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Standard Guide for Design of Built-Up Bituminous Membrane Waterproofing Systems for Building Decks[1]

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1. Scope

1.1 This guide describes the design and installation of bituminous membrane waterproofing systems for plaza deck and promenade construction over occupied spaces of buildings where covered by a separate wearing course.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates[2]
C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[2]
C 208 Specification for Cellulosic Fiber Insulating Board[3]
C 717 Terminology of Building Seals and Sealants[4]
C 755 Practice for Selection of Vapor Barriers for Thermal Insulation[3]
D 41 Specification for Asphalt Primer Used in Roofing, Dampproofing, and Waterproofing[5]
D 43 Specification for Coal Tar Primer Used in Roofing, Dampproofing, and Waterproofing[5]
D 173 Specification for Bitumen-Saturated Cotton Fabrics Used in Roofing and Waterproofing[5]
D 226 Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing[5]
D 227 Specification for Coal-Tar Saturated Organic Felt Used in Roofing and Waterproofing[5]
D 312 Specification for Asphalt Used in Roofing[5]
D 449 Specification for Asphalt Used in Dampproofing and Waterproofing[5]
D 450 Specification for Coal-Tar Pitch Used in Roofing, Dampproofing, and Waterproofing[5]
D 1327 Specification for Bitumen-Saturated Woven Burlap Fabrics Used in Roofing and Waterproofing[5]
D 1668 Specification for Glass Fabrics (Woven and Treated) for Roofing and Waterproofing[5]
D 2178 Specification for Asphalt Glass Felt Used in Roofing and Waterproofing[5]
D 2626 Specification for Asphalt-Saturated and Coated Organic Felt Base Sheet Used in Roofing[5]
D 2822 Specification for Asphalt Roof Cement[5]
D 4022 Specification for Coal Tar Roof Cement, Asbestos Containing[5]
D 4586 Specification for Asphalt Roof Cement, Asbestos Free[5]
D 4601 Specification for Asphalt-Coated Glass Fiber Base Sheet Used in Roofing[5]
D 4990 Specification for Coal Tar Glass Felt Used in Roofing and Waterproofing[5]
D 5295 Guide for Preparation of Concrete Surfaces for Adhered (Bonded) Membrane Waterproofing Systems[5]

3. Terminology

3.1 *Definitions*—The definitions of the following terms used in this guide are found in Terminology C 717: creep; cold joint; compatibility; construction joint; hydrostatic pressure; laitance; reglet; spalling; waterproofing.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cellular (adj).*—having a composition of plastic or rubber with relative density decreased by the presence of cells disposed throughout its mass. In closed-cell materials, the cells are predominantly separate from each other. In open-cell materials, the cells are predominantly interconnected.

3.2.2 *construction joint*—a butt joint formed in a structural slab in order to end one pour and start another pour later. The joint is usually a cold joint and may be held together with reinforcing steel in the slab, or the steel may be discontinuous by design.

3.2.3 *curing time*—the period between application and the time when the material reaches its design physical properties.

3.2.4 *deck*—the horizontal structural substrate supporting the plaza deck system. See also *structural slab.*

3.2.5 *deflection*—the deviation of a structural element from its original shape or plane due to physical loading, temperature changes, or rotation of its supports.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.06.

[4] *Annual Book of ASTM Standards*, Vol 04.07.

[5] *Annual Book of ASTM Standards*, Vol 04.04.

3.2.6 *drainage course*—See *percolation layer, geotextile drainage composite,* and Fig. 1.

3.2.7 *dry occupancy*—an occupied space below the plaza deck system in which the computed or anticipated relative humidity is below 30%.

3.2.8 *dynamic*—exhibiting change or movement.

3.2.9 *finish*—the exposed top surface of the plaza deck system, or traffic, or wearing surface.

3.2.10 *flashing*—(*1*) a generic term describing the transitional area between the waterproofing membrane and surfaces above the wearing surface of the plaza. (*2*) a terminal closure to prevent ingress of water into the system.

3.2.11 *floated finish*—a concrete finish provided by consolidating and leveling the concrete with only a power driver or hand float, or both. A floated finish is coarser than a troweled finish. For specifications, see ACI-301-72 (1975).

3.2.12 *freeze-thaw cycle*—the freezing and subsequent thawing of a material.

3.2.13 *geotextile drainage composite*—a performed porous material, usually plastic, with a filter-type fabric over it.

3.2.14 *grout*—concrete containing no coarse aggregates; a thin mortar.

3.2.15 *insulating concrete*—a lightweight concrete made with lightweight coarse aggregate and having relatively low insulating characteristics.

3.2.16 *percolation layer (drainage course)*—a layer of washed gravel that allows water to filter through to the drain (see Fig. 1).

3.2.17 *ply*—a single layer of membrane reinforcement in the bituminous membrane waterproofing system.

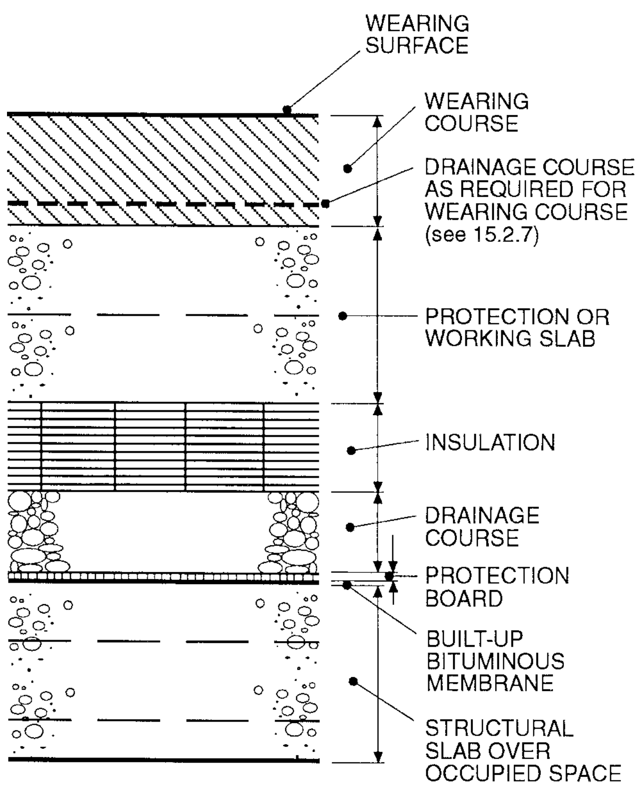

FIG. 1 Basic Components of Built-up Bituminous Membrane Waterproofing System with Separate Wearing Course (see Section 7)

3.2.18 *protection board*—a semi-rigid sheet material placed on top of waterproofing membrane to protect it against damage during subsequent construction and to provide a protective barrier against compressive and shearing forces induced by materials placed above it (see Fig. 1).

3.2.19 *raggle*—same as reglet.

3.2.20 *scaling*—same as spalling.

3.2.21 *static*—exhibiting little or no change or movement.

3.2.22 *structural slab*—a horizontal, supporting, cast-in-place, concrete building deck (see Fig. 1).

4. Significance and Use

4.1 This guide provides information and guidelines for the selection of components and the design of a built-up bituminous membrane waterproofing system in building deck construction. Where the state of the art is such that criteria for particular conditions are not established or have numerous variables that require consideration, applicable portions of Design Considerations, Sections 5-17, serve as reference and guidance for selection by the designer of the system.

DESIGN CONSIDERATIONS

5. General

5.1 The design of plaza deck waterproofing cannot be satisfactorily determined without consideration of the several subsystems, their material components, and interrelationships. The proper selection from a variety of components that form a built-up bituminous membrane waterproofing system must be predicated upon specific project requirements and the interrelationship of components. The variety of the types of surfaces exposed to weather, the difference of climatic conditions to which the deck is exposed, and the interior environmental requirements of the occupied space are major determinants in the process of component selection. Essential to determination of the deck design components is information relative to temperature extremes of the inner and outer surfaces, precipitation rates, solar exposure, prevailing wind direction, the pattern and reflectivity of adjacent structures, anticipated amount and intensity of vibration resulting from function or adjacent occupancies, and design live loads both normal and emergency.

6. Compatibility

6.1 It is essential that all components and contiguous elements be compatible and coordinated to form a totally integrated waterproofing system.

7. Major Components and Subsystems

7.1 The plaza deck system is normally composed of several subsystems: the structural building deck (membrane substrate), the waterproofing membrane, the drainage subsystem, the thermal insulation, protection or working slab, and the wearing course (see Fig. 1). Fig. 1 as well as details, subsystems, components, and illustrations that follow are intended to illustrate a principle but are not necessarily the only solution for a diversity of environments.

8. Horizontal or Deck Substrate

8.1 The building deck or substrate referred to in this guide is reinforced cast-in-place structural concrete.

8.1.1 High early strength and insulating concretes do not provide suitable substrates. Additives made to the concrete mix (such as calcium chloride) to promote curing, reduce water requirements, or modify application temperature requirements should not be used unless the manufacturer of the waterproofing system specifically agrees.

8.1.2 Precast concrete slabs pose more technical problems than cast-in-place concrete, and the probability of lasting watertightness is greatly diminished and difficult to achieve because of the multitude of joints that have the capability of movement and must be treated accordingly. Moving joints are critical features of waterproofing systems and are more critical when sealed at the membrane level than at a higher level with the use of integral concrete curbs. Such curbs are impractical with precast concrete slabs and necessitate an even more impractical drain in each slab. Other disadvantages of precast concrete slabs are their inflexibility in achieving contoured slope to drains and the difficulty of coordinating the placement of such drains.

8.2 *Slope for Drainage*—Drainage at the membrane level is important. When the waterproofing membrane is placed directly on the concrete slab, a monolithic concrete substrate slope of a minimum 11 mm/m (⅛ in./ft) should be maintained. The maximum slope is related to the type of membrane used. Slope is best achieved with a monolithic pour as compared with a separate concrete fill. The fill presents the potential of additional cracks and provides a cleavage plane between the fill and structural slab. This cleavage plane complicates the detection of leakage in the event that water should penetrate the membrane at a crack in the fill and travel along the separation until reaching a crack in the structural slab.

8.3 *Strength*—The strength of concrete is a factor to be considered with respect to the built-up bituminous membrane insofar as it relates to finish, bond strength, and continuing integrity. The cast-in-place structural concrete should have a minimum density of 1762 kg/m^3 (110 lb/ft^3).

8.4 *Finish*—The structural slab should have a finish of sufficiently rough texture to provide a mechanical bond for the membrane but not so rough to preclude achieving continuity of the membrane across the surface. As a minimum, ACI 301-72 (1975) floated finish is required with ACI 301-72 (1975) troweled finish preferred, deleting the final troweling.

8.5 *Curing*—Curing the structural slab is necessary to provide a sound concrete surface and to obtain the quality of concrete required. Curing is accomplished chemically with moisture and should not be construed as drying.

8.5.1 *Moist Curing*—Moist curing is achieved by keeping the surfaces continuously wet by covering with burlap saturated with water and kept wet by spraying or hosing. The covering materials should be placed to provide complete surface coverage with joints lapped a minimum of 75 mm (3 in.).

8.5.2 *Sheet Curing*—Sheet curing is accomplished with a sheet vapor retarder that reduces the loss of water from the concrete and moistens the surface of the concrete by condensation, thus preventing the surface from drying while curing. Laps of sheets covering the slab should be not less than 50 mm (2 in.) and should be sealed or weighted (see Practice C 755).

8.5.3 *Chemical Curing*—Liquid or chemical curing compounds applied to the surface of the structural slab should not be used unless approved by the manufacturer of the built-up bituminous membrane as the material may interfere with the bond of the membrane to the structural slab.

8.6 *Dryness*—Membrane manufacturer's requirements for substrate dryness vary from being visibly dry to having a specific maximum moisture content. Since there is a lack of unanimity in this regard, it is necessary to conform to the manufacturer's requirements for the particular membrane being applied. Adequate drying of residual moisture from slabs poured over a permanent metal deck will normally take longer than from slabs stripped of forming. Subsequent underside painting of stripped concrete slabs that might inhibit moisture vapor transmission and possibly cause loss of membrane adhesion should be avoided.

8.7 *Joints*—Joints in a structural concrete slab are herein referred to as reinforced joints, unreinforced joints, and expansion joints.

8.7.1 *Reinforced Joints*—Reinforced joints consist of hairline cracks, cold joints, construction joints, and isolation joints held together with reinforcing steel bars or wire fabric. These are considered static joints with little or no movement anticipated because the slab reinforcement is continuous across the joint.

8.7.2 *Nonreinforced Joints*—Nonreinforced joints consist of butt-type construction joints and isolation joints not held together with reinforcing steel bars or wire fabric. These joints are generally considered by the designer of the structural system as nonmoving or static joints. However, the joints should be considered as capable of having some movement, the magnitude of which is difficult to predict.

8.7.3 *Expansion and Seismic Joints*—Expansion joints, as differentiated from control joints, are designed to accommodate movement in more than one direction, are an integral part of the building structural system, and must be carried through the entire structure. Expansion joints are incorporated in the structural frame (*1*) to reduce internal stresses caused by wide temperature ranges or differential movement, or both, between structural elements as might be the case in large adjoining heated and unheated spaces; (*2*) where there are different foundation settlement conditions between adjacent elements; or (*3*) where movements between high- and low-attached structures are anticipated. Seismic joints are a special case in which the joints are generally quite large and are designed to limit damage to the structural frame during earthquakes. Expansion and seismic joints are best located at high points of contoured substrates to deflect water away from the joint. For expansion joints designed for thermal movement only, the movement is expected to be only in the horizontal plane. Seismic joints are designed to accommodate both vertical and horizontal movement.

8.8 *Flashing Substrate*—The vertical surface that the membrane waterproofing intersects must be sound, with a smooth or floated finish, dry, and free of cracks and loose materials as stated for the horizontal or deck substrate. The vertical surfaces may be of concrete, stone, or masonry, and should be reinforced against shrinkage and cracks.

9. Membrane Components

9.1 The major membrane components include primers, bitumens, reinforcements and flashing materials.

9.2 *Primers*—Primers (Specifications D 41 and D 43) are used to prepare the substrate to obtain maximum adhesion of the bitumen to the substrate. Asphalt derivative primers should be used with asphalt and coal-tar derivative primers with coal-tar bitumen.

9.3 *Bitumens*—Bitumens in a waterproofing system serve two functions. They provide the prime waterproofing component of the system and the adhesive component for the membrane reinforcement. The bitumens used in plaza building deck waterproofing are asphalt (Specifications D 312 and D 449, Types I or II) or coal-tar pitch (Specification D 450, Types II or III). In some instances these products are modified to serve a particular purpose. In building deck waterproofing, waterproofing grade asphalts and coal-tar pitches, as noted, are primarily used because of their cold-flow (self-healing) properties.

9.3.1 *Asphalt*—Asphalt is derived from the residue of the process of manufacturing light petroleum distillates and further processed into waterproofing and roofing grade asphalts. Asphalts tend to be aliphatic, chain-like hydrocarbon compounds.

9.3.2 *Coal-Tar Pitch*—Coal-tar pitch is derived from crude coal tar, a by-product from high temperature coke ovens, by a refining process of distillation and chemical extraction. Coal tar pitches tend to be aromatic, ring-like hydrocarbon compounds.

9.3.3 *Modified Bitumens*—Modified bitumens are normally proprietary type products and may not necessarily be classified by organizations such as ASTM. They are designed to develop a particular objective such as extensibility, for example, viscosity variation, strength, reduction of volatiles, etc.

9.3.4 *Selection*—The selection of bitumen type for a specific project is related to the numerous variables and options described in this guide and that must be taken into consideration by the designer of the waterproofing system.

9.4 *Reinforcements*—The types of membrane reinforcement used in waterproofing are treated glass fabric, saturated woven cotton and saturated jute fabric, saturated felts, impregnated glass felts, and coated sheets. Specialty preformed sheets are also incorporated in plaza waterproofing. The requirements for plaza deck waterproofing are complex. Thus, the designer knowing his particular building problem must select the membrane component types that will satisfy the design requirements. Combinations of the various membrane reinforcement are commonly used in alternate plies, depending upon the design requirement. Unless otherwise directed by the manufacturer, asphalt bitumen should be used with asphalt-based membranes and coal-tar bitumen with coal-tar based membranes.

9.4.1 *Treated Glass Fabric*—Untreated glass fabrics are lightweight, inorganic, very high in tensile strength, open-mesh, and will not absorb water or any other material. As finished treated products, (Specification D 1668, Type I Asphalt Treated, Type II Coal-Tar Pitch Treated and Type III Organic Resin Treated), they provide excellent strength in waterproofing and are particularly effective in areas of vibration, deflection, or where heavy loads are applied over the waterproofing system. Their flexibility allows them to be used in corners, in angles, and over irregular surfaces. Due to the open-mesh woven design, they can be applied without entrapment of air.

9.4.2 *Saturated Woven Cotton Fabric*—Saturated woven cotton fabric is an organic material, thus requiring the saturant to penetrate the interstitial cells of the cotton fibers. It has good tensile strength, although not as strong as woven glass fabric but superior to felts. It is of an open-mesh woven design and is excellent where flexibility and adaptability to irregular surfaces, corners, and angles are a requirement. Woven cotton fabric (Specification D 173) is saturated with asphalt or coal-tar saturants.

9.4.3 *Saturated Woven Jute*—Saturated woven jute is an organic material, thus requiring the saturant to penetrate the interstitial cells of the jute fibers. It is generally woven with thicker thread than cotton, thus retaining a great quantity of bitumen. It has many of the same characteristics of cotton in relation to waterproofing. Woven jute fabric (Specification D 1327) may be saturated with asphalt or coal-tar saturants.

9.4.4 *Saturated Felts*—Dry felts are organic mats saturated with saturating grade asphalt or coal tars. They provide a container and reinforcement for the interply bitumen. They are of the same type used in roofing systems and are classified as Specification D 226, Asphalt-Saturated (organic) and Specification D 227, Coal-Tar-Saturated (organic).

9.4.5 *Glass Fiber Felts*—Glass fiber felts are light in weight. The glass fibers are dispersed at random to form a sheet. The fibers may be continuous or in a jackstraw pattern depending upon the method of manufacture and are bonded together with resinous binder. Glass fiber felts (Specification D 2178) are coated with asphalt (Specification D 4990).

9.4.6 *Asphalt-Coated Base Sheets and Coated Felts*—Asphalt-coated base sheets and coated felts, used as membrane reinforcement, consist of asphalt-saturated roofing grade felt coated on both sides with coating-grade asphalt filled with mineral stabilizer and finished on the top side with fine mineral surfacing. They are heavier and slightly stronger than saturated felts. Coated felts have less quantity of coating asphalt than coated base sheets. In cold temperatures a coated felt is difficult to lay flat and avoid edge voids. The felts may be organic or inorganic. Asphalt coated glass fiber base sheet is described in Specification D 4601.

9.5 *Specialty Preformed Membrane*—Specialty sheets may incorporate membrane reinforcement in single or multilayers and be produced as a single preformed sheet. The bitumen is normally modified to provide special characteristics for the composite sheet. These membranes are generally proprietary and not presently classified by reference standards such as those of ASTM.

9.6 *Flashing*—The major flashing components for terminal conditions include fibrated troweling roofing cement, reinforced flashing felts, and proprietary elastomeric materials.

9.6.1 *Bituminous Plastic Cement*—Bituminous plastic ce9ment such as those meeting Specifications D 4022 for coal tar roof cement and D 2822 for asphalt roof cement or D 4586 for asphalt roof cement, asbestos-free (Type I) are made from (*1*) bitumen characterized as self-healing, adhesive, and ductile; (*2*) compatible volatile solvents; and (*3*) mineral stabilizers including asbestos fiber mixed to a smooth uniform consistency suitable for troweling applications. A similar product but which does not contain asbestos is typified by material meeting Specification D 4586 (Type I).

9.6.2 *Reinforced Flashing Felts*—Reinforced flashing felts are composed of asbestos or glass fiber roofing felts impregnated with asphalt, reinforced with a scrim of woven glass fabric or cotton fabric and coated on both sides with asphaltic material compounded with a fine material stabilizer. The reinforced flashing felt with its low flexibility is applicable to gradual transitions.

9.6.3 *Proprietary Elastomeric Materials*—Proprietary elastomeric materials based on neoprene (cured or cure-in-place), butyl, and ethylene-propylene diene monomer (EPDM) may be set into hot bitumen or a cold-applied adhesive per manufacturer's instructions. Application on roof cement may lead to solvent blistering and softening.

9.6.4 *Selection*—Unless otherwise directed by manufacturers, asphalt-flashing materials should be used with asphalt membranes and coal-tar bitumen flashing materials used with coal-tar bitumen membranes.

9.7 *Handling and Storage*—Proper handling, storage, and protection of waterproofing materials is essential. During application the presence of moisture, dirt accumulation, and damaged materials are primary causes of lack of bond, bond failure, and delamination. Since some waterproofing materials are susceptible to moisture damage and adsorption, optimum storage and protection is in a weathertight enclosure. When job conditions make this unrealistic, materials should, as a minimum, be stored off the ground or deck on pallets and covered above, on all sides, and ends with breathable-type canvas tarpaulins. Plastic sheets should not be used because they permit condensation buildup under them.

9.8 *Membrane Composition and Application*—A built-up bituminous waterproofing membrane consists of components joined together and bonded to its substrate at the site. Paragraphs 9.8.1-9.8.8.5 cover its composition and application on a structural concrete substrate. See Section 13 for insulation considerations.

9.8.1 *Substrate Preparation*—Surfaces to receive waterproofing must be clean, dry, reasonably smooth, and free of dust, dirt, voids, cracks, laitance, or sharp projections before application of materials. Refer to Guide D 5295.

9.8.2 *Primer Application*—Concrete surfaces should be uniformly primed to enhance the bond between the membrane and the substrate, and thus inhibiting lateral movement of water. The primer must not be left in puddles. The normal application rate is 1 gal/100 ft^2 (0.003 m^3/9.0 m^2). Asphalt Primer (Specification D 41) should be used with asphalt bitumen. Coal-tar primer (Specification D 43) should be used with coal-tar pitch bitumen unless waived by the manufacturer of the membrane for the particular project conditions. Primer should be allowed to become tacky or dry before application of bitumen. A wet primer may soften the bitumen.

9.8.3 *Position and Composition of Membrane Plies*—The number of plies of membrane reinforcement required is dependent upon the head of water and strength required by the design function of the wearing surface. Plaza deck membranes should be composed of not less than three plies. The composition of the membrane is normally of a "shingle" or "ply-on-ply" (phased) construction.

9.8.3.1 *Shingle Method*—The "shingle" method is achieved by successive lapping of one ply over another, using prescribed overlaps, until the required number of plies of membrane reinforcements are achieved. For example, a four-ply system is achieved by lapping each successive ply slightly over three quarters of the previously laid ply. Based upon a 914-mm (36-in.) wide membrane reinforcement, each ply overlap is approximately 699 mm (27½ in.), leaving a 216-mm (8½-in.) exposure to the weather. To determine the amount of ply exposed to the weather, using a 914-mm (36-in.) width as a base, divide 864 mm (34 in.) by the number of plies. The resultant is the exposure to the weather. To determine the overlap distance, subtract the exposure obtained from the width of the 914-mm (36-in.) wide roll. For example, a three-ply system would have an "exposure" of 288 mm (11⅓ in.) or 34 divided by 3, and the "overlap" would be 627 mm (24⅔ in.) or 11⅓ substracted from 36. The extra 50 mm (2 in.) (36 minus 34) serves as a safety factor to assure that the vertical cross section will contain the designated number of plies.

9.8.3.2 *Ply-on-Ply (Phased Method)*—"Ply-on-ply" or "phased" construction is a method whereby each ply or group of plies are in a single-connecting layer over which the next phase is applied. The phased method is often employed when different types of membrane are used in the construction of the waterproofing membrane system. For example, a system of two plies of felt plus two plies of fabric plus one ply of felt consists in phase 1 of the application of two plies of felt in shingle fashion, in phase 2 of the application of two plies of fabric in shingle fashion, and in phase 3 of the application of the final ply of felt with normal 50 mm (2-in.) single-ply overlaps.

9.8.3.3 *Comparison of Methods*—Shingle method advantages over the phased method are (*1*) less potential for slippage, (*2*) less susceptibility to moisture entrapment, (*3*) greater potential for ply-to-ply adhesion, (*4*) reduction of potential slippage planes of bitumen, (*5*) any desired number of plies can be laid in a single progressive operation, and (*6*) overall is a faster method. The phased method has an advantage over the shingle method insofar as the operation permits a full layer of bitumen between the entire layer of membrane reinforcements providing a secondary waterproofing plane.

9.8.3.4 *Placement of Plies*—Membrane reinforcements should start at the low point of the deck working to the high level so that the direction of the flow of water is over the lap. All plies should be firmly embedded into the hot bitumen by brooming, pressing, or other suitable means so that ply shall not touch ply and to prevent formation of wrinkles, buckles, kinks, blisters, or pockets. After plies are in place, the surface of the membrane system should be coated with hot bitumen and while still hot, a sheet of protection board embedded (see Section 10). Only an area of size that will allow completion of the membrane and placing of protection board upon the membrane in one working day should be undertaken; exposure of membrane reinforcing plies to weather, dew, condensation, or frost can result in membrane failure. Consideration of bitumen flow or creep merits attention to temperature gradients and the estimated maximum temperature of the membrane in the deck system. The slope of the substrate and membrane should also be considered.

9.8.4 *Bitumen Application and Quantities*—The layer of bitumen between plies of the membrane reinforcement should not be excessive. The maximum bond strength is achieved with the thinnest practical, continuous application of bitumen between the plies. There should be sufficient bitumen to penetrate the membrane reinforcing in addition to that required to provide adhesion properties. The criterion is to apply a sufficient quantity of bitumen to provide a full and continuous course of bitumen for embedment of each subsequent ply of membrane reinforcement. The quantities to achieve this may vary from 0.83 kg/m^2 (17 lb/100 ft^2) to 1.47 kg/m^2 (30 lb/100 ft^2) for each course of bitumen between membrane plies. Differences in rates may result from atmospheric conditions, method of application, and temperature at actual time of placement. As the bitumens flow less readily at lower application temperatures, the interply layer of bitumen tends to be higher in weight. The quantity may also vary depending upon the speed the applicator moves mechanically operated bitumen-spreading equipment. These variations are not necessarily troublesome provided the bitumen is hot enough to develop adhesion to the membrane reinforcement, and the interply weights are not excessive or so low as to prevent continuous bond. The use of excessive quantities of bitumen in areas subject to horizontal and vertical loads should be avoided. For estimating purposes, an average quantity of bitumen between plies of membrane reinforcement may be classified as 1.13 kg/m^2 (23 lb/100 ft^2) for asphalt and 1.22 kg/m^2 (25 lb/100 ft^2) for coal-tar pitch. Glass felts may require greater quantities of interply bitumen due to the interstices of the reinforcement. Use manufacturer's recommendations to ascertain quantities of bitumen required.

9.8.4.1 *Application Temperature*—For the proper application of bitumen in a built-up bituminous membrane, it is important to note that bitumen is a water-resistant, viscous adhesive that depends upon flow for its adhesive and wetting properties. Bitumen flow is best measured by the viscosity of the material. Viscosity changes with temperature; the higher the temperature the lower the viscosity. (*1*) *Asphalts*—Studies have shown that asphalts having a viscosity from 100 to 150 cSt (0.0001 to 0.0002 m^2/s) have optimum wetting and adhesive properties. The optimum application temperature of asphalt is the "equiviscous temperature," the temperature at which asphalt will attain a target viscosity of 125 cSt (0.0001 m^2/s), at the point of application. A tolerance range of ±25°F (±3.9°C) is added for practical application in the field to accommodate the effects of wind chill, sunshine, or ambient temperature. Asphalt should not be heated to or above the actual Cleveland Open Cup (COC) flash point or heated and held above the finished blowing temperature for more than 4 h. (*2*) *Coal Tar Pitches*—Studies have shown that coal tar pitches have a viscosity from 12 to 32 cSt or 15 to 40 centipoise have optimum wetting and adhesive properties. The optimum application temperature of coal tar pitch is the "equiviscous temperature," the temperature at which coal tar pitch will attain a target viscosity of 20 cSt or 25 centipoise at the point of application. A tolerance range of ±25°F (±13.9°C) is added for practical application in the field to accomodate the effects of wind chill, sunshine, or ambient temperature. Coal tar pitch should not be heated to or above the actural Cleveland Open Club (COC) flash point.

9.8.5 *Treatment at Reinforced Joints*—Over the reinforced structural slab joints, one ply of 6-in. wide membrane reinforcement embedded in products like bituminous plastic cement (Specifications D 2822, D 4056, or D 4022) (see also 9.6.1) should be applied before application of the bituminous membrane as indicated in Fig. 2.

9.8.6 *Treatment at Nonreinforced Joints*—Nonreinforced joints between the structural slab (membrane substrate) and vertical surfaces that are not subject to movement should receive a bead of compatible sealant in a recessed joint before application of the membrane to reduce potential leakage of bitumen through the joint (see Fig. 3). Where movement is anticipated, these joints should be designed as expansion joints (see 9.8.7).

9.8.7 *Treatment at Expansion Joints*—There are basically two concepts that could be considered in the detailing of expansion joints at the membrane level of membrane waterproofing systems. These are (*1*) the positive seal concept directly at the membrane level, or (*2*) the water shed concept with the seal at a higher level than the membrane. Where additional safeguards are desired, a drainage gutter under the joint could be considered (see Fig. 4). Flexible support of the membrane is required in each case. Expansion joint details should be considered and used in accordance with their movement capability.

9.8.7.1 *Positive Seal Concept*—The positive seal concept entails a greater risk than the water shed concept since it relies fully on positive seal joining of materials at the membrane level, where the membrane is most vulnerable to water penetration. The materials used, and their joining, must be carefully engineered by the manufacturer of the bituminous membrane waterproofing system, and subsequent field installation requires the best of workmanship for potential success,

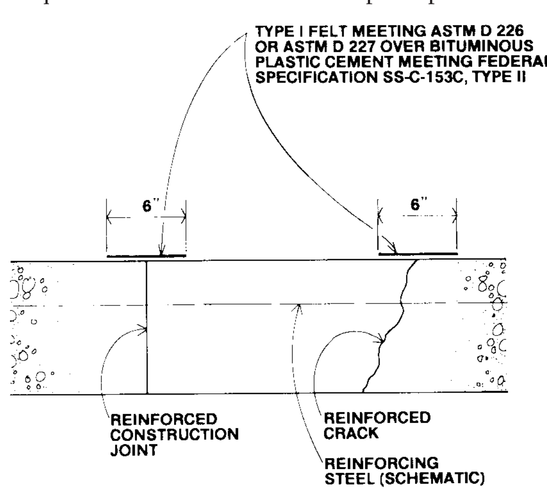

FIG. 2 Treatment at Reinforced Joints (see 9.8.5)

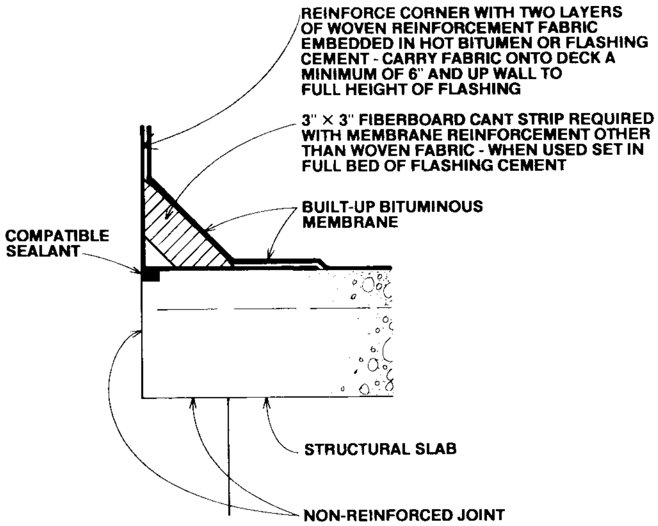

FIG. 3 Treatment at Nonreinforced Joints (see 9.8.6 and 9.8.8.1)

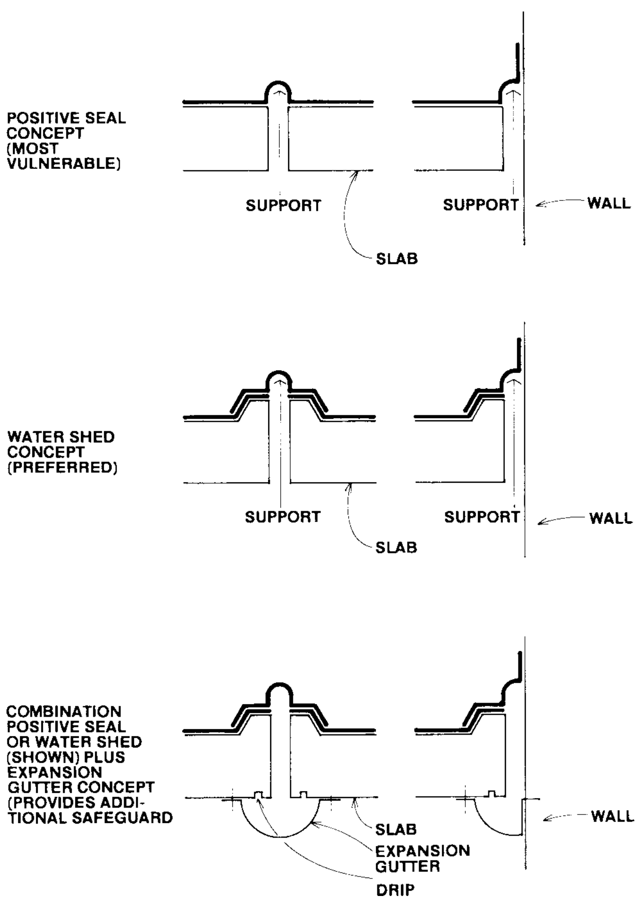

FIG. 4 Schematic Expansion Joint Concepts at Membrane Level (see 9.8.7)

leaving no margin for error. Therefore, use of this concept is not recommended.

9.8.7.2 *Water Shed Concept*—The water shed concept, although requiring a greater height and more costly concrete forming, is superior in safeguarding against leakage, having the advantage of providing a water dam at the membrane level. The joining of differing materials can then be placed at a higher level and treated somewhat in the manner of counterflashing, hence the term "watershed concept." However, if a head of water rises to the height of the material joined, this concept becomes almost as vulnerable as the positive seal concept. Therefore, drainage is recommended at the membrane level and is further analyzed in Section 11.

9.8.7.3 *Provision for Movement*—Generally, expansion joints in a structural slab are seldom less than 30 m (100 ft) apart and may be as much as 91 m (300 ft) or more apart. Therefore, relatively large amounts of total movement are to be dealt with, generally in the range from 13 mm (½ in.) up to 38 mm (1½ in.). Maximum movement generally occurs during the construction phase before insulation and wearing course are installed over the membrane, but the joint should be detailed for maximum movement at any time. Gaskets and flexible preformed sheets are required to absorb such amounts of movement inasmuch as bituminous membranes have little or no movement capability. Since such materials, when used at an expansion joint, must be joined to the bituminous membrane, the watershed concept should be used. Figs. 5-7 indicate expansion joints using the watershed concept that have a movement capability of ±9 mm (⅜ in.) when installed in a designed concrete opening of the width indicated. These details could be increased in movement capability with a larger gasket and concrete opening if so desired.

9.8.8 *Transitional Changes and Terminal Conditions*—Transitional changes and terminal conditions should be designed for simplicity of installation and repetitive operations and normally consist of composite sheets of felts, fabrics, and bitumens with a mineral surface. Square corners, sharp arrises, and smooth planes are not adaptable to bitumen and bitumen reinforcements. The functional effectiveness results from design simplicity of the field installation, consideration of location, handling, similarity of details, material selection, and method of placement. Bitumens and reinforcing must be compatible with the membrane and substrate. Surfaces to receive waterproofing must be in accordance with Section 8. Masonry surfaces to receive flashings should be primed before application of the flashing (see 9.2). Corners must be designed to allow easy installation using hand tools with consideration of the required system and type of flashing material suitable to the installation. Anchorage of the terminal edge of the membrane system is essential (see Figs. 8-10). Hot bitumen should be applied sparingly at terminal conditions. Temporary terminations of flashing must be provided at the end of each workday to prevent water infiltration and loss of bond. The surface of flashing should be protected by protection board cover against construction damage.

9.8.8.1 *Transitional Changes in Membrane*—Reinforce all intersections with walls, corners, or any location that may be subject to unusual stress, with two layers of woven fabric embedded in hot bitumen. Extend the fabric onto the deck at least 150 mm (6 in.) and extend up the wall the full height to the wearing surface, carrying fully into corners. Woven fabrics are employed in this initial preliminary phase because of their inherent flexibility and because they easily conform to a 90° juncture. Felts and coated sheets do not easily conform to a 90° bend. When the membrane reinforcement is of a type that

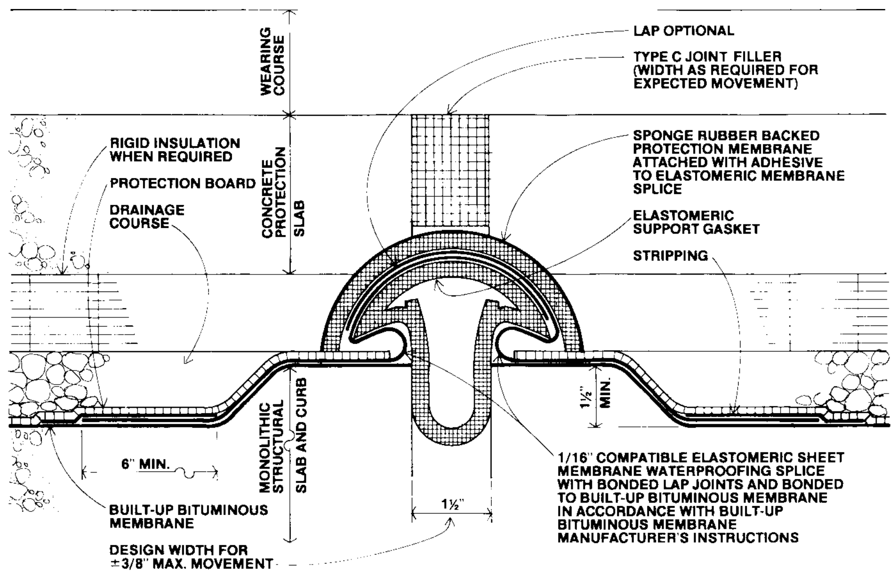

FIG. 5 Water Shed Concept Expansion Joint (see 9.8.7.2)

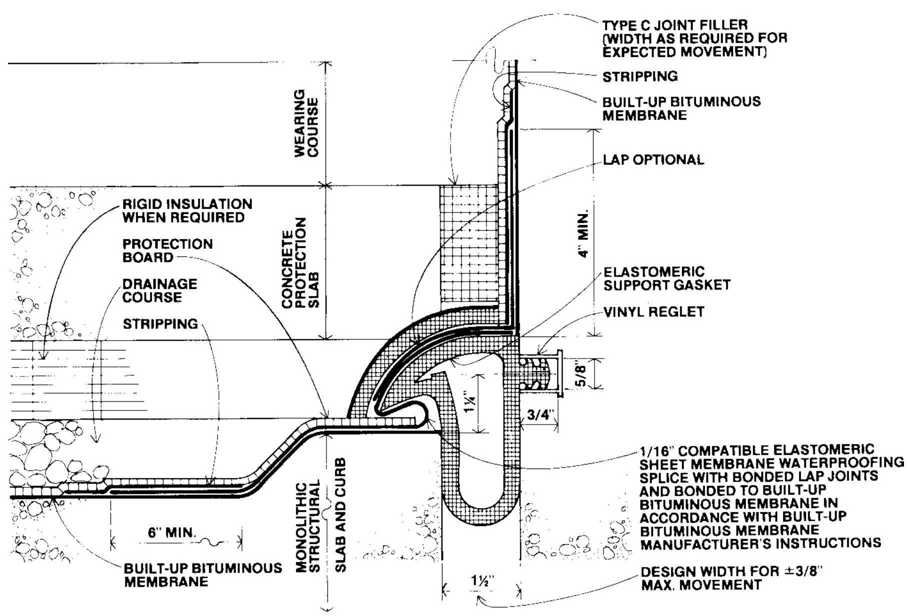

FIG. 6 Water Shed Concept Expansion Joint (see also 9.8.7.2 and Fig. 7 for Easier Gasket Installation Detail)

cannot easily conform to a 90° bend, a 75 by 75-mm (3 by 3-in.) fiberboard cant (Specification C 208) is required. The faces of the cant contiguous with the deck and wall shall be "buttered" with bituminous plastic cement and firmly set in a full bed of bituminous plastic cement before application of the membrane (see Fig. 3).

9.8.8.2 *Terminal Flashing Above Membrane*—Flashing membranes should extend above the wearing surface and the highest possible water level and not less than 150 mm (6 in.) onto the deck membrane. Flashing bitumens and reinforcements must be compatible with the deck membrane. These normally consist of a number of plies not less than that of the deck membrane and are tapered from flashing membrane thickness to the terminal edge at the top where they are secured to the substrate by nailing or by a horizontal transition. The terminal edge should be covered by metal counter or through wall flashing. Where the terminal edge is nailed to a wood nailer, greater protection is provided by stripping over the nailed edge before covering with protection board and the metal counter flashing. The latter serves only as a watershed and protection against construction damage or subsequent damage when it becomes vulnerable to finish wearing surface maintenance or physical abuse. Where the metal counterflashing can be punctured, torn, or easily cut and damaged, it is advisable to provide additional protection board over the face during construction and placement of the wearing surface (see Figs. 8-10). Fig. 8 shows how protection is provided above the finish wearing surface and against physical damage from maintenance of the wearing surface. Fig. 9 shows how protection is not provided as well as in Fig. 8 since the terminal edge is below the finish wearing surface but provides for simpler construction. Fig. 10 shows where a masonry or similar facing

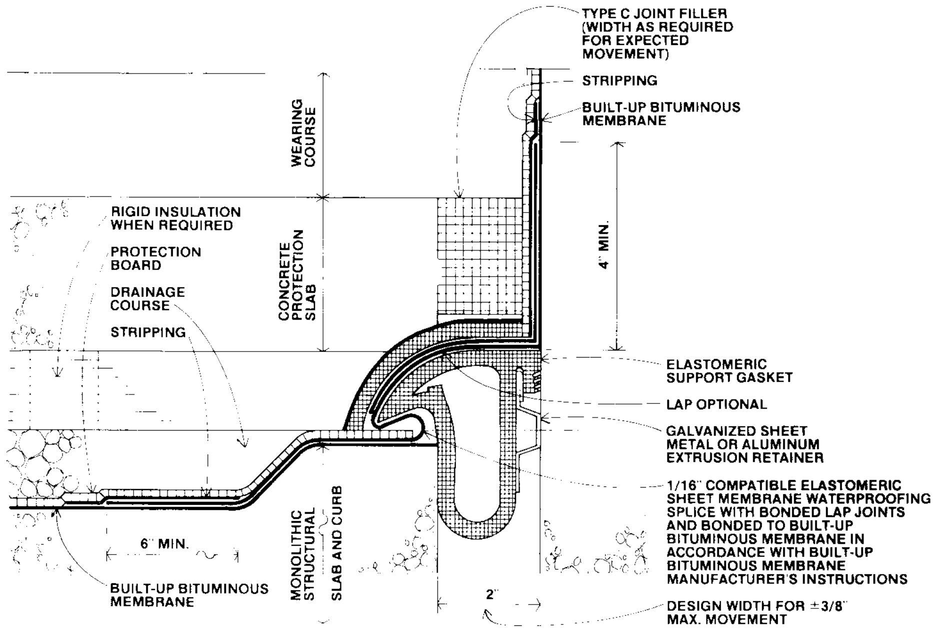

FIG. 7 Water Shed Concept Expansion Joint (see also 9.8.7.2 and Fig. 6)

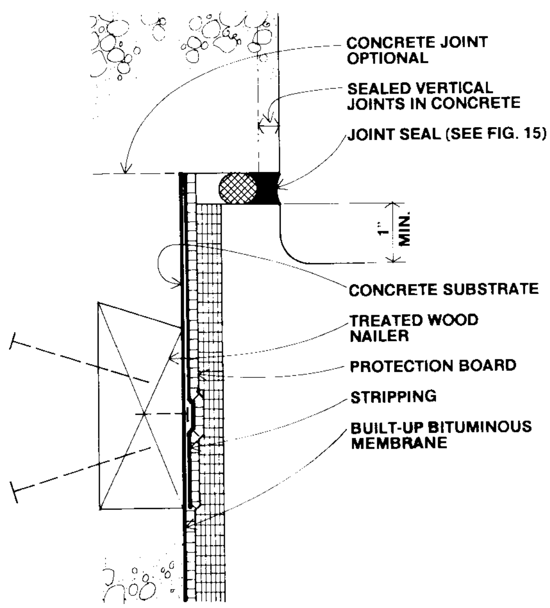

FIG. 8 Terminal Condition Above Finish Grade on Concrete Wall (see 9.8.8 and 9.8.8.2)

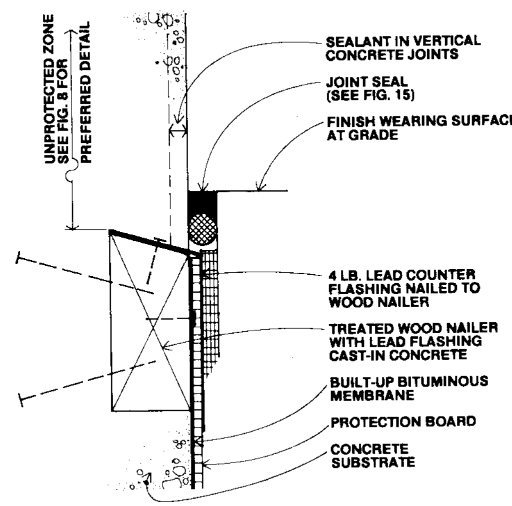

FIG. 9 Terminal Conditions on Concrete Wall Below Finish Wearing Surface at Grade (see 9.8.8 and 9.8.8.2)

material is used above the finish wearing surface over a horizontal concrete ledge.

9.8.8.3 *Terminal Flashing Below Membrane*—Turndown flashing of membranes must be treated similarly to turnup flashing, and of similar materials. The flashing should extend over the wall dampproofing or membrane waterproofing not less than 100 mm (4 in.).

9.8.8.4 *Termination at Drain*—Drains must be provided with a wide metal flange or base and set slightly below the drainage level. Metal flashing for the drain, if required, and the clamping ring should be set on the membrane in bituminous plastic cement. The metal flashing is stripped in to provide the primary seal at the periphery of the joint between the metal flashing and the membrane. The stripping consists of a minimum of two plies of membrane reinforcement and three applications of bituminous plastic cement (see Fig. 11).

9.8.8.5 *Termination at Penetrations*—Penetrations through the membrane such as conduits and pipes should be avoided whenever possible. Penetrations must be flashed to a height above the anticipated water table that may extend above the wearing surface. Proprietary devices are available, which will allow for pipe movements and which provide for the necessary flashing to be knit into the membrane similar to the drainage fitting. It is desirable to cant the surface of the substrate upward to lift the flashing above the surface of the membrane and thus apply the watershed principle (see Fig. 12).

10. Protection Board

10.1 The built-up bituminous membrane should be protected from damage before and during remainder of the deck

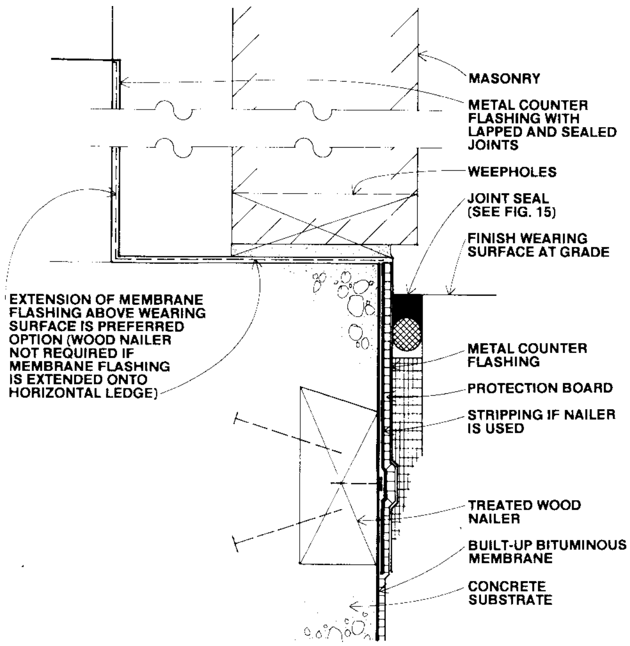

FIG. 10 Terminal Condition with Masonry Above Finish Wearing Surface at Grade (see 9.8.8 and 9.8.8.2)

construction. Protection board should be applied after the membrane is installed. The board also serves to protect the membrane from damage due to movement and penetration of materials above after the deck construction is complete. Protection board should be placed on the waterproofing membrane when the final mopping is being placed. It will then be adhered to the finished membrane.

11. Drainage

11.1 When the membrane waterproofing is covered over with a wearing course, it is necessarily assumed that water can and will reach the membrane. Otherwise, the membrane below the wearing course would not be needed. Drainage should then be considered as a total system from the wearing surface down to the membrane. The design of the drainage sub-system should be determined considering the probable interior and exterior temperatures, and the rainfall both direct and that which is wind diverted by adjacent structures. The wearing course may consist of such materials as stone, brick or tile, asphalt paving or blocks, and concrete, either as a finish or as a substrate for the above finish materials. Some of these materials can absorb varying amounts of moisture that may cause some to rapidly deteriorate if subjected to freezing temperatures. The plaza drainage system should be designed to minimize cyclic saturation of the wearing surface and its substrate. Since it would be undesirable to permit water to build up below the wearing surface, multilevel drains should be used with particular emphasis on rate of flow into the drain at the membrane level. Basically, the drainage system is analyzed for functioning both at the membrane level and at the wearing surface.

11.2 *Need for Drainage at Membrane Level*—It is essential that water be removed from the membrane level for the following reasons:

11.2.1 To avoid building up a pressure head against the membrane and particularly against the more vulnerable splices and joints in the system.

11.2.2 To avoid freeze-thaw cycling of trapped water that could heave and disrupt the wearing course.

11.2.3 To minimize the deleterious effect that prolonged undrained water could have on wearing course materials.

11.2.4 To minimize thermal inefficiency of wet insulation and of water under the insulation.

11.3 *Recommendations for Proper Drainage at the Membrane Level*:

11.3.1 Slope the monolithic concrete substrate under the membrane a minimum of 11 mm/m (⅛ in./ft).

11.3.2 Slope the monolithic concrete substrate under the membrane to drain away from expansion joints and walls.

11.3.3 Use a drainage course to increase the rate of flow to drains.

11.3.4 Avoid undrained pockets such as downward loops of flashing into expansion joints.

11.3.5 Use multilevel drains capable of draining all layers of the building deck. The drain should have an integral flange at least 50 mm (2 in.) wide for adherence and bonding with the concrete slab and to provide for termination of the built-up bituminous membrane with sufficient room for an adhesive bond. The flange should be set level with the structural slab surface.

11.4 *Drainage at Wearing Surface*—Drainage at the wearing surface is generally accomplished in one of two ways: (*1*) by an open-joint system permitting most of the rainwater to penetrate rapidly down to the membrane level and subsurface drainage system, or (*2*) by a closed-joint system designed to remove most of the rainwater rapidly by slope-to-surface drains and allowing a minor portion to gradually infiltrate down to the membrane level. Either system may be used over a lower-level membrane, the choice generally being governed by the materials desired for the wearing course. In each case, provision should be made to permit inspection and maintenance of drains.

11.4.1 *Open-Joint System*—The vertical joints in the horizontal wearing course could be left open (unsealed) provided the joints are less than 6.3 mm (¼ in.) wide and do not present a walking hazard, and if proper drainage is provided at the membrane level. This is generally accomplished by what is known as a "pedestal system" described in 11.4.1.2.

11.4.1.1 *Advantages and Disadvantages*—An open joint eliminates the cost and maintenance of sealant joints and compression seals. With this construction, precipitation and water from melting snow are discharged into the drainage void through the open paver joints. From there it drains over the surface of the insulation. That which reaches the membrane follows the insulation-joint drainage channels through secondary drainage perforations in drains at the membrane level. Another advantage is that the wearing surface can be designed to be level, but it is advisable for each individual panel to have a slight crown upward at the center to avoid possible ponded water for a period of time after a rainfall. An option would be a weep hole in the center of each panel. A disadvantage is the problem of debris that can collect in the joints and in subsurface drains. In the deck design, drain maintenance

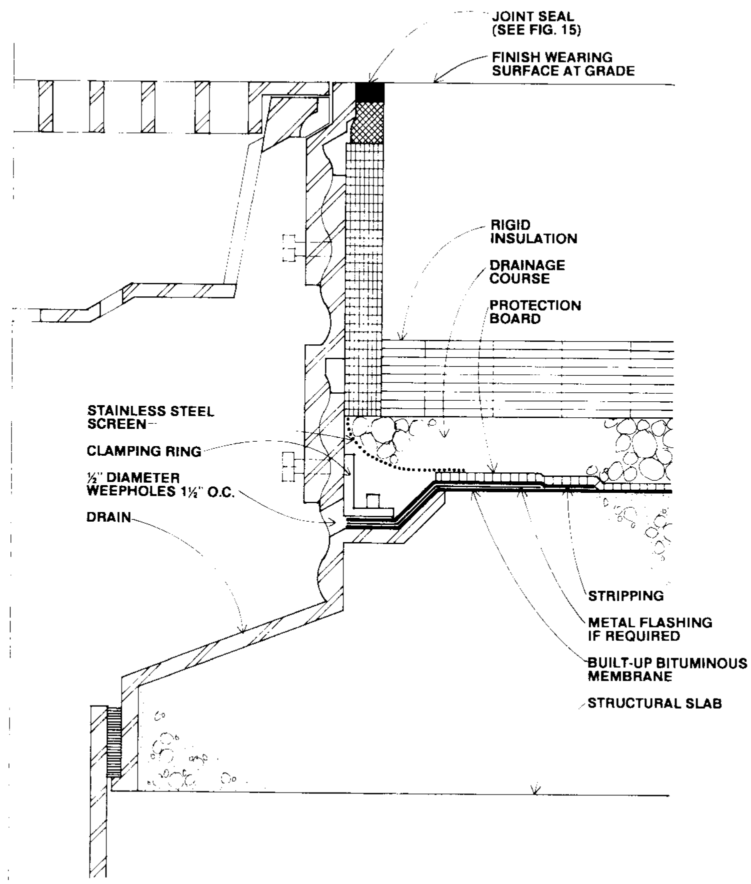

FIG. 11 Termination at Drain (see 9.8.8.4)

methods should be carefully considered. Another design problem presented by open joints in the wearing course is the possibility of inducing condensation on the interior ceiling of the space below the plaza deck. This potential problem can be minimized by placing the insulation as close to the waterproofing membrane as possible so that cold water is not continually taking the heat out of the structural slab.

11.4.1.2 *Pedestal System*—Pedestals are used to support relatively large areas of such materials as precast concrete slabs, stone slabs and prefabricated masonry. The space below the wearing course is left open and the varying height is accommodated by adjusting the height of the pedestals. Although left open, the joints should have resilient spacers to avoid problems of creeping or shifting panels. In a design where pedestals are intended to bear directly on the protection board, the designer of the system should consult the membrane and protection board manufacturers and determine that the imposed loads will not have damaging effects on the membrane and protection board under the service conditions anticipated. The amount of compression deflection expected should also be analyzed as to the possibility of creating uneven settlement of the wearing course panels. The open joint system is not well suited to areas subject to frequent vehicular traffic. Consideration should be given to the possible damaging effects on the membrane and protection board caused by initial installation of pedestals as well as subsequent traffic, emergency vehicles, or thermally induced lateral loads transmitted to the pedestals from the wearing course panels. In no case should the pedestals be placed directly on the membrane, and where insulation is required and the designer considers placement of the pedestals directly on the insulation, a type should be used that has, as a minimum, the following characteristics:

(a) (*a*) Extremely low absorptivity,

(b) (*b*) A specific gravity greater than water,

(c) (*c*) Sufficiently high compressive strength to resist reduction in thickness or penetration by the pedestals under the imposed dead and live loads,

(d) (*d*) Long-term resistance to water immersion and freeze-thaw cycling, and

(e) (*e*) Ability to sustain construction damage while work is progressing at the site until the final wearing course can be installed.

An insulating material meeting the above requirements would be difficult to find. The present state of the art dictates using a concrete protection slab over a suitable insulation (see also Section 14).

11.4.2 *Closed-Joint System*—A closed-joint system is normally used with a wearing course of relatively small prefabricated units, impractical to support on pedestals, or with larger areas of cast-in-place concrete. Dynamically moving joints in such systems are filled with sealant or compression seals. The wearing course materials are relatively impermeable. The wearing surface is sloped to drains, but provisions should be made for the infiltration of water to the membrane level and the subsurface drainage system.

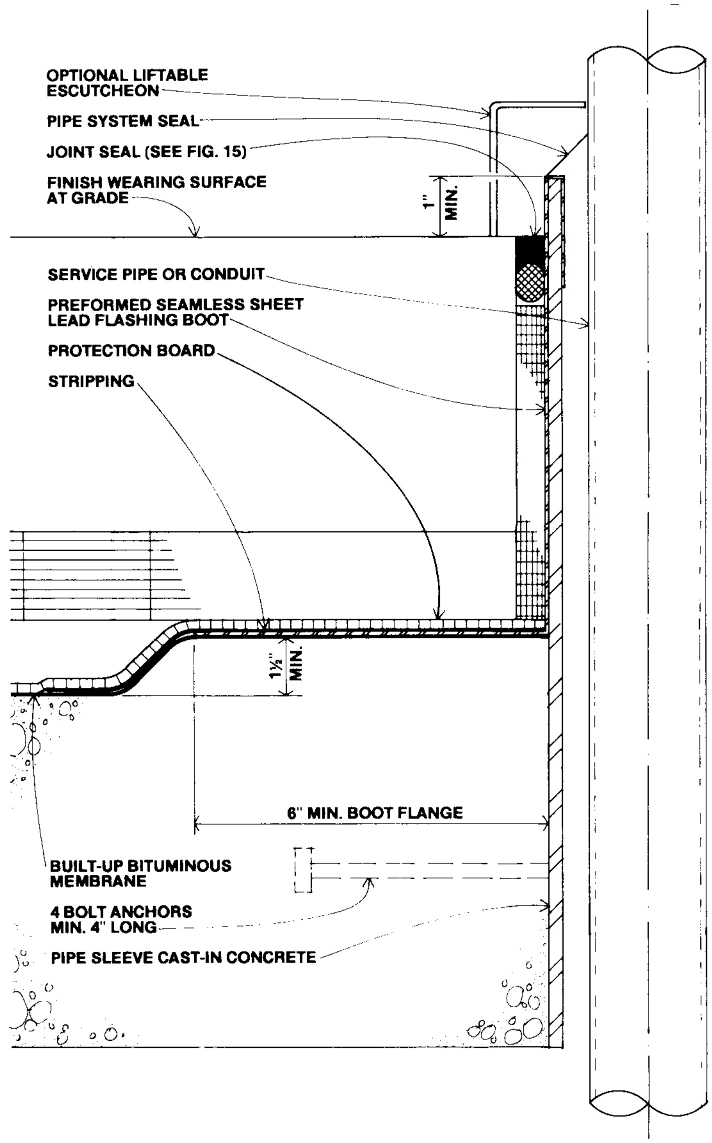

FIG. 12 Termination at Pipe Penetrations (see 9.8.8.5)

12. Drainage Course

12.1 Recognizing that water may infiltrate below the wearing course to be carried off on top of the membrane to the drains, a drainage course of washed, round gravel should be provided above the protection board, over the built-up bituminous membrane. This permits water to filter to the drain and provides a place where it can collect and freeze without potential damage to the wearing course. If concrete is placed as the wearing course, a minimum 0.1 mm (4 mil) perforated, polyethylene layer should be placed over the drainage course to prevent concrete from filling the drainage course voids. Also, the drainage course should be stabilized if the deck is to withstand vehicular traffic, because of the likelihood of lateral shifting under thrust, even without vehicular traffic, if free to move laterally on a sloping surface. One method of stabilizing aggregate, while still maintaining its percolation characteristics, is to use a controlled amount of epoxy binder, thoroughly mixed with the aggregate before installation. The quantity to be used is related to aggregate size and gradation. Several proprietary binders are available, and the manufacturer's instructions should be followed regarding their use and installation. A cement binder is also used for this purpose in a material known as no-fines concrete. Sufficient binder is necessary to stabilize the aggregate, but an excessive amount could overly restrict drainage through the voids that could become clogged with fine, loose particles. The drainage course aggregate should be washed, round river gravel conforming to gradation size no. 8 in accordance with Specification C 33 when tested in accordance with Method C 136.

12.2 If a geotextile drainage composite is used under vehicular traffic, it is important to select a type that can bear traffic loads.

13. Insulation

13.1 *General*—The selection of insulation, its quantity, and location in the system are influenced by the design of the deck system, the total environment under which it may be required to function, the physical or chemical properties, or both, of available insulating materials, the nature of the wearing course, and the loads to be supported. Each of these finish components will result in a small difference in the total heat resistance of this system and the dew-point locations for the changing seasons, all of which relate to the membrane location within the total system. A graphic analysis of the temperature gradient between the wearing surface and the interior should be made in order to determine the location of the dew point and its effect upon the total system and in regions of low temperature, the effect upon the drainage system. See Practice C 755 for temperature and dew point determination method.

13.1.1 *Temperature and Humidity Gradient*—Temperature and humidity gradients must be determined to check a system for location of dew point and temperatures of components, that is, membrane, drainage course, and surfaces (see Fig. 1). This is influenced by such factors as:

13.1.1.1 Type of occupancy of the space below the system.

13.1.1.2 Heat loss and heat gain restrictions.

13.1.1.3 Temperature and humidity levels to be maintained in the underlying occupied space.

13.1.1.4 Climatic pattern (temperature extremes), sharpness and frequency of thermal cycling, nature and amount of precipitation, ambient humidity pattern, degree and prevalence of sky cover, and exposure of the affected area.

13.1.1.5 Drainage pattern of design (over sloped surface to drains), percolation through system to membrane-covered substrate to drain, and combination of over-the-surface drainage and percolation to membrane-covered substrate.

13.1.1.6 Nature of wearing course (composition, unit size, pattern and stabilization), and

13.1.1.7 Relationship to adjacent structures (the reflection of radiant heat from an adjacent building (adds materially to the heat gain by direct exposure to solar radiation)), the cascading water of a heavy, wind-driven rain down the face of such a building increasing the flow on adjacent plaza drainage system.

13.2 *Properties Affecting Performance*—The only real basis for the determination of the performance of an insulation in plaza service is the spectrum of its physical properties, which are basic to the specific performance requirements of the insulation in the plaza system under the total ambience in which the insulation will be required to function. Such properties must be based upon tests, and be expressed in terms, which accurately reflect the service conditions which will be imposed upon the insulation in the specific plaza service. There is a dearth of testing procedures and significant catalog information that are essential to intelligent choice of insulation. However, such lack does not negate the crucial importance of basing the choice of insulation on the whole spectrum of pertinent physical and chemical properties of the insulation in light of the totality of service requirements.

13.2.1 *Coefficients of Thermal Expansion*—Insulations that will be located near the wearing surface should be characterized by low coefficients of thermal expansion. This becomes increasingly important with increase in the range of thermal cycling. When the membrane is over the insulation, and where it must provide dimensional stability in the face of rather large temperature changes, a low coefficient is essential. It cannot be ignored at any time when the insulation is close to the wearing surface.

13.2.2 *Moisture Sensitivity*—Insulations that will be in the path of water vapor movement, which are permeable to water vapor and which will be subjected to temperatures to condense this water vapor, must be dimensionally and structurally unaffected by the presence of internal water or use of a vapor retarder is required. In situations where insulations would be subjected to internal-condensing conditions, the impact of such water content upon thermal resistance of the insulation must be recognized. Insulations that are likely to be in substantial contact with free water in the drainage system should be as hydrophobic as possible. Also, the less water- and vapor-permeable and hygroscopic they are, the better they will serve. The presence of such water as it accumulates should have minimal effect upon dimensional, thermal, and structural properties, and service life. Moisture-related dimensional change not only affects the stability of the insulation, as an element in the structural composite, but it also has an effect on the maintenance of drainage channels that consist of open jointing of the insulation. The disposition to hold in suspension such water as is internally condensed, instead of permitting its free flow to drains has an impact upon thermal resistance and accelerates the degradation of most insulations. Important also, is the degree to which the insulation absorbs and holds free water. The typical plaza system is seldom dry, almost always contains free water, and is subjected to flowing water in quantity. Insulation with a hydrophobic character is an advantage. The constituents of the insulation should not be softened or degraded by water, and the adhesives and bonding agents used in its structure should not lose their bond strength under conditions of persistent wetness.

13.2.3 *Load Resistance*—Insulations must be selected in full recognition of their long-term ability to withstand projected loads. Compressive strength should be determined for periodic durations of loads at temperatures that are realistically representative of possible service conditions. Insulations to be used under traffic that involves horizontal thrust must possess the necessary strength in shear as well as in compression. In the event that an excessive vertical load is applied to an area of insulation, it is necessary that such a load should not fracture or unrecoverably deform the insulation. System design must make ample provision for distributing concentrated loads. Where vehicular traffic is anticipated, effects of fuel, oil, ethylene glycol, and ice-melting materials on the insulation should be investigated.

13.2.4 *Fungus Resistance*—Insulations should contain no nutrients for fungi, vermin, insects, or other organisms. Most insulated waterproofing systems will contain enough moisture to encourage growth of these organisms in the presence of nutrients. Fungi are sure to be active if the insulation contains any substances that can serve as nutrients. Vegetable fiber insulation cannot be used indiscriminately.

13.2.5 *Freeze-Thaw Resistance*—In those designs that locate the membrane between the insulation and the wearing course in climates that include below freezing temperatures, any moisture in the system will tend to move toward the underside of the membrane during cold weather. A relatively closed-cell cellular insulation with inelastic walls such as foamed concrete or cellular glass is vulnerable to freeze-thaw damage under these conditions, especially at the insulation/membrane interface. The cell walls of any cellular insulation that shall be used must be flexible and resilient with the volumetric changes accompanying the cylic freezing and thawing of water.

13.2.6 *Thermal Resistance*—The thermal resistivity of the insulation must be such that the thickness required to provide the necessary total thermal resistance can be accommodated in the available space. The amount of insulation required is determined by desired heat loss and heat retention characteristics. Under the full range of occupancy, temperature and humidity levels, the temperature of the deck must remain above the dew point of the building air. Generally, insulation tends to lose some thermal resistance as it ages.

13.2.7 *Compatibility*—Care must be exercised to be sure that the insulation and other materials in the system with which it is in contact are compatible. This is especially important when polymeric materials are used.

13.2.8 *Compressive Strength, Deflection, and Yield*—Compressive strength is determined by the dead load and the range of live loads to which it will be subjected and recovery from compression loads. Substrates are seldom perfectly planar. Insulation must not be fractured by profile irregularities. The ability to conform under compression or yield in flexure before fracture should be considered in selection of insulation.

13.2.9 *Shear Strength*—Strength in shear should be considered for designs in which the insulation will be required to transmit the shear stresses imposed by horizontal thrust of traffic to its substrate and in turn be transmitted to the structural slab. Unitary pavers and thermoplastic asphalt paving impose such stresses upon the insulation, the magnitude of which are determined by the type of traffic.

13.2.10 *Fatigue Stress*—Fatigue under imposed cyclic compression loading and structural relaxation should be considered for its effect upon durability.

13.2.11 *Dimensional Stability*—Dimensional changes and stability are influenced by the coefficient of thermal expansion and moisture sensitivity (see 13.2.1 and 13.2.2).

13.2.12 *Vapor Permeance*—Vapor permeance is significant only for systems that place the insulation on the underside of the structural slab.

13.2.13 *Depolymerization*—All synthetic polymers undergo depolymerization that is a joint function of the molecular structure, time, and temperature. There are great differences between the polymers in their rates of depolymerization.

13.3 *Location Analysis*—Basic to the location determination is the humidity pattern of the occupancy. In the case of high humidity occupancy, in temperature climates with cold winters, it is important that the insulation be so located as to protect the membrane from the thermal effects of outside temperatures. Otherwise, there will be condensation on the underside of the membrane under winter weather conditions (see Fig. 1). The temperature/humidity pattern in warm climates, where air conditioning is employed for much of the year, (where winters are mild) and to the extent that the membrane temperature reflects building interior temperature and the membrane temperature falls below the dew point of ambient air, there will be condensation on the exterior side of the membrane. If insulation is so located as to permit condensation at the membrane, provision must be made for the free flow of the resulting water to drainage. Winter in a warm climate presents few of the problems and eliminates most of the moisture-related problems that characterize temperature zone design. There are occasions when the choice of insulation type is primary to the design. Taking into account the conditions of occupancy and climate, the water sensitivity and permeability of the insulation will determine its proper location in the plaza system.

13.3.1 *Placement Below Structural Slab*—Insulation placed below the structural slab subjects the membrane to maximum thermal cycling. Membrane temperature will be affected largely by outside ambient air temperatures, modified only by (*1*) solar radiation absorption, (*2*) nighttime radiation from the interior to a clear sky, (*3*) distance of the membrane below the exposed surface, (*4*) runoff of melting snow or cold summer rain, (*5*) the heat capacity of the overlying system, and (*6*) the degree of openness in the overlying system. Unless ambient conditions and cure time have been such as to permit the evaporation of essentially all the uncombined water in the concrete, insulation cannot safely be applied to the underside of the deck. In such construction, if winter damage to slab and membrane is to be avoided, water vapor from a heated occupied space cannot be permitted to reach the underside of the membrane, nor the structural deck. Therefore, either a vapor retarder on the underside of the insulation or a highly impermeable insulation system would be required. However, this method would lock the concrete's free water in the deck where it would promote both concrete freeze-damage and membrane deterioration. If insulation must be applied to the underside of the structural deck, the concrete must be dry and the insulation vapor-tight. In freezing weather, any drainage channels above the membrane are vulnerable to damage.

13.3.2 *Principles Governing Selection for Placement Below Structural Slab*

13.3.2.1 *Fire Code Requirements*—When insulation is applied to the underside of the deck, its fire resistance and high-temperature behavior are important considerations. Newer fire code requirements substantially rule out the more adaptable insulations in this service. The approvable inorganic spray-on materials are of comparatively low thermal resistance, are highly permeable to vapor, and tend to be somewhat water sensitive.

13.3.2.2 *Vapor Retarder Requirements*—In temperate zones, for all but the driest of occupancies, water vapor will be driven through the insulation and structural deck to the membrane during most of the hours of the heating season. Normally, it would be advisable not only to employ an insulation of low permeance, but to surface it with a very low permeance vapor retarder. However, the free-water content of the concrete remains high when the plaza system is constructed, and the normal construction schedule makes no real provision for the effective drying out of the structural deck slab. It would therefore be inadvisable to sandwich the concrete between the membrane and the vapor retarder. It could be years before the heavy excess of water in the concrete would have been released. In the meantime, the excess water would be concentrated in the concrete under the membrane all winter long where it would be subject to freezing and thawing. In summer it would be concentrated in the insulation at the vapor retarder. To omit the vapor retarder would progressively add to the water content of the concrete during the winter. In warm climates, this problem is not encountered. During the entire air-conditioning season, the vapor drive is from the membrane underside toward the low-vapor-pressure interior. Without a vapor retarder, the concrete is effectively dried out during the first air-conditioned summer of occupancy. A vapor retarder here would have negative value except in instances of unusually high humidity winter occupancies. In general, the application of insulation below the structural deck should be limited to warm climates and to low-humidity occupancies in temperate climates.

13.3.2.3 *Use of Ventilated Plenum Between Insulation and Slab*—Under one design condition, the disadvantages in 13.3.2.2 (Vapor Retarder Requirements) are eliminated. This is one in which a ventilated plenum is located between the structural deck and ceiling and outside air is force-circulated through it during the entire heating season. In this system, the ceiling must incorporate an effective vapor retarder. Atop the ceiling, continuous insulation such as batt or loose type, is placed in thickness to provide desired total resistance. During the air conditioning season, the ventilation system is closed off tightly. This system could thus eliminate insulation wetness, freeze-thaw problems, and concrete-drying-out problems.

13.3.2.4 *Suitable Insulation Types*—For most applications, flammability and smoke potential are foremost among selection considerations. This rules out use of most organic foams and insulations containing a large proportion of organic fibers.

13.3.3 *Placement Between Structural Slab and Membrane*—Location of insulation between structural slab and membrane requires that the insulation serve as a structurally sound substrate for the membrane and a laterally stable base for the wearing course and its traffic loads. The wearing course must also be effectively laterally stabilized. Few insulations would serve as satisfactory substrates for a membrane for even occasional vehicular traffic unless the wearing course is effectively laterally stabilized. This design can prevent condensation in or on the underside of the structural deck if total thermal resistance of the system overlying the deck has been determined in the light of possible minimum outside temperatures. However, moisture will accumulate in the sandwich during cold weather to the extent of the free water in the concrete, the magnitude and duration of vapor pressure differential between occupancy and the underside of the membrane and the net permeance of the deck/insulation composite. This may be augmented by membrane or flashing discontinuities and by moisture that entered during construction. As long as weather conditions are such as to keep the temperature of the membrane below that of the top surface of the structural deck, this moisture will be held in the upper part of the sandwich if the insulation is capable of holding it capillarily. When weather moderation reverses the temperature differential, the free water will move into contact with the deck. This can result in a generally wet deck unless occupancy conditions are such that the free water will be evaporated before it reaches the underside of the deck by capillary action. If the membrane is to be placed on the top (weather side) of insulation, a temperature and humidity gradient should be calculated between the occupied area and the wearing surface to determine the necessity of providing a vapor retarder between the structural slab and insulation. If a hot-applied bituminous vapor retarder is required under the insulation, it shall be turned up at its perimeter and made continuous with the waterproofing membrane system. It is recommended that the insulation chamber be provided with drainage. If a cold-applied vapor retarder is considered, investigate compatibility, attachment, and adhesion with substrate and insulation. When thermal insulation is to be used below the membrane, embed it in a full and continuous application of hot bitumen applied to the primed concrete deck or to the vapor retarder. In light of the moisture migration mechanism inherent in this design, when employed in climates which include near freezing temperatures, several purposes would be served by the use of vapor retarders on the top surface of the structural deck. If the vapor retarder membrane is open to the drains serving the upper primary membrane, the second lower membrane could serve to (*1*) drain leakage of the primary membrane, (*2*) sharply restrict the entry of vapor from occupancy into the sandwich, (*3*) release to drain openings much of any vapor that does penetrate into the sandwich, and (*4*) prevent moisture condensed within the sandwich from entering the structural slab. In the event that such a second membrane is employed, it becomes especially important that the underside of the structural deck be and remain free and unfinished until the deck has lost nearly all of its free water.

13.3.4 *Principles Governing Selection for Placement Between Structural Slab and Membrane*—The insulation must be a structurally substantial material. It would appear mandatory to superpose a stable, reinforced concrete slab over other less structurally adequate insulation types as a suitable substrate for the membrane. If a concrete slab is provided over the insulation, and especially if a second vapor retarder membrane is not provided on the structural deck, the insulation should be such as to (*1*) remain substantially unaffected by water absorption, (*2*) be effectively resistant to freeze damage, and (*3*) be capable of sustaining imposed loads. This would appear to rule out those insulations that contain vegetable fiber. Neither insulating concrete nor a protective concrete layer over less structurally adequate insulation types are suitable substrates for the membrane (see analysis in 6.1 and 6.3).

13.3.5 *Placement Between Membrane and Wearing Course*—With the membrane placed on the structural deck and the insulation placed between it and the wearing course, a good, stable substrate is provided for the membrane with a minimum of thermal cycling. Compared to other types, this system makes possible a level, wearing surface in an open-joint system without surface runoff by providing for quick percolation to a sloped-to-drain structural deck. Under these circumstances the insulation, laid with butted joints for drainage through them, is applied over the membrane. An effective watershedding drainage system must be provided to prevent such water from becoming residual. A variation of this construction is the placement of the insulation atop a well-stabilized coarse-aggregate drainage system placed over the membrane (see Section 12). Under this design, the wearing surface is sloped to drain and has sloped secondary drainage at the membrane level. The drainage course under the insulation must be completely stable in itself to ensure the structural stability of the insulation-wearing course composite. If a reinforced concrete slab is cast over the insulation for protection and wearing course, or protection and substrate for the wearing course, it should be sloped for drainage and stabilized against displacement other than for thermal movement.

13.3.6 *Principles Governing Selection for Placement Between Membrane and Wearing Course*—To the extent that the design is such that it brings the insulation into frequent contact with water, it should be correspondingly water-insensitive. It should effectively resist water entry under prolonged immersion and persistent wetness. If no pedestal-void or coarse-aggregate drainage course separates it from the wearing course composite, it should be as thermally stable as possible because of the sharp thermal cycling to which its surface will be subjected. Full account should be taken of any horizontal-thrust stresses to which it will be subjected in service.

14. Protection or Working Slab

14.1 A major problem in the waterproofing of building decks is that the waterproofing is usually required early in the construction phase so that finishing materials could be installed in the occupied spaces below. In larger structures, construction may continue long after waterproofing of the adjacent building deck is required. Storage of materials as well as vehicular and pedestrian traffic can impose an intolerable strain on a membrane covered only with protection board (see Section 10). A concrete slab, intended for the final wearing course, installed shortly after the membrane is installed could provide the necessary protection but could also be abused and damaged. Methods by which the problem can be resolved are (*1*) temporary waterproofing requiring later removal, (*2*) temporary protection of the waterproofing (the quality and maintenance of which could cause disputes among the various interested trades), or (*3*) by a permanent concrete protection slab. This slab could be placed soon after the membrane, protection board, drainage course, and insulation, if required, have been installed. It would serve as protection for the permanent waterproofing materials and insulation below, provide a working platform for construction traffic and storage of materials (within weight limits), and provide a substantial substrate for the placement of the finish wearing course materials near the completion of the project when they would be less vulnerable to damage. The protection slab should be reinforced and be of sufficient thickness and strength to withstand the imposed loads. The slab would be the foundation substrate for the final wearing course materials and should be not less than 76 mm (3 in.) in thickness (see Fig. 1). Prefabricated asphalt panels obtainable in a variety of widths, lengths, thicknesses, and compositions may be considered as an alternative protective cover for the membrane where light limited construction traffic is expected. Temporary waterproofing protection during construction must be evaluated with the same importance as the final waterproofing system design concerning membrane (temporary flashings), construction traffic and its damage, drains, expansion joints, etc., as well as methods of repair and re-replacement or removal of the temporary protection system.

14.2 *Joints*—It is not necessary to seal the joints in the protection slab but only to provide premolded resilient joint fillers. The downward filtration of water through these joints should be permitted so that the water can be drained away through the drainage course. Since cracks, joints, and movement in the protection slab affect the wearing course, joints in the two should be aligned and coordinated. A protection slab module of about 6 by 6 m (20 by 20 ft) is reasonable to minimize cracking and to keep the joint size minimal. Larger modules would require increased thickness and wider joint widths, which would have to be continued through the wearing course.

15. Wearing Course

15.1 It is beyond the scope of this guide to cover in depth the many technical considerations of the wearing course except those that are directly governed by the part of the system below the wearing course. The major concerns are a stable support of sufficient strength, lateral thrust, adequate drainage to avoid ponding of water on the surface, and proper treatment of joints in the wearing course.

15.2 *Joint Treatment*—The main concern in the wearing course is the joints in which movement is anticipated. These should be treated as expansion joints (see Fig. 13 for variations) with the following considerations:

15.2.1 The matter of appearance can influence the joint spacing and the type of joint design to be used. Widely spaced joints must be wider than those with a lesser spacing. Joints from 100 to 130 mm (from 4 to 5 in.) wide designed to accommodate possibly 25 mm (1 in.) of movement may be undesirable from an appearance standpoint. Joint spacing is therefore usually limited to reduce the required width of the joint, even though it may be technically feasible to use a wider spacing.

15.2.2 Special problems are encountered with expansion joints in an open-joint drainage system. As all the joints are

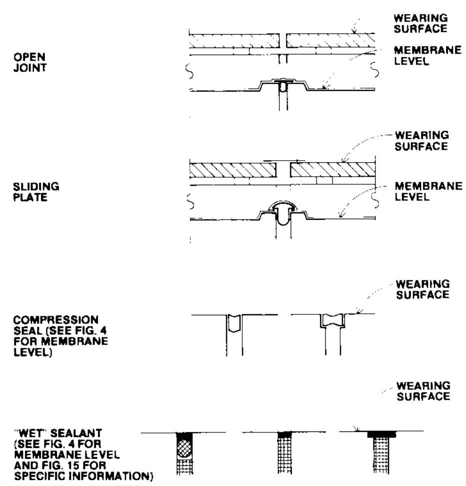

FIG. 13 Schematic Expansion Joint Concepts at Wearing Surface Level (see 15.2)

open, it would seem normal to have an open expansion joint. The design certainly is simple but could create a hazard for small heels that could be caught in the open joints. Attempting to provide a closed expansion joint in an open-joint drainage system also creates problems at the transverse joints when wet sealants are used. Compression seals or sliding plates could serve as solutions.

15.2.3 Sealed joints should be as durable and free of maintenance as possible. Premature deterioration of wet sealant joints due to faulty design or installation can cause hazardous, unsightly conditions and result in high maintenance costs.

15.2.4 The expansion joint in the wearing course, which of necessity, is over the structural slab expansion joint below, does not necessarily have to be designed to accommodate the same amount of movement as designed for in the structural slab expansion joint. The important question to consider in designing the expansion joint is whether the space below is to be heated and air-conditioned, or opened to the outside, as in the case of an underground, unheated parking space. If the space is to be heated below and insulated above, the greatest movement in the joint would occur while the structure is unfinished, uninsulated, and not heated or air-conditioned. After the insulation is installed and the space below is heated, the movement will be decreased significantly. With a controlled sequence of construction, a smaller and less costly joint can be used in the wearing course portion of the expansion joint even though the slab joint below may show greater movement during earlier construction. The key to this is to install the joint in the wearing course after the space below is heated. There is always the risk, however, that the mechanical system can fail or will be shut down and thereby cause greater movement than designed for. In the case of an open or unheated parking space below, the movement in the wearing-course portion of the joint will continue after occupancy and its width cannot be reduced. Intermediate joints in a protection slab are normally spaced at closer intervals than those in the latter, and their widths are related to the movement anticipated for them as well as their joint treatment.

15.2.5 Various proprietary compression seals are available that can be inserted into a formed joint under compression. Most of these, however, are not flush at the top surface and could fill up with sand or dirt.

15.2.6 Wet sealants are the materials most commonly used in moving joints at the wearing surface level. Fig. 14 shows various ways in which they may be installed. Dimension A is the design width dimension or the dimension at which the joint will be formed. The criteria normally used for determining this dimension with sealants capable of a movement of $\pm$ 25% is to multiply by 4 the maximum expected movement in one direction. Generally, this is expected to be about three fourths of the total anticipated joint movement, but if there is any doubt, multiply by 4 the total anticipated joint movement. It is better to have the joint too wide than too narrow. Dimension B (sealant depth) is related to Dimension A and is best established by the sealant manufacturer. Generally, B is equal to A for widths up to 13 mm (½ in.), 16 mm (⅝ in.) for widths up to 19 mm (¾ in.), and a maximum of 19 mm (¾ in.) for wider joints.

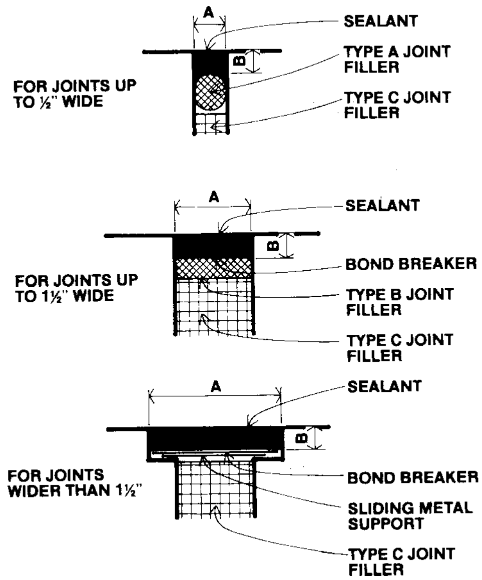

FIG. 14 Wet Sealant Details at Wearing Surface (see 15.2.6)

This allows some tolerance for self-leveling sealants.

15.2.7 A drainage course may be desirable to facilitate drainage below the wearing course, particularly under mortar and concrete. Geotextile drainage composites are available for this purpose. Under vehicular traffic it is important to select a type that can bear the traffic loads. See Fig. 1.

16. Earth Fill and Planted Areas

16.1 In areas of plaza decks where lawns or planting will constitute the finish surface, the design procedure is similar to that for the paved wearing surfaces, except that additional criteria must be satisfied by the plaza system. Certain requirements such as depth of soil, normal zone temperatures conducive to the growth of the proposed plant materials and ground cover, soil temperature at roof systems, length of daylight and shade, and pH of soil, will regulate the design of the complete system. As most plants cannot tolerate a water saturated soil, a drainage course is essential. To prevent the intermixing of the planting soil and the drainage course, and thus the impedance of water movement, the placement of a durable permeable filter above the drainage course is essential (see Fig. 15). Perforated drain pipes in the drainage course, connected with a storm water system, may be necessary to prevent water saturation of the soil. The thermal resistance of insulation must be sufficient to prevent early budding of plant materials in areas subject to winter dormancy. Normal loam soil suitable for planted areas will act as building insulation with a thermal resistance value (R) of approximately 0.61 m (2.0/ft) of depth.

17. Testing

17.1 Testing the membrane for leakage before additional materials are placed on it has the advantage of permitting corrections to be made without having to remove any of the materials placed above it. On the other hand, the placement of materials over it can sometimes damage an already tested membrane. One matter of concern is the flow characteristics of the water as it gravitates down to the membrane and then to the subsurface drainage system. A slow restricted flow, by design

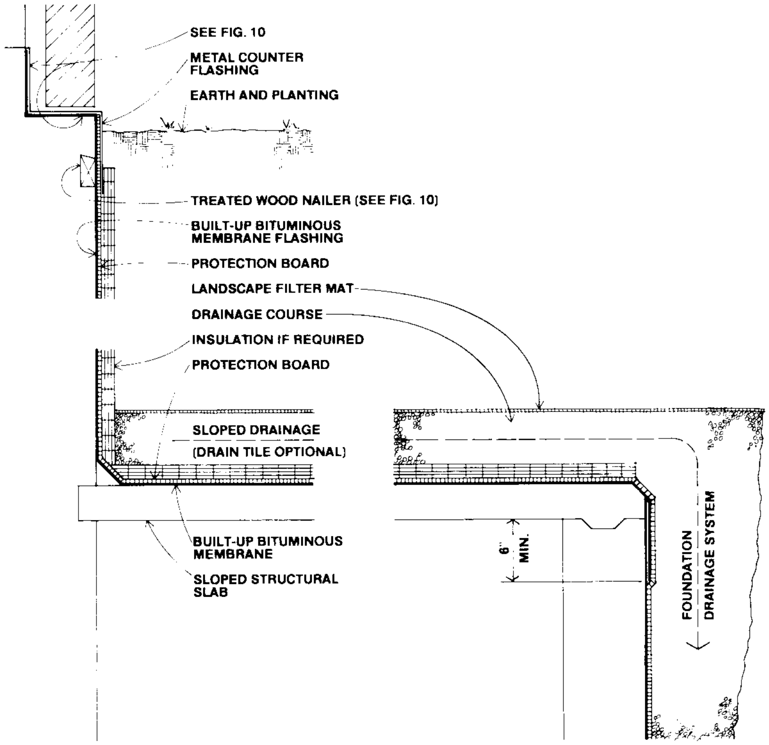

FIG. 15 Earth Fill and Planted Areas (see 16.1)

or improper construction, can cause buildup of water pressure above the membrane before it is drained away.

17.2 *Requirements*—When testing is desired, the requirements should be carefully considered to simulate realistic conditions. Some testing requirements are difficult to achieve. To be of significant value, it is generally felt that minimum requirements are a head of water of 50 mm (2 in.) for 24 to 48 h. With a sloping membrane, a considerable head of water and resultant weight on the structure could develop at the drain low points, depending on their spacing. Intermittent water dams above the membrane may be required to keep the head of water down to the desired testing height. The flood test should best be conducted on the waterproofing membrane alone, if proper protection can be provided prior to placement of the protection board. As an alternative, the test could be held with the protection boards in place.

17.3 *Value of Testing*—It is felt by some that sophisticated testing need not be performed since natural rainfall will reasonably have tested the system long before final acceptance. Others are of the opinion that testing of the membrane should be the option of the contractor who must bear responsibility for the membrane once it is covered. It would be desirable, however, to be assured of the integrity of the membrane before materials are placed over it so that schedules are not disrupted in the event repairs are required after the membrane is covered.

18. Keywords

18.1 building decks; membrane; waterproofing