A Low-slope Commercial Roofing Overview

by Steve Patterson and Madan Mehta

THE AESTHETIC ASPECTS OF A ROOF may or may not be important, but in functional performance, the roof is one of the most critical components of a building. Most energy loss from a building envelope (particularly from a single-story building) occurs through the roof. Disastrous wind-caused damage to a building begins when the roof fails to function as a structural diaphragm. An overload due to inadequate roof drainage may cause the roof to collapse. Water leakage, the most aggravating aspect of the malperformance of a building envelope, occurs primarily through the roof.

In fact, a large majority of owners' complaints with the design and construction of buildings are with roofs that leak. Although authoritative data are not available, it is estimated that nearly 50 percent of building construction lawsuits relate, in one way or the other, to roofing problems. The above statistic assumes significance when viewed in conjunction with the fact that the roof covering of a typical building is replaced every few years—one estimate gives a seven- to ten-year period. This replacement frequency would be unacceptable for any other envelope component—doors, windows, curtain walls, etc.

Water-shedding versus Water-resisting Roof

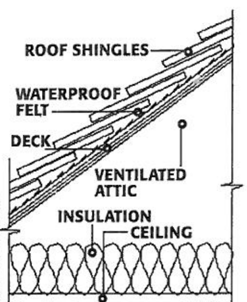

Figure 1

A DISCUSSION OF roofing issues must begin with its classification under two types: *water-shedding roof* and *water-resisting roof.* A water-shedding roof typically consists of small individual roofing units (shingles) that overlap each other (Figure 1). The roof surface must be sloped so that the water is shed off the roof by gravity. The slope must generate adequate gravitational force to overcome the forces generated by wind, head pressure, and capillary action that might push the water up the slope between adjacent shingles and cause the roof to leak.

A water-resisting roof consists of a continuous roofing membrane over a relatively flat roof surface. Although water ponding is generally to be avoided, a water-resisting roof has to be designed for a certain minimum depth of ponding (usually a minimum of two inches—50 mm—of water) that might collect on the roof in the event of a blockage in roof's drainage system. The roof membrane must therefore act as waterproofing membrane and be able to resist water pressure until the drainage system is able to function again. This period may be as long as several hours or a few days.

A water-shedding roof is generally referred to as a *steep roof*, and is commonly used for residential structures—individual homes, apartments, motels, etc. A water-resisting roof is referred to as a *low-slope commercial roof*, since it is generally used for commercial and industrial structures. Although a low-slope roof, by definition, has a slope of 3:12 (three units horizontal to 12 units vertical—a 25 percent slope) or less, it is generally a flat roof. However, even a flat roof is mandated by building codes to have a minimum slope of 0.25:12 (two percent).

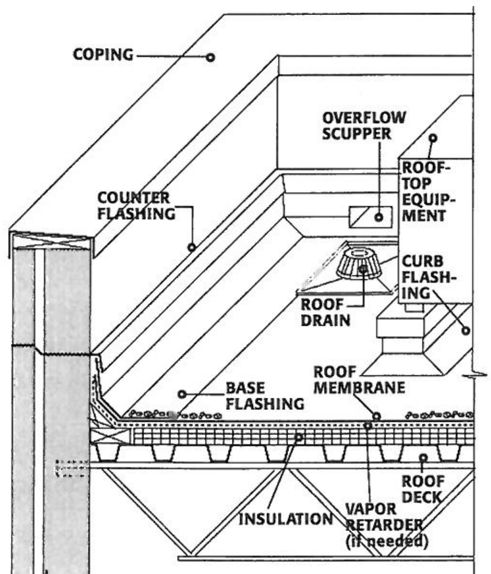

Figure 2

In a low-slope roof, the insulation is usually provided between the deck and the roofing membrane (Figure 2). In a steep roof, on the other hand, the insulation is provided above the ceiling, and there is usually a large ventilated attic space between the deck and the ceiling. The results of this fact are that the temperature range to which the roofing units in a steep roof are subjected is much smaller than in a low-slope roof. In a steep roof, the heat can easily travel from the roofing units to the attic space, from which it is extracted by ventilation.

In a low-slope roof, the location of insulation just below the membrane retards the escape of heat away from the membrane. Consequently, the roof membrane can become extremely hot during a summer afternoon. A roof membrane temperature of 155° F (68° C) on a 100° F (38° C) afternoon is fairly common in Texas. At night, the roof membrane temperature is lower than the air temperature due to nocturnal heat radiation from the roof to the sky. Typically under a clear night sky, the membrane is 10° F (6° C) cooler than the air temperature.

Thus, a 65° F (36 ° C) diurnal temperature differential of the roof membrane over and above the diurnal air temperature differential is not uncommon. In other words, if the

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Learning Objectives

After reading this article and completing the exercises, you will have:

1. learned the important components of a low-slope roof;
2. learned the major design and system selection criteria for a low-slope roof;
3. understood the processes of laying a built-up roof, modified bitumen roof, and a single-ply roof;
4. understood the advantages and limitations of a built-up roof, modified bitument roof, and a single-ply roof, and in which situation to specify each roof type; and
5. learned about the commonly used roof decks and roofing insulations.

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Components of a Low-slope Roof

- Roof membrane and surfacing
- Insulation
- Vapor retarder (if needed)
- Roof deck
- Base flashing and counter flashing
- Roof-top equipment and flashing
- Roof penetrations and flashing
- Roof drainage system—primary and secondary
- Expansion joints and area dividers
- Traffic pads

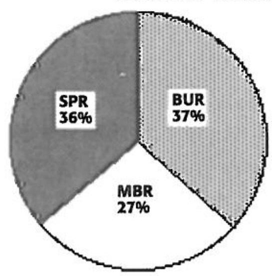
Figure 3

Major Design and System Selection Criteria of a Low-slope Roof

- Local climate and energy conservation
- Building type and size
- Type and number of roof penetrations
- Roof drainage
- Fire-safety
- Wind resistance
- Sound transmission
- Roof traffic
- Economics and roof warranties

Figure 4

Market Shares (1995) of Roof Membranes



EPDM roof consisted of 86 percent of single-ply roofs

APP and SBS each had 50 percent of MBR market share

Figure 5

minimum air temperature on a day is 75° F, and the maximum 100° F—a 25° F differential—the roof membrane may experience a temperature differential of nearly 90° F (50° C). Therefore, the yearly temperature differential of the roof membrane may well exceed 150° F (83° C).

Temperature differentials create expansion and contraction of a material, inducing fatigue—a major cause of a material's deterioration. That is why the durability of a low-slope roof membrane decreased substantially with the introduction of insulation on roofs. Several built-up roofs laid directly on reinforced concrete decks without any insulation have survived in excess of 50 years. Today, when high-R roof insulations are common, a 25-year life span is the upper limit for a low-slope roof membrane.

Low-slope Roofing—A System

Thermal factor is not the only factor that affects the durability or performance of a roof. Several other factors, such as chemical degradation of roof membrane by ultraviolet (UV) radiation and pollutants deposited on the roof (e.g., the oils emitted by kitchen exhausts); the effects of wind, rain, and hailstorm; chemical incompatibility between the insulation and the membrane and between the deck and the insulation; and roof drainage, etc., affect the performance of a roof substantially.

With several factors that affect its performance, and with several components that constitute a low-slope roof, roofing design must take a systems approach, in which the interaction between components (subsystems) and with external factors such as solar radiation, wind, rain, hailstorm, fire, etc., must be considered.

Figure 3 lists important components of a low-slope roof, and Figure 4 indicates the major factors that must be considered in roof system selection and design.

Low-slope Roof Types

Depending on the roof membrane used, a low-slope roof is classified as:

- Built-up roof (BUR)
- Modified bitumen roof (MBR)
- Single-ply roof (SPR)

As explained in the following section, a BUR membrane consists of several individual layers laminated into one membrane. An SPR membrane consists of a single layer. An MBR is in between BUR and SPR, and usually consists of two to three layers. A BUR is, therefore, the most labor-intensive roof, followed by MBR; an SPR is generally the least labor intensive.

It is interesting to note that according to the market survey conducted by the National Roofing Contractors Association (NRCA) in 1995, the above three roof types had an almost equal percentage U.S. market share (Figure 5).

Built-Up Roof: A BUR membrane consists of several layers of roofing felts adhered together by bitumen (asphalt or coal tar). In this combination of felts and bitumen, the bitumen is the waterproofing material. However, bitumen alone cannot be used, since, being a thermoplastic material, it becomes soft at high temperatures and begins to flow. At low temperatures, it becomes hard and brittle, and cracks. Thus, bitumen does not have the requisite tensile strength to withstand stresses imposed by the changes in temperature, deck movement, foot traffic, hail storm, etc.

Figure 6a

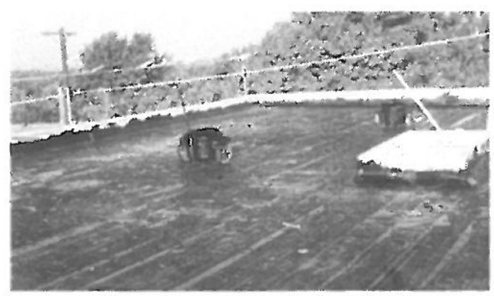


Figure 6b

Figure 6c

6a laying a BUR: joints between insulation boards being covered with strips of felt and mopping of bitumen, as a preparation for laying the first ply

6b All felt plies have been laid.

6c flood coat and surfacing operations

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The felts work as reinforcing material, giving the required tensile strength. Although organic felts (made of paper pulp) are still used, most BUR felts in contemporary low-slope roofs are made of fiberglass scrim, which is impregnated with bitumen. Thus, a fiberglass felt is black in color, and has tiny voids between individual fiberglass strands. In a BUR, a felt is laid over a mopping of bitumen, followed by second mopping of bitumen, and then the second felt, and so on. Thus, a number of felt layers (called plies), separated by moppings of bitumen, are necessary to build a BUR membrane—hence the name built-up roof.

A BUR normally consists of three to five plies. The greater the number of plies, the thicker and hence the stronger and more durable the membrane. The last felt is typically covered with a surfacing material to protect the membrane from the effects of weather (UV radiation, rain and wind erosion, and hail impact) and external fire. The most common surfacing material is gravel over a flood coat of bitumen in which the bitumen is poured over the roof (not mopped on). Figures 6a-c show a few stages in the laying of a typical BUR.

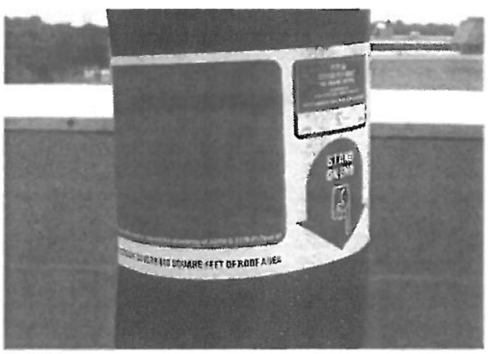

Figure 7

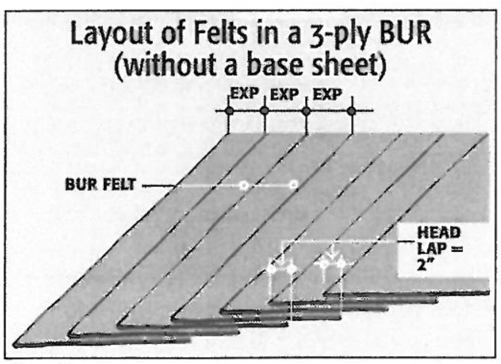

Figure 8

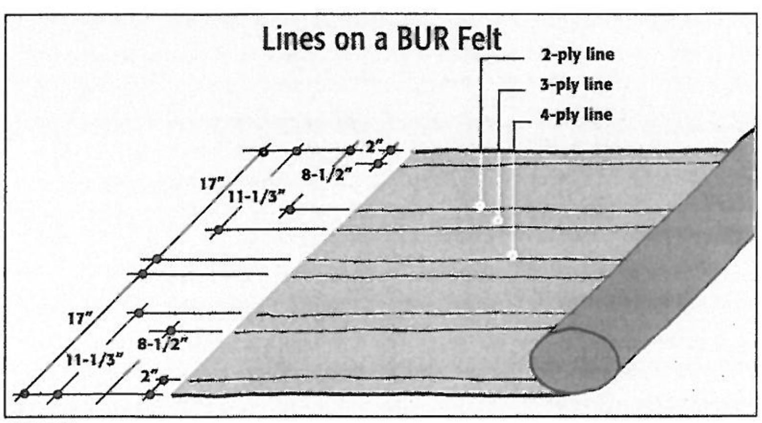

Figure 9

BUR Felts: According to the American Society of Testing and Materials (ASTM) standard D 2178, fiberglass roofing felts are classified as type III, IV, and VI, having a tensile strength of 22 pounds per inch (3.85 N/mm), 44 pounds per inch (7.70 N/mm) and 60 pounds per inch (10.51 N/mm) respectively. Types IV and VI are more commonly specified. Type VI, the strongest felt (Figure 7) is recommended where the membrane is subjected to a high tensile stress. These stresses may be caused by a high annual temperature differential that occurs in most parts of Texas, or a relatively flexible deck, or excessive impact on a roof due to hailstorm and/or foot traffic. In addition to using type VI felt, a thicker (four- to five-ply) BUR is recommended for the above situations, since a thicker membrane is stronger. Long-term roofing warranties by roofing manufacturers are usually contingent on the use of type VI felt. However, type IV felt is a little easier to work with.

Fiberglass felts are manufactured in rolls, usually three feet (914 mm) wide. They are laid in shingle fashion[1]: the upper felt overlaps the lower felt by a constant dimension. In a three-ply roof, there must be at least three plies under any roof point. Similarly, a four-ply roof must have four plies at every point.

The lap at the exposed end of a ply with respect to the lowest ply at that end, referred to as the *head lap*, is two inches (50 mm)—the industry standard (Figure 8). Under the head lap, there is one additional ply. Thus, there are four plies under a head lap in a three-ply BUR. The dimension EXP is called the *exposure* of the felt. EXP is related to the number of plies by the following relationship:

Table 1: Softening Point Temperatures and Maximum Roof Slopes of Various Asphalt Types

Asphalt type	SPT °F (°C)	Maximum slope
Type 1	135-151 (57-66)	0.5:12 (14%)
Type II	158-176 (70-80)	1.5:12 (12%)
Type III	185-205 (85-96)	3:12 (25%)
Type IV	210-225 (99-107)	6:12 (50%)

$$\text{EXP} = \frac{\text{Felt width} - \text{Head lap}}{\text{Number of BUR plies}}$$

Thus, in a two-ply BUR, EXP = 17 inches (432 mm); in a three-ply BUR, EXP = 11-three inches (288 mm); and so on. BUR felts are manufactured with two-, three-, and four-ply lines marked on them (as shown in Figure 9) to help roofers lay the felts correctly.

Bitumen: As stated previously, bitumen is used as an adhesive between BUR plies. Two types of bitumen—*asphalt* and *coal tar*—are used. Although both materials have the same appearance (both are black in color and highly viscous), and both are hydrocarbons, they are chemically different. Coal tar has a ring-like molecular structure, while the molecular structure of asphalt is chain-like. It is nature's law that a material with a ring-like structure weathers more slowly (is more durable) than the one with a chain-like structure. Thus, everything else being the same, a coal tar BUR is more durable than an asphalt BUR.

Asphalt is the waste product (residue) obtained from crude oil refineries. Although asphalt appeared much later in the roofing industry, it is the one that is commonly used today, because of its lower cost and greater availability. ASTM standard D 312 divides roofing asphalts into four types—types I, II, III, and IV. The most important property that

Figure 10

Figure 10 asphalt kegs at a job site

distinguishes one type from the other is the softening point temperature (SPT) of asphalt. SPT is the temperature at which the asphalt begins to flow. It is directly related to the weathering characteristics of asphalt. The lower the SPT, the more durable the asphalt, and the more easily the asphalt will heal any cracks caused by expansion or contraction in roof membrane. Table 1 gives the SPT of the four asphalt types.

Historically (when organic felts were in use), type I asphalt was recommended for extremely small slopes—less than 0.5:12 (four percent); type II asphalt for slopes less than 1.5:12 (12 percent); type III asphalt for slopes less than 3:12 (25 percent); and type IV asphalt for slopes less than 6:12 (50 percent). With the introduction of fiberglass felts, which have a greater slippage problem[2] than the organic felts, the asphalt commonly used these days for interply moppings is type III.

Type III asphalt is easier to use (has better workability) and can be heated with relatively less damage to a much higher temperature than types I and II. The higher temperature of mopped-on asphalt helps melt the asphalt already in the felts, providing a better fusion between the felts. Type IV asphalt can do the same thing better than type III, but its lower durability is a deterrent. However, type IV asphalt is commonly used with SBS modified bitumen membranes (see the following section), in which a higher asphalt temperature is an advantage.

Type III asphalt is also specified frequently for the flood coat for roofs in Texas, due to the higher ambient temperatures in the state. However, where low temperatures exist (and with the roof slope permitting), type I or type II asphalt should be considered for the flood coat due to their better weathering characteristics.

Type III and IV asphalts are typically supplied at job sites in solid paper-wrapped kegs (Figure 10); types I and II asphalts and coal tar are supplied in metal containers because of their lower SPT. The asphalt is melted in a roofing kettle on the ground and pumped up to the roof. Squeegees and buckets are used for mopping operations. Typically, 25-pounds of asphalt per roof square[3] is recommended for interply moppings and 65- to 75-pounds per roof square for the flood coat. The flood coat is poured on the roof, not mopped on, to provide the large asphalt quantity required for the flood coat.

Coal tar (also called *tar* or *pitch*) is obtained from the distillation of coal. While the distillate in this process is coal tar, the residue is coke. Coal tar is more expensive, its fumes are considered more hazardous to roofers, and it has a much smaller number of manufacturers than asphalt. It has a much lower SPT than asphalt, and hence it is more self-healing and more durable. Because of its lower SPT, tar flow is a major problem, particularly in the warm climate of Texas. Special detailing is required to overcome the flow and possible drippage of tar from the roof.

Although available in three types—types I, II, and III—types I and III are roofing tars. Type III used to be the more commonly used roofing tar, because of its lower fume hazard, but of late there have been been numerous performance-related questions with respect to type III. Therefore, the most commonly used tar these days is type I. However, note that coal tar fumes are hazardous, which must be duly considered before specifying a tar roof. Additionally, because of its low SPT, slippage can be a problem with tar BURs in Texas on slopes greater than 0.125:12 (one percent).

Due to its higher durability and greater water-resisting characteristics, a coal tar BUR may be considered for reroofing of an existing roof, where the roof slope is less than the mandated 0.25:12 (two percent), and where incorporating the required minimum slo on the roof is not a possibility.

Note that tar and asphalt, being chen cally different, are not compatible with ea other. They should not be mixed together. other words, only coal tar felts should be us with coal tar moppings, and vice versa. Ho ever, asphalt products are used for flashin on coal tar roofs.

BUR Surfacing: Although coal tar is ge erally considered more weather-resista than asphalt, both will degrade over a peri of time. The primary degrading agent is U radiation. Therefore, the final flood coat bitumen on a BUR must be protected. T best available protection is gravel. This n only blocks sunlight, but provides resistan against wind uplift and damage from fo traffic and hail impact. It also adds to the fi resistance of the roof. Gravel surfacing (4 pounds per square—190 Pa) on a BUR wit slope not exceeding 3:12 meets Underwrit Laboratory's (UL) class A rating[5] in the g neric category.

Other surfacing materials include ceran mineral granules, crushed-stone aggrega blast-furnace slag, and volcanic rock. Mine granule surfacing is the lightest surfacing b is more prone to damage as a result of fo traffic and wind uplift. Once the granul have come off, the bitumen is exposed, whi leads to a more rapid deterioration of t roof. However, granule surfacing is genera more durable than coatings, which requi constant maintenance.

Gravel-covered BURs have a long histo of superior performance in Texas. Howev gravel surfacing has some disadvantage Gravel surfacing can hide poor workmansh making roof inspection and roof repairs mo difficult. A mineral-surfaced modified bit men cap sheet, in place of the flood coat a surfacing, also provides an excellent prote tion for Texas climate, provided the cap she is counted as a sacrificial (additional) ply— replacement for the flood coat.

Cap sheets are applied after the last ply h been mopped. They are laid in roll roofi format—with two-inch (50 mm) overlaps the edges—not shingled with the rest of t plies. Typically, the cap sheets are laid usi a "mop and flop" technique, in which the c sheet is unrolled, laid upside down so that h bitumen can be applied, and finally turn

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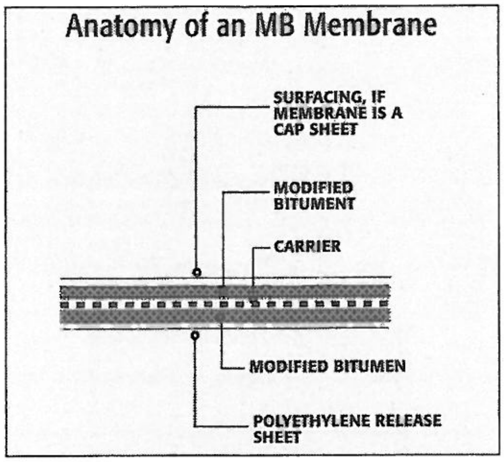

Figure 11

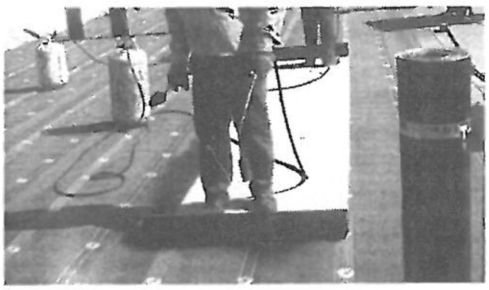

Figure 12

Figure 13

Figure 10 asphalt kegs at a job site

Figure 12 torch-applied APP membrane

Figure 13 field covering the flow-out with mineral granules in an APP membrane

over and laid on the roof. Cap sheets are particularly suitable for warm coastal (high-wind) locations, where a gravel (or aggregate) covered BUR may be undesirable due to the possibility of gravel (or aggregate) becoming wind-borne missiles. Wind-borne gravel has been identified as a source of much damage to buildings in high-wind locations.

Modified Bitumen Roof: A modified bitumen membrane may be regarded as similar to a BUR membrane, since the waterproofing agent is asphalt, to which polymers have been added to modify the asphalt's properties. The polymer's addition improves the membrane's ability to withstand standing water and UV radiation. It also adds pliability to the membrane, which improves the membrane's ability to withstand temperature extremes.

The polymer added to asphalt is either styrene butadiene styrene (SBS) or attactic polypropylene (APP). SBS is a synthetic rubber. Therefore, it is more flexible and more resistant to thermal shock than APP. An APP membrane is more resistant to UV radiation than an SBS membrane.

An MB membrane consists of a reinforcing mat, called the *carrier*, which is impregnated and coated with modified bitumen on both sides (Figure 11). The carriers commonly used are polyester or fiberglass or both. Polyester gives the membrane pliability and puncture and tear resistance, but increases problems related to shrinkage. Fiberglass provides tensile strength and increases fire resistance, but reduces the membrane's pliability.

The thickness of an MB membrane varies from 90 to 200 mil (2 mm to 5 mm). Therefore, an MB membrane is much thicker than an asphalt felt, which is nearly 40 mil (1 mm) thick. It is also non-porous, unlike the asphalt felt. Therefore, an MB membrane need only consist of two to three plies, as compared with three to five plies of a BUR.

APP Membrane: An APP membrane is typically applied using a propane torch (Figure 12). In this application, the heat from the torch melts the asphalt on the underside of the membrane. The felts are usually factory laminated with a thin polyethylene release sheet, to prevent stickiness in the roll. The torch burns the polyethylene sheet.

In laying the APP membrane, a certain amount of molten bitumen flows out at the edges. The bitumen flow-out verifies that the bitumen in the membrane has melted sufficiently to ensure the membrane's adhesion. If the APP membrane is a mineral-surfaced cap sheet, the flow-out asphalt must be protected with field-applied mineral surfacing (Figure 13).

The open torch used in laying an APP membrane presents a fire risk, which must be considered when selecting an APP membrane system. Fire extinguishers must be available on the roof, and perlite board cants (not wood cants) should be used with an APP system.[6] If plastic foam insulation is used with an APP sheet, it should be covered over by a non-combustible board—e.g., perlite board—before applying the APP membrane.

An APP membrane system is particularly suitable for a roof where the hot bitumen used in a conventional BUR (or in an SBS MBR) cannot be pumped from the ground to the roof such as on the roof of a high-rise building. The system is also suitable for a roof with numerous penetrations. A two-layer An APP membrane, the first layer a smooth-top membrane and the top layer a mineral-surfaced cap sheet, can provide the necessary redundancy in most situations.

Most manufacturers recommend lap seams of nearly four inches (100 mm) for APP membranes. A quality-control mechanism ensuring complete adhesion of the lap seams is fundamental to the success of an APP system. An APP membrane system is not generally specified for high-wind locations, since the failure of a lap seam can become progressively worse under high winds.

SBS Membrane: SBS membrane is typically mop-applied, like the BUR. Its advantage lies in its greater low-temperature pliability. It is, therefore, suitable for colder climates, where a conventional BUR (even an APP membrane) would become brittle sooner. It is also suitable for a roof deck that is subjected to abnormal movements. The asphalt used with SBS membranes may either be the same (unmodified) asphalt as for BUR, or the SBS-modified asphalt. The temperature of the asphalt must be higher than that required for laying the conventional BUR in order to melt the asphalt in the membrane. Therefore, type IV asphalt is the norm with an SBS membrane.

The best-performing SBS roof system uses three plies, consisting of a base sheet (on a nailable deck), a smooth SBS ply felt, and a granule-surfaced SBS cap sheet. Another option includes a two- or three-ply conventional BUR with a granule-surfaced SBS cap sheet.

Being fully adhered, an SBS system is suitable for high-wind regions if the top sheet is a granule-surfaced cap sheet. In low- or normal-wind regions, an SBS roof may be covered with a flood coat of (preferably modified) asphalt and gravel surfacing.

An SBS membrane roof applied with a cold adhesive is becoming increasingly popu-

Figure 14

Figure 15

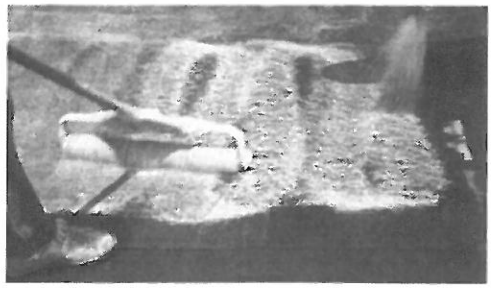

Figure 16

Figure 17

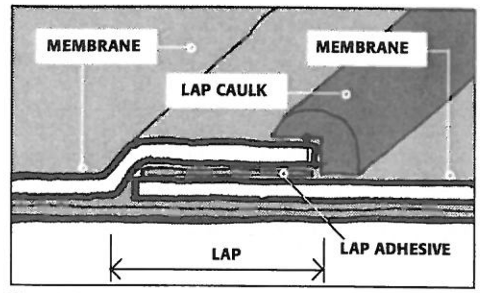

Figure 18

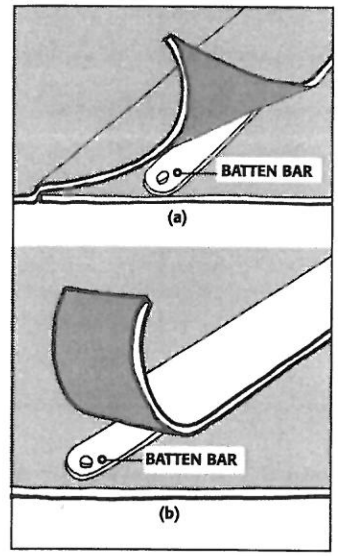

Figure 19

lar, particularly with high-rise roofs, where hot asphalt cannot be pumped up and the liquid propane cylinders used with an APP membrane may be hazardous.[7] Cold adhesives are generally asphalt-based, modified with petroleum distillates, so that the resulting product is not thermoplastic like the conventional hot-applied asphalt. A cold adhesive cures (hardens) as the distillate evaporates.

Cold adhesive is applied using either a squeegee or airless spray equipment. It is generally more expensive than a hot-applied SBS or BUR. It is also very sensitive to workmanship and hence less forgiving of on-site quality control lapses.

Single-Ply Roof: A single-ply roof (SPR) has only one ply of roofing membrane. Being only one ply, it is easier to lay. But that is also its disadvantage, since it does not have a second or third layer of defense against water penetration—a redundancy that is helpful in any waterproofing application. A single membrane puncture or split can lead to roof leakage in an SPR.

Other advantages of an SPR are: it does not require the cumbersome use of hot bitumen and it has a great deal of flexibility. A typical SPR can stretch by 300 percent up to failure, as compared with three percent for a BUR and 100 percent for an SBS MBR. Consequently, an SPR is very well suited for cold northern climates.

SPRs became popular after the 1973 oil embargo when the cost of BUR jumped dramatically. However, partly due to persistently depressed oil prices, and partly due to SPR's performance, SPR market share in the U.S. has remained virtually unchanged for a long time.

SPR membranes are made of polymeric materials, and are classified as *thermosetting plastics* (materials that do not soften on heating once they are cured) and *thermoplastics* (materials that soften on heating and harden on cooling over and over again). Thermosetting materials are synthetic rubbers. The commonly used synthetic rubbers for roofing are ethylene propylene-diene monomer (EPDM) and polychloroprene (neoprene). The commonly used thermoplastics are polyvinyl chloride (PVC), polyisobutylene (PIB), and chlorinated polyethylene (CPE). Thermoplastic membranes can be heat-fused together at the seams; synthetic rubbers must be adhered together with the use of adhesives.

Although each SPR membrane type has its own specific pros and cons, the most commonly used SPR membrane is EPDM. Therefore the discussion in this section is related primarily to EPDM roofs. Being essentially the same material that is used in automobile tires, EPDM roof membrane manufacturers are the same as the major tire manufacturers—Firestone and Carlisle.

Due to its physical characteristics, a typical EPDM membrane comes in much wider and longer rolls than a BUR felt or an MBR membrane. Although this is an advantage, since it reduces the number of lap splices, which reduces lap-failure possibilities, a large roll size also means that roof penetrations are difficult to work around. In fact, an SPR roof is generally more suitable for a roof with fewer penetrations (Figure 14). For a roof with numerous penetrations, an MBR or a BUR may be preferable.

Figure 14 Ideally, an SPR system is suited for a roof with a few penetrations.

Figure 15 the application of adhesive over the folded EPDM membrane and the substrate

Figure 16 application details of adhesive in a fully adhered EPDM membrane

Figure 17 pressing the EPDM membrane down after adhering it to the substrate

Figure 18 anatomy of a lap seam in an EPDM membrane

Figure 19 batten bars (a) in a lap seam and (b) under a splice tape

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The typical thickness of an EPDM membrane is 40 to 60 mil (1 to 1.5 mm), although some manufacturers make a thicker membrane. The color of the membrane may either be white or black, but the black membrane (or the black membrane with a white topping) is more durable. An EPDM membrane is inherently not fire-resistive, but fire-resistive EPDM systems are available. Although resistant to UV radiation, ozone, acids, and alkalies, an EPDM membrane is sensitive to oils and animal fats. Therefore, an oil-resistant membrane cover should be used over an EPDM membrane around kitchen exhausts.

Installation Systems of an SPR

An SPR membrane may be attached to the deck in one the following three ways:

- a fully adhered system;
- a mechanically fastened system; and
- a ballasted system.

In a fully adhered system, the EPDM membrane is attached by applying an adhesive to the underside of the entire membrane. Typically, the membrane is laid out flat on the roof according to a predetermined pattern. The membrane is then folded back on itself, and the adhesive applied to the back of the membrane (Figure 15) and also to the substrate with a roller (Figure 16), making the adhesive is not applied to the lap seams. After applying the adhesive, the membrane is unfolded, and the same procedure repeated for the other half of the membrane. Finally, the entire membrane is pressed down (Figure 17).

After adhering the membrane, the laps are cleaned with manufacturer's solvent, a lap adhesive is applied to the upper and the lower membranes of the lap, and the seam is pressed down with a roller. Finally, the seam joint is caulked with a continuous bead of caulk to protect the joint from physical damage (Figure 18). A fully adhered EPDM is labor intensive, but is particularly suited to a contoured roof and for a high-wind location.

In a mechanically fastened system, the membrane is laid loose over the insulation, which has already been anchored or adhered to the deck. The membrane is then anchored to the deck using manufacturer's fasteners at required spacings, which are a function of the wind loads on the roof. Typically, the fastening system consists of a continuous metal bar (referred to as the *batten bar* in the industry), through which the fasteners are applied. The batten bar is then covered by the lap seam (Figure 19a). The batten bars that are not under the seam are covered with an EPDM self-adhesive splice tape (Figure 19b).

A mechanically fastened system is subjected to point loads under the effect of wind loads, unlike the fully adhered system in which the loads are distributed over the entire membrane. Being dynamic in nature, the wind loads can make the membrane flutter, causing its premature failure at the fasteners. Therefore, care should be taken in specifying a mechanically fastened system in high-wind locations.

In a loose-laid ballasted system, the entire membrane is laid loose over the substrate. The lap seams are adhered together in the same way as a fully adhered or a mechanically fastened system. The membrane is anchored to the deck only at the roof perimeter. The entire membrane is then covered with gravel, 3/4 inch to 1-1/2 inch (19 to 38 mm) in particle size, to provide a total weight of nearly 15 pounds per square foot (720 Pa) over the membrane.

The ballasted system is the most economical SPR system, since it requires no material and labor cost in anchoring the system, except at the roof perimeter. The ballast adds to fire resistance and weatherability. The system is well suited for roofs of low-rise buildings in normal-wind regions. It is also suited for reroofing of an existing roof, since chemical compatibility between the existing and the new roof is less of a concern. A loose-laid cover board over the existing roof is basically all that is needed to separate the new roof from the old. However, the structural capacity of the existing deck to withstand the ballast load must be carefully verified.

A loose-laid ballasted system is not recommended for slopes greater than 1:12 (8 percent). The dead load due to the ballast adds to the structural cost of the deck, particularly in long-span buildings. In windy conditions, ballast migration is a serious problem, which can jeopardize the fire and wind uplift ratings and durability of the roof. A ballasted system is, therefore, not recommended for high-wind locations. A ballasted system's biggest weakness, however, is that due to thermal expansion and contraction of the membrane, all the stresses are concentrated at the perimeter, which can result in fastener failures at the perimeter.

Insulation in a Low-slope Roof

In a low-slope roof, the insulation is the second layer from the top—below the membrane, except in an inverted roof system (rarely used), in which the insulation is above the membrane. A low-slope roof insulation must be rigid to withstand foot traffic and hail impact. Although there are several types, the two commonly used low-slope roof insulations are:

- rigid board insulation—consisting primarily of plastic foams, high-density fiberglass, wood fiberboard, and perlite board; and
- foamed concrete.

Rigid Board Insulations: The two more commonly used plastic foam insulations are polyisocyanurate (ISO) and extruded polystyrene (EPS). Out of the two, ISO has gained much greater acceptance in the roofing industry, since it is more fire-resistive and can withstand higher temperatures than EPS, and provides a higher R-value per unit thickness than EPS. In fact, ISO provides the highest R-value per unit thickness (unit R-value) among all roofing insulations.

EPS is not chemically compatible with petroleum products. Extreme care must be taken in using EPS with both BURs and MBMs. ISO can be used with BURs and MBMs. However, ISO should be covered over with a layer of perlite board or wood fiberboard, so that the asphalt is applied directly to the perlite board or wood fiberboard, not to ISO. Adding a layer of perlite or wood fiberboard above ISO, with the joints between the two insulation boards staggered, eliminates thermal bridging, increasing the insulation's thermal efficiency. It also reduces the splitting of the membrane.

Both wood fiberboard and perlite board provide a lower unit R-value than the plastic foams. Since wood fiberboard is combustible, it should not be used with an APP membrane roof. Being noncombustible, perlite board is most commonly used today over ISO as an underlayer for BUR and MBM roofs. It is also chemically compatible with most roofing membranes. However, it is usually not recommended with fully adhered EPDM.

High-density fiberglass provides a higher unit R-value than perlite or wood fiberboard,

Figure 20

Figure 21

Figure 20 foamed concrete being poured on a roof

Figure 21 bead boards used with foamed concrete

but lower than ISO and EPS. It is noncombustible and generally compatible with most roofing membranes. Being soft (low compressive strength), it should be avoided on roofs with excessive foot traffic, particularly if a thick layer of fiberglass is used.

Foamed Concrete: Another insulation that is gaining acceptance in Texas is foamed concrete. Foamed concrete[8] is made from a Portland cement-water slurry to which a foaming agent is added to introduce air bubbles in the mix. The mixture is pumped on the roof and laid like (a high-slump) concrete (Figure 20). Major advantages of foamed concrete are: (i) slopes to drains can be created with relative ease; and (ii) and the entire insulation layer is monolithic and jointless. It is ideally suited over a metal deck,[9] with which it functions as a deck-insulation composite.

Since foamed concrete's unit R-value is low (lower than plastic foams), molded polystyrene boards (bead boards) are sandwiched between two layers of foamed concrete to increase the insulation's effectiveness. Bead boards used with foam concrete are provided with holes (nearly two inches or 50 mm in diameter) to provide a mechanical key between concrete and the boards (Figure 21).

After the foamed concrete is sufficiently dry and hard, a base sheet (which is an asphalt saturated and coated fiberglass felt) is anchored to the insulation using manufacturer's fasteners and disks. BUR or MBR felts can then be mopped over the base sheet.

With the exception of a few cold or wet days, the climate in Texas allows foamed concrete to be laid throughout the year. A major limitation of foamed concrete is the height of the roof to which it can be pumped without unduly raising its cost.

Roof Decks

Since it supports all the components, the deck is the single most important component of a roofing system. It should not only be strong enough to support all the dead loads and live loads, but also provide a stable substrate for the membrane and the insulation. In other words, the deck should not deflect excessively under the loads, since an excessive deflection will cause greater water ponding, adversely affecting the roof, which may even lead to a progressive collapse of the roof.

Structural expansion joints, which are necessary for the dimensional stability of the entire structure, are also necessary for the integrity of the roof. They should be provided as needed—approximately every 150 to 200 feet (45 to 60 m)—particularly where there is a major change in building geometry, such as at an L-junction, T-junction, or a U-junction of a building.

In addition to expansion joints, roof area dividers may be needed. Unlike an expansion joint, which divides the entire structure (including the deck) into two independent structures, a roof area divider divides the deck only in two parts, but does not penetrate the deck. It is usually needed where the two parts of the deck will behave differently, due to the deck geometry or the deck's structural framing.

In the roofing industry, roof decks are classified as *nailable* or *nonnailable*. Plywood and steel decks are nailable decks, since insulation or a base sheet is mechanically fastened to them (nailable also implies screwable). Reinforced concrete or prestressed concrete decks are examples of nonnailable decks, since insulation or a base sheet must be mopped to them.

Metal Decks: The most commonly used deck for commercial buildings is the metal (painted or galvanized steel) deck with a ribbed profile. It should not be less than 22-gauge. Virtually all roofing insurance requirements—Factory Mutual (FM) for wind uplift considerations, and Underwriters Laboratory (UL) for fire resistance requirements—are based on 22-gauge thickness of steel decks. Fastener retention improves dramatically with the increase in the gauge of the deck.

Since a metal deck can expand and contract substantially due to temperature changes, it must be insulated at the top. The insulation not only stabilizes the deck thermally, it also provides a flat surface for the roofing membrane, since a deck's own surface is unsuitable to receive the membrane directly over it. The insulation must be strong enough to span the distance between the ribs.

As indicated previously, it is always better to provide insulation in two layers, with the joints of both layers staggered. The first insulation layer should be mechanically fastened to the deck, and the second layer fully adhered (mopped) to the first layer. This insulation attachment method protects the membrane from coming into contact with the head of the fasteners. It also prevents short circuiting of heat transfer through the fasteners. The staggering of joints between insulation layers increases the strength of the membrane-insulation composite.

A joint in the insulation must be placed over the flange of the deck. This may require cutting of the insulation, which is obviously wasteful of insulation. Alternatively, a 22-gauge metal plate should be screwed over the ribs of the deck under the joints in the insulation. The size and spacing of the fasteners must be adequate to resist the wind loads, and should conform to the appropriate Factory Mutual standard.

Reinforced Concrete Decks: Reinforced concrete (RC) decks are commonly used for commercial buildings, particularly high-rise structures. Roofing or insulation can be fully adhered (mopped) to the deck. The most common procedure is to prime the deck first and then mop the deck with hot asphalt and apply the insulation or the membrane. Priming the deck cleans the deck of dirt, which generally cannot be removed by other means such as sweeping or brushing.

The residual moisture in concrete can, however, create problems of blistering when the hot asphalt is applied. This is particularly

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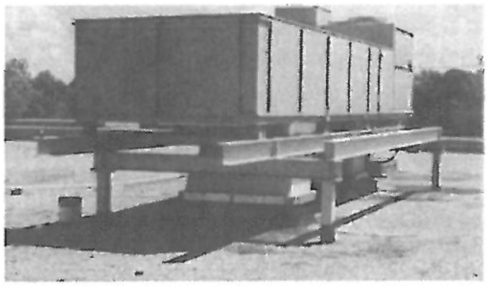

Figure 22

Figure 22 Rooftop equipment supported on a frame must have adequate clearance (18 inches to 450 mm or more) above the roof surface.

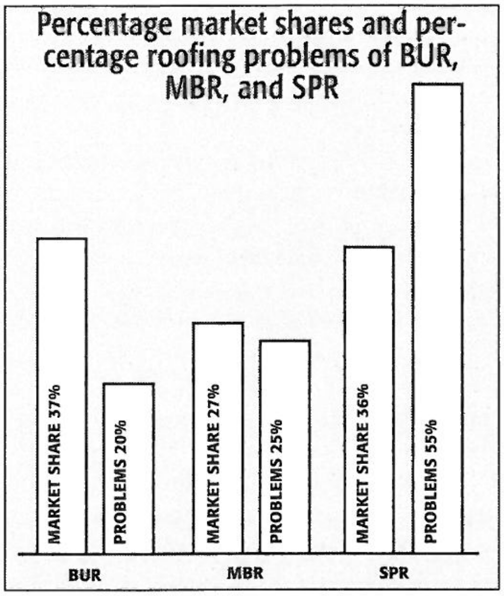

Figure 23

problematic when a plastic foam insulation (such as ISO) is placed over hot bitumen. Being nonporous, ISO does not allow the water vapor produced from the blisters to escape. One way to limit this problem is to use fiberglass insulation as the first layer, which helps dissipate the moisture. ISO or other insulation can then be mopped over the fiberglass insulation.

There are mechanical fasteners and nonasphaltic adhesives available that are suitable for RC decks, for which roofing material manufacturers must be consulted. Some RC decks, particularly in high-rise buildings, are post-tensioned. Using mechanical fasteners over such decks may be risky, since the post-tensioning cables are under high tensile stress. Roofing fasteners may penetrate the plastic sleeves housing the post-tensioning cables, adversely affecting the structural capacity of the deck.

Precast Concrete Decks: Precast concrete decks generally consist of single tees, double tees, channels, and hollow-core slabs. Because of excessive surface irregularities in a precast concrete deck, particularly at the joints, a precast concrete deck must be covered with lightweight concrete screed to provide a reasonably level surface—suitable to receive the roofing. The screed must be reinforced throughout the deck. Failure to do so may result in roofing failure at the joints. Insulation and membrane may be applied over the concrete screed as in a RC deck.

Plywood Decks: Plywood decks, although not as common as the other decks, are also used for commercial and industrial buildings. A plywood deck is a nailable deck. However, screws with disks, similar to those for metal decks, are recommended. Although insulation may be solidly adhered (using hot asphalt), it is recommended that the first layer be fastened and the second layer mopped. If the first insulation layer must be mopped, fasten a base sheet over the plywood, and then mop the insulation over the base sheet.

Unlike other decks, plywood can be severely damaged by water. Therefore, good detailing and extra quality control measures at the site are essential for a plywood deck. Using the American Plywood Association's (APA's) "exterior" grade plywood is desirable.

Flashings and Other Roof Details

Flashings at the base of parapets, at curbs around rooftop equipment, at the edges of the roof, and around penetrations through the roof are critical, since an improperly or inadequately flashed roof will eventually leak. Flashing and other details such as those for parapet copings, expansion joints, area dividers, roof drains, etc., have been developed by the National Roofing Contractors Association (NRCA) for various situations. These details (see the bibliography at the end) are now regarded as the industry standard, and most major roofing material manufacturers have accepted them with minor modifications. These details should form the basis for any roof design.

An important point worth highlighting here is that, as far as possible, rooftop equipment should be supported on a steel frame base resting on steel legs, giving at least 18 inches (450 mm) clearance, to allow for an easier application of the roof membrane under the equipment (Figure 22). Round pipe supports to the supporting frame are preferable over rectangular tube supports, as the former are easy to flash.

Design for Drainage, Wind, and Fire

Drainage, wind uplift, and fire resistance are some of the other important design considerations of roof construction. Drainage design is typically based on the local building code, wind uplift design on Factory Mutual requirements, and fire resistance on the Underwriters Laboratory requirements. Although not covered here due to space limitations, these aspects are integral to any roofing design.

General Roof Design Guidelines

Although every roof is different, requiring an independent design solution, a few general design guidelines can still be made. The important ones are:

- *Same manufacturer:* Roofing materials (membranes, flashings, insulation, fasteners, adhesives, etc.) are highly manufacturer specific. Therefore, use the same manufacturer's materials throughout the roof, unless written permission for the substitution of a material is obtained from the manufacturer.
- *Major roofing manufacturer:* As far as possible, use a major roofing manufacturer's materials.
- *Manufacturer-specific details:* Try to follow manufacturer-specific details for base and curb flashings, penetration flashings, expansion joints, area dividers, wall copings, etc. In case the manufacturer does not have a detail for a condition, follow NRCA-developed details before developing your own detail.
- *Time-tested products and systems:* The best performance test of any roofing system is its test on several actual roofs. Unfortunately, it takes 10 years or longer to field test a new product, and several years more to test its improved versions. Therefore, be careful in specifying a new system or product. This fact is endorsed by a recent (1995) NRCA performance survey of roofing membranes, in which the BUR system, being more than a century old, was found to be least susceptible to major problems, as compared with MBR or

SPR systems. The survey reports that although BUR market share was 37 percent, only 20 percent of roofing problems occurred in buildings with BURs. By comparison, SPR market share was 36 percent, but it had 55 percent of roofing problems (Figure 23).

- *Lifecycle cost vs. initial cost:* Examine the lifecycle cost of the roofing system, not just its initial cost, since a roof will probably be replaced several times during the life of a building. In examining the lifecycle cost, include the cost of all materials that will be replaced, including the insulation, since in most roofing systems insulation will need replacement along with the membrane.
- *Roof maintenance:* Every roof will require some degree of regular maintenance. Make the owner aware of the necessary maintenance schedule.
- *Roofing warranties:* Warranties (or guaranties) came into the roofing business as sales tools used by the roofing manufacturers. Once a manufacturer introduced better warranty terms to the owners, other manufacturers had to follow suit in order to stay competitive. Most earlier roofing warranties were of questionable value. In fact, they limited the manufacturer's liability rather than providing a protection to the owner or the designer. The competition among roofing manufacturers and a better informed design community has led to better roofing warranties.

The two critical issues in a warranty are the penal sum and the workmanship. Some warranties have a limit on the penal sum—a cap on the amount that the warrantor will pay in the event of a roof failure. This is generally in terms of a dollar figure, say $100 per roof square. Other warranties may have limits based on the original materials cost, i.e., not to exceed the cost of the original installation. With ever-increasing roofing material and installation costs, such a warranty may be worth very little when an actual failure occurs.

The best roofing warranty is the one that has no limit on the penal sum—referred to as a no-dollar-limit (NDL) warranty. Such a warranty guarantees to pay for all the repairs (material and labor), regardless of the cost involved. It is usually given by a manufacturer as a full-system (FS) warranty. In an FS NDL warranty, all materials and specifications must be per the manufacturer, and only a manufacturer-certified and approved contractor can install the roof.

Although an FS NDL warranty is ideal from an owner's or a designer's point of view, it is expensive, since the manufacturer usually forces the use of expensive materials. The additional cost of on-site quality control is also built into the warranty.

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Self-Test Questions

1. On the average, which of the following roof assemblies is least prone to major failures? a) built-up roof b) modified bitumen roof c)single-ply roof. ________

2. In a three-ply built-up roof, the exposure of plies is a) 12-1/2 inches b) nine inches c)11-1/3 inches d) 15-1/3 inches. ________

3. In a built-up roof, the most commonly used asphalt type for inter-ply moppings is a) type I b) type II c) type III d) type IV. ________

4. For a durable built-up roof, which fiberglass felt would you recommend? a) type III b) tyype IV c) type V d) type VI. ________

5. Which of the following modified bitumen membranes is torch-applied? a) SBS modified bitumen b) APP modified bitumen. ________

6. The carrier in a modified bitumen membrane consists of a) an organic felt b) a fiberglass felt c) organic and fiberglass felts d) polyester and fiberglass felts. ________

7. Which of the following roofing membranes is most unsuitable for a roof with numerous penetrations? a) built-up roof membrane b) modified bitumen membrane c) single-ply membrane. ________

8. Which of the following roofing assemblies are most unsuitable for a roof in a high-wind region? a) gravel-covered built-up roof b) APP modified bitumen roof with mineral-surfaced cap sheet c) mechanically fastened single-ply roof d) fully-adhered single-ply roof. ________

9. Which of the following single-ply membranes is most commonly specified? a) neoprene b) EPDM c) PVC. ________

10. Which of the following two plastic foam insulations is most commonly specified for low-slope roofs? a) extruded polystyrene foam b) polyisocyanurate foam. ________

11. Which of the following roof insulations is least hazardous in the event of a fire? a) polyisocyanurate b) extruded polystyrene c) wood fiberboard d) perlite board. ________

12. Foamed concrete consists of a) Portland cement, vermiculite, foaming agent, and water b) Portland cement, perlite, foaming agent, and water c) Portland cement, foaming agent, and water. ________

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Further Reading

As the reader may have realized, roofing design and construction issues are too numerous and complex to be covered adequately in an overview article. Therefore, the following bibliography will be of help as further reading.

1. National Roofing Contractors Association, Rosemont, Illinois: *NRCA Roofing and Waterproofing Manual*, 1996.

2. National Roofing Contractors Association, Rosemont, Illinois: *Commercial Low-slope Roofing Materials*, 1997.

3. Sheet Metal and Air Conditioning Contractors National Association, Chantilly, Virginia: *Architectural Sheet Metal Manual, 1993*.

References

[1] Sometimes, a base sheet may be used as the lowest felt, which is not shingled with the upper felts. It is laid simply with two-inch (50 mm) laps at edges and six-inch (150 mm) laps at the ends.

[2] If asphalt BUR is used for slopes greater than 1:12, felts must be back-nailed, to prevent their slippage.

[3] One roof square is equal to 100 ft^2 (9.3 m^2).

[4] Many experts believe that the durability difference between asphalt and tar BURs is marginal.

[5] UL class A rating is the maximum fire-rating of a roof assembly.

[6] Some roofing system manufacturers do not require cant strips with an MBR.

[7] This is particularly true in reroofing applications, where the building owners may justifiably refuse the transport of liquid propane cylinders through the building elevators.

[8] Foamed concrete should not be confused with lightweight insulating concrete, which consists of Portland cement and lightweight aggregate (perlite or vermiculite).

[9] A slotted metal deck with tiny slots at its underside is preferable to allow a more rapid evaporation of water from foam concrete.

Answers to Self-Test Questions

1. a) built-up roof

2. c) 11-1/3 inches

3. c) type III

4. d) type VI

5. b) APP modified bitumen

6. b) a fiberglass felt or d) polyester and fiberglass felts

7. c) single-ply membrane

8. a) gravel-covered built-up roof

9. b) EPDM

10. b) polyisocyanurate foam

11. d) perlite board

12. c) Portland cement, foaming agent, and water

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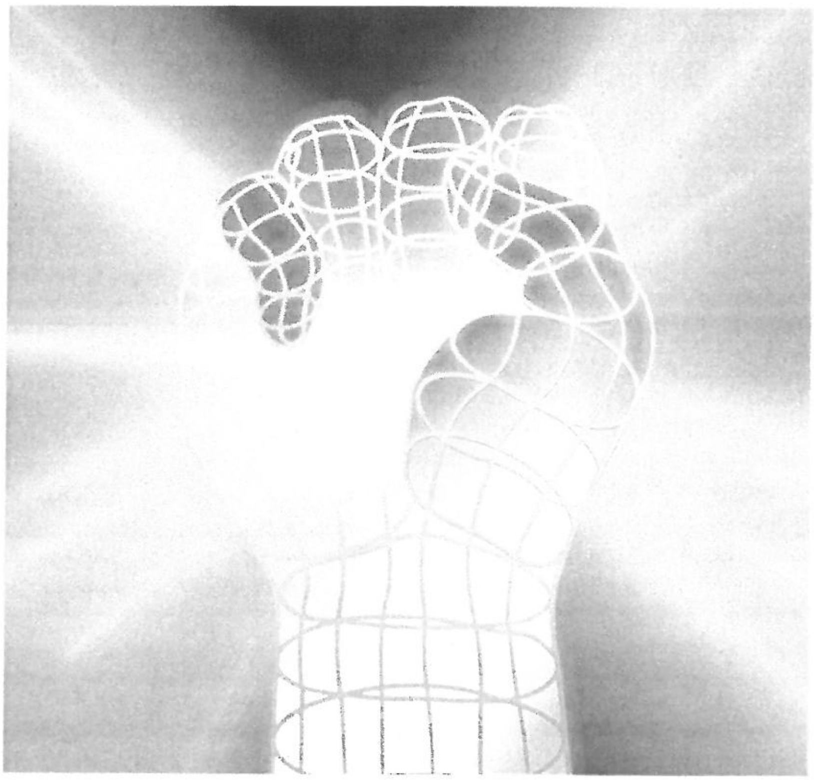

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