Application of roof design principles

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Please note

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The basic considerations involved in the design of roof systems have been outlined in CBD 67. Other Digests have dealt in more detail with various requirements including resistance to wind uplift, flashing design, structural loads and deflections, and thermal and moisture considerations, all individual factors that must be recognized and their relative influence assessed in developing a system for optimum over-all performance. This Digest offers an analysis of the conventional, above-deck, insulated membrane roof system, with some suggested features for improved performance.

The roof system illustrated in Figure 1 represents one of the most common arrangements in current use - a reinforced concrete deck, over which is applied a membrane vapour barrier, rigid insulation and a multiple-ply membrane roofing, bitumen and gravel. The roof is regarded as flat, and very often drains are placed at column locations to simplify piping and facilitate concealment of the rain water leaders inside the building. The calculated temperature gradients representing extreme winter and summer conditions are superimposed on the roof section. Winter conditions are assumed to be 73°F inside and -27°F outside, with a clear night sky. Summer conditions are assumed to be 75°F indoors and 90°F air temperature outdoors, with bright sun and a solar absorption coefficient of 0.75.

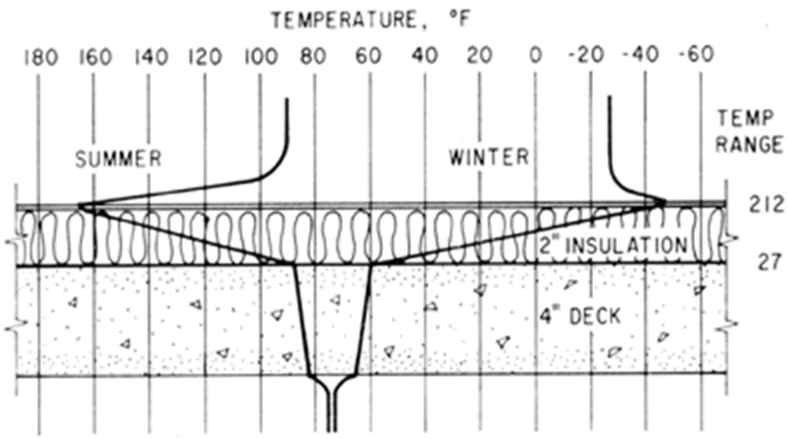

Figure 1. Insulated concrete roof.

Placement of the insulation above the deck results in a relatively constant deck temperature throughout the year. For the conditions assumed, the temperature range is only 27 F deg. This is a most desirable situation as far as the structural deck is concerned for it avoids problems occasioned by expansion and contraction of the deck in relation to other structural elements. The roof membrane, however, is exposed to a severe thermal variation, summer to winter, a variation that increases as the thermal effectiveness of the insulation increases. For the conditions illustrated in Figure 1, the temperature range at the membrane is 212 F deg. While improving the thermal environment of the structural deck, such an arrangement increases the differential thermal movement between the membrane and the deck, a factor suspected of contributing to membrane splitting.

The thermal contraction coefficient of bituminous membranes is high and increases as the temperature is decreased (**CBD 74**). If the membrane is held to the dimensions of the deck, it will experience a thermally induced strain of an amount depending on its potential shrinkage in relation to the deck. Based on laboratory properties of new membranes, the calculated uniform strain under severe low-temperature conditions is less than the required breaking strain. The factor of safety may be low, however, and it is possible that localized weaknesses in the membrane or localized increases in strain occur at such locations as insulation joints.

The use of roof coverings that have greater flexibility and higher breaking strains at low temperature offers one solution to the problem. As splitting is believed to result from concentration of movement, expansion joints can be employed at known locations of movement in the deck or insulation. Where such locations cannot be predicted or are too frequent to make expansion joints practical intermittent attachment of the membrane can be considered. Whether this is accomplished by intermittent or strip-mopping, by taping of joints or by proprietary systems, it provides a means of reducing the strain on the membrane caused by localized movement in the substrate.

The high temperature extremes to which the roof membrane is subjected in this arrangement are also undesirable because they can contribute to deterioration of the membrane by accelerated oxidation, bleeding or bitumen flow. The membrane is thus not located in the most desirable thermal environment to enable it to perform its function in the total system.

The design arrangement illustrated in Figure 1 has disadvantages from the standpoint of moisture considerations also. Normal elastic deflection of the structural deck, coupled with deflection due to creep, tends to result in low areas between structural supports that allow the ponding of water. This, in itself, can lead to accelerated deterioration of the membrane, and if a break occurs in it - from deterioration or splitting, or through mechanical damage - the "pond" provides a reservoir that increases the amount of water entering the system. Furthermore, the vapour barrier, if it is effective, will hold the water (resulting from the break) within the system to contribute to the further deterioration of the roof membrane by promoting ridging and blistering, while also reducing the effectiveness of the insulation.

The vapour barrier, in effect, may act as a secondary "flat" roof as far as water entering the building is concerned, and if effective as such may hide any indication from the occupants that a roofing problem exists. On the other hand, if it is not complete, it may allow water to enter the building wherever an opening in the barrier or roof slab occurs, and this location may bear little relation to that of the break in the roof membrane.

Sloping the roof surface to drains would do much to reduce the amount of water entering the system through breaks in the membrane, and slope should be recognized as a most desirable practical feature of roofs. The creation of drainage by sloping the deck provides an opportunity to use the vapour barrier as a means of removing water that still manages to enter the system. In fact, the vapour barrier might even he considered as the location for the primary roof membrane. One obvious advantage is the favourable thermal environment.

Figure 2 represents the same basic system shown in Figure 1, but with the deck surface sloped to a double-drain arrangement. The temperature gradients through the system are unchanged, and it will be noted that the lower membrane cycles through the same moderate temperature conditions as the deck. The differential movement between deck and membrane due to temperature is thus minimal and the membrane remains at a temperature well above its brittle point. Localized strains may still occur from shrinkage cracking or structural movement of the deck, but the transfer of these to the membrane can be minimized by intermittent bonding of the two, giving proper consideration to the adherence required to resist wind uplift. In this location the membrane is also protected from the deteriorating effect of other weather factors such as solar radiation and traffic.

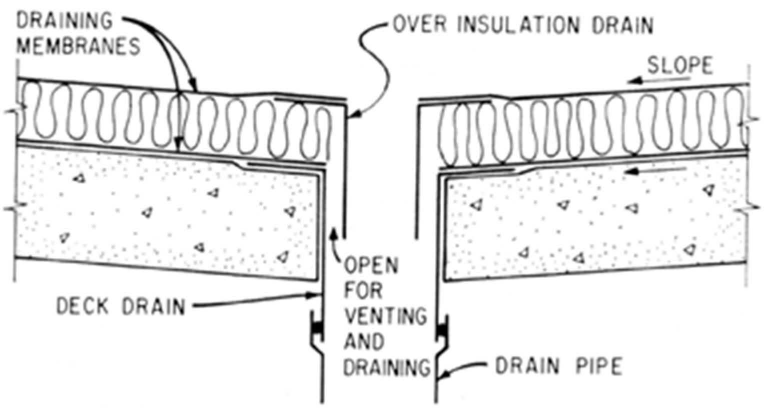

Figure 2. Double-drained roof.

The lower drain, in its simplest form, might consist of a flanged sheet metal section connected to the rain water leader and properly flashed to the membrane at the deck. Cast metal with a clamp arrangement to hold the drain rigidly to the deck and a sliding joint connection would be required in more sophisticated design. The upper drain might basically also be a simple flanged section of smaller diameter, properly flashed to the upper membrane. The sizing of the upper drain to take care of the anticipated run-off would be the determining factor for the sizing of the lower drain and the rain water leader. The upper drain would probably have to be clamped to the lower drain at several points around the perimeter and might require a gravel guard and strainer arrangement, depending on the type of roofing. Separation of the upper and lower drains could help to avoid condensation on the drain pipe inside the building during winter. More important, the double-drain arrangement would allow pressure venting of the insulation to the outside, while eliminating the break in the vapour barrier that usually occurs at this location with a conventional drain arrangement.

As a pressure venting system, the double-drain arrangement would be as effective as the projecting vent stacks currently recommended by some authorities. As the vents and drains are combined, the over-all number of roof penetrations is reduced so that there are fewer chances of leakage from poor workmanship. Projecting vent stacks are also very susceptible to damage.

Venting under the insulation can be expected to be more effective than top venting for the removal of moisture vapour. Most venting of moisture vapour will probably take place during the summer under the influence of solar heating, heating that promotes migration of moisture to the lower membrane. Although the type of insulation used might inhibit the rate of lateral water and vapour flow in the insulation, some opportunity for flow is provided at the insulation joints. The creation of lateral channels through intermittent bonding of the insulation or provision of intentional grooves or chamfered edges at the lower face of the insulation can facilitate lateral flow of water or vapour.

Acceptance of the vapour barrier as a basic roof membrane requires that it be treated as such at all penetrations and interruptions at the deck. This demands strict attention to details in design and application: proper flashing at each penetration of the deck membrane; and at large openings - penthouses or similar projections above the roof - construction, in some cases, of saddles on the up-slope side to ensure that water in the system is not trapped against an up-standing wall.

There is a possibility that in many roofing applications the lower membrane could be applied as a temporary roof for the construction operation, leaving the application of insulation and upper membrane until the building is substantially complete. The initial roof membrane would have the benefit of a less compressible substrate during the period when traffic on the deck is greatest and any damage would be more easily noted and repaired prior to the application of insulation. Final inspection could also be carried out when the danger of subsequent damage is least, and the temporary roof period would provide an opportunity for field testing of the application.

To reduce the possibility of buckling or ridging due to moisture absorption of hygroscopic felts used in such a temporary roof, the use of coated felts would be most desirable. The coated surface might well be adequate as a temporary upper surface and eliminate the need for field application of bitumen until insulation is to be secured. As it is recognized that some moisture may be trapped during construction or find its way into insulation, protection of the under side of the upper membrane from moisture entry is also desirable if it is to be fabricated from organic felts. A coated base sheet as the first ply or taped insulation joints would be desirable to help prevent membrane ridging.

Acceptance of the lower membrane as the primary drainage surface suggests that the upper membrane need only act as a protection for insulation in certain circumstances. Indeed, elimination of the upper membrane is conceivable if the insulation used is unaffected by moisture. The insulation must be durable or have appropriate protection, and some satisfactory means to secure it to the deck surface is necessary. In roof terraces, (**CBD 75**) such a system holds promise with paving stones or slabs acting as protection and providing weight to secure the assembly against uplift.

Conclusions

Assessment of the roofing system outlined in this Digest suggests a departure from the conventional approach to design, but involves little change in the components or their arrangement. It illustrates the application of principles based on thermal and moisture considerations that can be summarized as follows:

1. An insulated roof system must be designed to prevent the entry of moisture into the assembly, from both inside and outside, or it must be capable of dealing with the moisture that enters during or after construction.
2. The primary membrane must be designed to handle differential movements occasioned by its environment, or it must be placed in an environment that reduces the stresses it experiences.

These features can best be attained by:

1. sloping of the membrane to drains;

2. protecting moisture-sensitive membranes from water or water vapour entry;
3. allowing for pressure relief of spaces in the assembly;
4. intermittent bonding of the membranes to their substrate;
5. placing the primary membrane below the insulation.