainage at the membrane level is required for the following reasons:

- To avoid building up hydrostatic pressure due to collected water against the membrane
- To avoid freeze-thaw cycling of trapped water that could heave and disrupt the wearing surface
- To minimize the harmful effect that standing, undrained water may have on the wearing surface material and membrane
- To minimize thermal inefficiency of wet insulation or water below the insulation

A 2 percent (6-mm - 1/4-in per ft) slope is recommended for positive drainage. The substrate should slope away from expansion joints and walls. Gravel or plastic drainage panels (Figure 11) and grooved or ribbed insulation boards can provide the necessary medium to facilitate water flow to drains.

Waterproofed decks should incorporate multilevel drains capable of draining all layers (Figure 12). These drains must permit differential movement between the strainer located at the wearing level and the drain body that is cast into the structural concrete slab to prevent shearing.

The drainage of a waterproofing system at the wearing surface level can be accomplished through an open-jointed or closed-jointed system. The open-jointed system allows rainwater to quickly filter down to the membrane level and subsurface drainage system. A closed-jointed system is designed to remove most of the rainwater rapidly by sloping surface drains and allowing a minor portion to gradually infiltrate down to the membrane level.

Open-jointed systems include pavers on pedestals or pavers placed directly on ribbed polystyrene insulation boards (Figure 13). Joints should be less than 6 mm (1/4-in) wide to minimize catching high-heels and cigarettes. Advantages are:

- Elimination of the cost and maintenance of sealant joints
- Ease of adaptability to a dead-level wearing surface
- Faster and more efficient drainage
- Easier access for cleaning and repairs to subsurface components

The disadvantages are:

- Rocking of improperly set pavers due to pedestrian traffic
- Unpleasant reverberations from heel impact
- Possible hazards for pedestrians wearing high-heeled shoes

![Figure 11 - Plastic drainage panel.](image1)

![Figure 12 - Two-stage plaza drain. (Courtesy of ASTM International.)](image2)
Closed-joint systems consist of either a mortar-setting bed or caulked joints. This type of construction changes the waterproofing membrane to a secondary line of waterproofing defense, since the majority of rainwater is drained from the wearing surface level (Figure 14). The closed-joint system should slope away from adjoining walls and expansion joints to direct water away above and below the wearing surface level. The advantages of a closed-jointed system include:

- Protection of the membrane from de-icing chemicals, dirt, and debris
- Its flexibility to a greater variety of paver types, designs, and sizes
- The feeling of solidity under pedestrian traffic

The main disadvantages are:

- Its slow drainage rate
- Its imposition of a hydrostatic head of pressure on the membrane.

A third system that is better than a closed-jointed system, but not as good as an open-jointed system, is one that provides for brick or stone pavers in a sand-setting bed.

**INSULATION**

The selection of insulation and its location in the system is influenced by:

- Deck design
- The environment under which it may be functioning
- Its physical and chemical properties
- The characteristics of the wearing surface
- The loads to be supported

Insulation placed over the waterproofing membrane, protection, and drainage layer results in maximum system benefit. When insulation is placed in this location, the deck and membrane are insulated against...
extreme temperature cycles and the membrane can then function as a vapor retarder. The location of the insulation above the membrane also provides additional protection to the membrane.

The choice of insulation type is limited to extruded polystyrene (XPS) (ASTM International C-578 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation). It must be able to accommodate the plaza’s dead and live loads and be dimensionally stable and compatible with the waterproofing membrane. It must also be nonabsorbent as possible and resistant to freeze/thaw deterioration.

**FLASHING AND EXPANSION JOINTS**

Waterproofed deck systems, like roof systems, require flashings where the membrane terminates at walls, penetrations, and expansion joints. However, unlike roof systems where the flashing installation follows the membrane installation, flashing waterproofed deck terminations or penetrations must be installed first, prior to the membrane application.

**FLASHING INSTALLATION**

Reinforce all intersections that occur at walls, corners, or any other location that may be subjected to unusual stress with one additional ply of membrane.

Extend flashing membranes above the wearing surface a minimum of 100 mm (8 in). This height is critical if the plaza design incorporates a wearing surface with closed joints. When the flashing extends above the wearing surface, it must be covered or protected against exposure to ultraviolet sunlight with sheet metal or vertical wall finishes such as stone or stucco. Some liquid-applied membranes (LAM) are self flashing.

When 100-mm (8-in) flashing heights are impractical—particularly at access doors that open onto the plaza at the same elevation for ADA accessibility—gutters with gratings are recommended (Figure 15).

**EXPANSION JOINTS**

Flashing at expansion joints located in the field of the plaza or at rising walls should be installed on a curb that is raised at minimum 37 mm (1-1/2 in) above the structural deck (Figure 16). This allows water to be directed away from the joint. This method is far superior in safeguarding against leakage.

A less costly method is to flash the joint at the membrane level. This method entails greater risk than the water shed concept, since it relies on positive sealing of materials at the membrane level, where the membrane is most vulnerable to water penetration. The materials used and their joining must be carefully considered and designed. The installation requires the highest degree of workmanship for success without any margin for error and is not advisable.

For moisture-sensitive occupancies, consider using a drainage gutter under the joint.

**CONCRETE PROTECTION SLAB**

A reinforced concrete protection slab that is a minimum of 75 mm (3 in) thick is an optional component in waterproofing systems for both plazas and earth-covered slabs. When a paved area is used for vehicular traffic, a concrete protection slab is mandatory to prevent damage and failure of the waterproofing membrane from braking loads, turning stresses, etc. Moreover, in a plaza system, a concrete protection slab will protect the membrane during subsequent construction activities. In earth-covered systems, it serves to protect the membrane from root damage that may penetrate the drainage course and protection board.

The inclusion or exclusion of a concrete protection slab is a major design decision in plaza waterproofing systems and balances accessibility against reliability. Gaining accessibility to the membrane by specifying removable components above the membrane is an enormous advantage. It can facilitate repairs and membrane replacement.

Accessibility to the membrane can sac-
sifice reliability. Protection boards and drainage composite boards can provide resistance to root intrusion for earth-covered slabs. However, they can neither provide the level of resistance to root intrusion that a concrete protection slab can nor the protection from landscaping equipment. The decision to incorporate a concrete protection slab must be based on cost, which includes the initial cost of the slab and the potential cost associated with its removal to access the waterproofing membrane.

WEARING COURSE

As stated previously, wearing surfaces are generally divided into open-joint systems that are drained at the membrane level and closed-joint systems that are drained at the surface.

Waterproofing membranes in an open-joint system are infrequently subjected to hydrostatic pressure exceeding 5 psf (25 mm [1 in] depth of water). Closed-joint systems shed water at the surface and similarly protect the membrane from hydrostatic pressure.

Any waterproofed plaza wearing surface must satisfy and meet the following criteria:
- Structurally sound to bear the intended traffic
- Durable under heavy wear and weathering
- Resistant to abrasion
- Aesthetically pleasing
- Heat reflecting

The first two items are mandatory, and the last two are optional.

EARTH-COVERED SLABS

Although beyond the scope of this paper, earth-covered slabs can be planted with groundcover, shrubs, and trees. Typically referred to as a green roof system, it is an extension of the existing roof that involves a high-quality waterproofing and root barrier system, a drainage system, filter cloth, a growing medium, and plants.

Green roof systems may be modular, with drainage layers, filter cloth, growing media, and plants already prepared in movable, interlocking grids; or each component of the system may be installed separately. A green roof involves the creation of “contained” green space on top of a man-made structure.

In today’s environment, building owners and architects are embracing green roof technology. The two distinct types of green roofs are intensive and extensive.

Extensive green roofs are much lighter in weight, with engineered soil depths ranging from 75 mm (3 in) to 175 mm (7 in). Due to the shallow soils and the extreme environment on many roofs, plants are typically low-growing groundcover that are extremely sun and drought tolerant.

Extensive green roofs can be installed over existing roof decks, provided a structural engineer first inspects the structure to ascertain its load capacity. Although the focus of most extensive green roofs are their environmental benefits, extensive green roofs still require periodic maintenance and must be designed to resist wind uplift.

Intensive green roofs are characterized by thick soil depths (200 mm [8 in] - 1.2 m [4 ft]), heavy weights, and elaborate plantings that include shrubs and trees. Intensive green roofs are installed primarily over concrete roof decks to withstand the weight requirements. These park-like green roofs can be at or above grade and require considerable maintenance to sustain their aesthetic appearance.

PLAZA FURNITURE

If a plaza design includes planters, reflecting pools, foundations, benches, and other plaza “furniture,” they should be installed over the waterproofing membrane. These items should be waterproofed individually and not part of the main waterproofing membrane. Trees should be planted in concrete containers (Figure 17) to avoid damage to the waterproofing membrane from root penetration or landscape shovels.

FLOOD TESTING

A failed waterproofing system is more destructive and expensive to correct than a failed roof. The replacement cost of a failed roof can be anywhere from $15 to $22 psf; a failed waterproofed plaza, between $75 and $125 psf, at a minimum.

It is therefore advisable to flood-test a waterproofed deck after the flashing and membrane have been installed. ASTM D-5957, Flood Testing Horizontal Waterproofing Installations, first published in 1996, provides the necessary method for testing the watertightness of a waterproofed deck (Figure 18). Some limitations of this standard are:
- Slope-of-deck or membrane to be tested must not exceed 2 percent (6.25 mm [1/4 inch]) per foot.
- Membranes can be LAMs, adhered or loose-laid sheets, or built-up and modified.
- Do not test until 24 hours after the membrane has been installed. (This requirement increases to 48 hours if the membrane was installed at ambient temperatures below 50˚ F.)
- Inspect and repair flashing and membrane prior to testing.

If a leak occurs during the test process, the following provisions are to be followed:
- Drain water.
- Locate and repair leak.
- Retest area under the same initial conditions.

Electric field vector mapping (EFVM™) is a new tool for improving quality control of waterproofing systems. Although relatively new to the United States, it has achieved a
long record of success in Europe. The system was pioneered in Germany. EFVM, unlike other leak-detection methods, can quickly and accurately locate the point of water entry.

EFVM uses water as an electrically conductive medium. A wire loop is installed around the perimeter of the area to be tested and introduces an electrical potential. The area within the loop is dampened and forms the upper electrical plate. The structural deck then becomes the lower plate. The membrane acts as separator and insulator between the two plates. If moisture enters a defect in the membrane, an electrical contact is established. The survey technician can then follow the direction of the electric field to the membrane defect. Advocates of EFVM state that the test method:

- Locates defects precisely, enabling efficient repairs
- Is able to re-test repairs immediately
- Can be used after cover systems are installed, especially with green roof landscapes
- Is less expensive than conventional flood testing
- Eliminates the hazard of overloading structural decks during testing
- Can be used on steeply sloped roof surfaces where flood testing is impossible

The suitability of EFVM depends on the electrical resistance of the waterproofing materials, and all membranes may not be compatible with this test method. Systems that employ a root barrier require special procedures, since the root barrier will act as an insulating layer. When root barriers are used, it is necessary to make small slits in the barrier to permit the establishment of electrical contact with the underlying waterproofing membrane. These cuts can be resealed after the leak is located.

**SUMMARY**

A plaza design over occupied spaces must create a system that waterproofs and insulates the structural building deck while supporting pedestrian and/or vehicle traffic, as well as landscaping elements.

The building deck must be reasonably smooth, be sound, and provide adequate slope to promote drainage. The waterproofing membrane selected and installed must be capable of withstanding long-term exposure to ponding water. Flashings at drains, penetrations, expansion joints, and other similar membrane terminations should be carefully detailed, since most leakage problems occur at these locations.

Insulation should be placed above the membrane to minimize temperature cycles of the membrane and deck and provide additional protection for the membrane. The insulation must have high compressive strength, low water absorption, and be resistant to freeze/thaw.

Drainage at the membrane level is an essential component of the system. Drainage at both the membrane level and below the wearing surface is particularly important to ensure water flow to drains and minimize freeze/thaw heaving or deterioration of the wearing surface.

The wearing surface should be aesthetically pleasing, durable, and able to accommodate loads associated with the plaza function. The wearing surface should consist of discrete components to facilitate removal and reinstallation and to allow for maintenance.

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