FIELD EXPERIENCES VERSUS STANDARDS AND DESIGNS

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Roofing technology is an applied science which has been built upon theoretical hypotheses, modified by practical experiences and developed into roofing theory. 'Good roofing practice' stems from the marriage of field experience and roofing theory. Most of the time there is agreement between roofing practitioners and roofing technologists but, inasmuch as "good roofing practice" can vary from region to region, there are instances where field experiences differ from theory. Obviously the reality of field experiences outweighs theory, but it is informative and interesting to consider situations where conventional roofing theory is inadequate, or simply too conservative, in setting design criteria for roofs.

This paper will include such issues as the use of perimeter nailers, roof area dividers, button-base sheets, mechanical fasteners and equiviscous temperatures.

KEYWORDS

Button-base sheets, equiviscous temperatures, mechanical fasteners, perimeter nailers, roof area dividers.

INTRODUCTION

This paper was prepared by the Canadian Roofing Contractors Association (CRCA) and relates to commercial roofing in Canada.

Canada is the second largest country in the world and has four major climatic zones: Mediterranean, Maritime, Continental and Arctic. Roofing practices vary with climate, but there is agreement upon the general principles of good roofing. Most roofs in Canada are constructed in fine weather, but the common denominator for all Canadian roofing contractors is the requirement to construct roofs in cold weather. For Canadians, cold weather usually means 0 to −25°C (32 to −13°F).

Roofing technology in Canada has benefitted greatly from research undertaken here and in the United States. The climate and many of the materials used in the northern U.S. are similar to those in Canada. This technology has resulted in roofing standards and designs which are intended to provide guidance in the construction of roofs that perform.

The purpose of this paper is to compare field experiences with roofing standards and designs, with emphasis on cold climates.

MATERIALS AND APPLICATION

Roof Decks

Three-quarters of commercial roof decks in Canada are metal. Since the introduction of large span fluted metal decks, some forty years ago, the size of roofs has tripled, from an average of 700 square meters to over 2,100 square meters (7,000 to over 21,000 square feet).[1]

The flexibility of design realized by the widespread use of metal decks brought with it an increased number of roofing problems due to the flexibility of the material itself. The lack of stiffness in metal roof decks was identified as a problem in 1971 by the CRCA[2] and the magnitude of the problem was identified by NRCA's Project Pinpoint. McCorkle, Dupuis and Lacosse[3] reported that deck type had more influence upon the occurrence of membrane splitting than membrane type, and that the frequency of membrane splits was 3 to 3.5 times more over metal decks as over wood decks.

Asphalts

The combination of cold temperatures, (CSA A123.4M) type 3 asphalt, and the high thermal conductivity and flexibility of steel roof decks has proven to be particularly troublesome.

In order to reduce the problem of asphalt seepage through discontinuities in metal roof decks many authorities specified that type 3 asphalt be used to adhere the vapor retarder or insulation to metal decks. Dupuis, Lee and Johnson[4] have demonstrated that hot (ASTM D 312) type III asphalt will cool below the point of adhesion on a steel deck within seven seconds when the air temperature is −8°C (18°F). Thus, successful attachment of materials to cold metal decks with type 3 asphalt is difficult.

It should be noted that Canadian type 1, 2 and 3 asphalts have similar physical properties to U.S. type I, II and III asphalts. Type IV asphalt is almost never used in Canada.

The problem of uncertain asphalt adhesion during construction is aggravated by the deflection characteristics of metal decks. Even if adhesion were obtained between the metal and the vapor retarder/insulation during roof construction, subsequent roof traffic could shear the adhesive and, with type 3 asphalt, it is doubtful that the adhesive would self-heal. In some colder regions, asphalt is simply not allowed as an adhesive to steel deck; in these areas mechanical fasteners or solvent adhesives are used.

Softer asphalts function as better adhesives in cold weather because they remain more fluid at lower temperatures. Data from Project Pinpoint indicates that type II asphalt should be the preferred interply mopping asphalt. Membranes built-up with type I, III and IV asphalts suffered 4 percent, 127 percent and 300 percent more problems than those built-up with type II asphalt.[3] It should be noted, however, that type III asphalt is more widely used in the U.S. and more reported problems with this asphalt type would be expected.

Roofing contractors generally use softer asphalts, higher asphalt tank temperatures and insulated equipment in colder weather. Felts are broomed in as quickly as possible after lay down—the good "broomability" of organic felts, plus their low cost and increased strength at low temperatures, may be reasons for the reluctance of the Canadian industry to convert to glass based felts.

Cullen[5] reported a +/−17 percent interply asphalt mopping variation when a professional roofing crew applied built-up roofing under ideal conditions. Baxter[6] reported a −20 percent to +30 percent variation in interply asphalt quantities simply due to the change in weight of a roll of felt as it was laid into hot asphalt. Despite this, requirements to "apply 1 Kg/m^2 (0.2 lb/ft^2) +/−20 percent of asphalt at the equiviscous temperature" are still common. The +/−20 percent asphalt quantity tolerance is required despite the practical difficulty of achievement, and the equiviscous temperature (EVT) is required regardless of temperature and material, e.g., cold steel or warm felts. Some discretion should be used when specifying EVT; it is often forgotten that EVT was derived from field experience (and recently changed due to a reassessment of field experience).

Recommended asphalt quantities and EVTs serve as good guidelines for roof construction, but the commonly suggested tolerances are often difficult to achieve. It is believed that the industry would be better served if:

- All asphalt suppliers would provide EVT information.
- Roofing mechanics attempted to maintain EVTs in the mop cart or felt layer just prior to asphalt application.
- Designers, specifiers and consultants accept that wider tolerances than those widely specified are a practical reality.

Mechanical Fasteners

The specification for asphalt attachment to steel deck should account for the practical difficulties due to the high conductivity of steel and the deflection limits of the deck versus the adhesive. In extremely cold weather, mechanical fasteners provide the most reliable method of securing materials to steel deck.

The issues surrounding the use of mechanical fasteners are fastener back-out (particularly with single-ply membranes) and corrosion.

Fastener back-out is not common in Canada. It is believed that this may be due to the evolution of ribbed fastener/washer combinations, the common use of fiberboard as an insulation overlay board and the use of bar attachment systems for single- ply membranes.

Corrosion of fasteners is an issue when a roof covers high humidity areas. Particularly in cold climates, metal fasteners provide a thermal short through the insulation and condensation on the fasteners can occur. The potential loss of the protective coating on both the metal deck and the fastener at the point where the fastener penetrates the steel deck exacerbates the problem. In such instances a two layer application of the insulation (or deck overlay + insulation), one screwed and one mopped, reduces the problem.

Vapor Retarders

In the colder areas of Canada vapor retarders are extensively used. In milder areas, vapor retarders are used if the design and use of the building requires them, or if the building construction is in cold weather. In the latter case, it is often necessary to protect roofing systems from construction moisture (e.g., in concrete) which can be driven into the roof after the building is closed-in and heated.

Vapor retarders do not function effectively as air barriers as normally installed. Vapor retarders can be designed and installed in a continuous fashion and, as such, do prevent air leakage into the roofing system. It is now accepted that air leakage is far more important than moisture vapor diffusion in the transfer of moisture into building envelopes.[7] The provision of wall and roof air retarders, and their effective tie-in, is of critical importance for some buildings.

Asphalt Felts and Coated Sheets

The use of a coated base sheet in a built-up roofing membrane was short lived in Canada. The main reason for using coated base sheets in BUR membranes was to stop moisture within the roofing system from attacking the underside of the organic ply felts. This was particularly useful when the insulation material did not absorb moisture and the roof moisture concentrated in the insulation board joints.

Strangely, the use of coated base sheets in the U.S. persisted long after the introduction of less moisture-sensitive glass ply felts (perhaps the phenomenon of asphalt percolation from early glass ply felts made this necessary). Whereas in Canada, where 90 percent of ply felts are still organic, the use of coated base sheets was problematic.

Many explanations for the lack of popularity of coated base sheets exist, and all of them have technical credibility. It is interesting to show how practical realities unveiled the flaws in an otherwise sound membrane design:

- The thick coated base sheets were very stiff and difficult to lay flat in cold weather. Manufacturers recommended that the sheets be cut into 10 foot lengths and laid on a roof to flatten out in the sun.
- The antistick agent on the coated rolls impeded the adhesion of the sheets.
- The small quantities of asphalt required to lay a single sheet (as opposed to shingling-in four plies of felt) coupled with the relatively high thermal mass of the base sheet resulted in more rapid asphalt cooling. More recently this increased rate of cooling was quantified as being over twice as fast as with ply felts.[4]
- The lack of perforations in the coated base sheet made it more difficult to obtain good adhesion compared to perforated ply felts.

Not surprisingly, the occurrence of blistering and lack of adhesion was sufficient to cause the industry to move back to a 4-ply perforated organic felt and asphalt BUR membrane, which is still the industry standard in Canada.

The widespread use of asphalt impregnated organic ply felts has provided durable roofing in Canada. The problems that do exist with this material are related to moisture and sticking in the roll. If felts containing too much moisture are used, they cause excessive foaming of the hot asphalt during application which results in excessive interply voids. Cullen[5] reported that roofing membranes laid under perfect conditions contained 3 percent voids.

Modified Bitumens

Modified bitumens appear to have appropriate properties for roofing in cold climates. Sheet products are flexible and rubber-like at low temperatures and yet have the good adhesion properties of bitumen.

Styrene-butadiene-styrene (SBS) modified sheets are far more common than atactic polypropene (APP) modified sheets because of their better low temperature properties. The sheets are almost exclusively used in 2-ply membranes, commonly with the upper ply reinforced with polyester and the lower ply reinforced with glass. The lower ply of the membrane is generally adhered with mopping asphalt and the upper ply is either mopped or torched on.

After early problems of membrane slippage and splitting were overcome, these materials have met expectations, except in the area of aesthetics. Membrane slippage has occurred when European manufacturers, used to their higher softening point asphalts, specified insufficient back-nailing of these heavy sheets on steeper roofs. Splitting occurred when products with weak reinforcements were used in colder regions. At rooftop temperatures of −40°C (−40°F), most modified bitumens are below their glass transition temperatures and membrane integrity relies on the strength of the reinforcement.

Modified bitumen sheets are coated sheets and suffer some of the previously mentioned problems of coated base sheets when being asphalt-adhered in cold weather. In extremely cold weather torch-on applications are recommended, but in milder conditions mop applications are often used. Type 2 asphalt is often used for modifieds because any wrinkles which are built-in during a cold-weather application may smooth out under the hot summer sun of the next season.

There are instances where modified sheets have laid flat during application, but have developed wrinkles later. Sometimes the period before wrinkles appear is a few weeks and sometimes a few years. The causes of these problems may be substrate movement, poor adhesion, asphalt incompatibility or sheets with too much stress built into them during manufacture.

Manufacturers of modified bitumen sheets promoted their products as good-looking roofs. Although these materials can be applied and finished in an aesthetically pleasing way, in most instances this may be unnecessary. For non-visible roofs, it is probably better to see bitumen exuding from sheet laps during application than to have neat looking but poorly adhered laps.

One way to virtually eliminate aesthetic problems with modified bitumen sheets would be to cover the membranes with an asphalt flood coat and gravel surface.

Single-Ply Membranes

The two most common single-ply materials used in Canada are EPDM rubber and PVC. The use of large prefabricated sheet roofing is advantageous because it reduces the number of laps which need to be made. However, the laps on single-ply membranes have to be perfectly sealed.

Lap defects in single-ply membranes accounted for the greatest proportion of reported problems in NRCA's Project Pinpoint.[8] It is important to note that these data must be analyzed cautiously, as little elaboration of the defects is noted in the report. Single-ply manufacturers place great emphasis on the integrity and validation of lap sealing.

Single-ply membranes have great appeal because of their ability to elongate and recover at tremendous rates. This is particularly valuable when dealing with lightweight construction involving deck deflection and structural movement. Temperature induced contraction and expansion of single-ply membranes can cause problems if the perimeter of the membrane is not restrained. Cold weather contraction of the material is not always regained in warmer weather because of the flexible nature of the material, akin to "pushing a rope." Most single-ply manufacturers now insist on perimeter fixation to restrain contraction forces.[9]

Considerable debate has centered on the need for vapor retarders when single-ply membranes are used. Some people argued that, because a single-ply membrane is considerably more vapor permeable than an asphalt-based membrane, any moisture which collected in a roofing assembly would diffuse through the membrane. What this argument failed to address was the problem of moisture-laden air movement. In 1984, Baxter[10] reported on the problems with moisture accumulation under single-ply membranes. Today most manufacturers acknowledge that building design and use considerations, not membrane type, governs the decision to include or exclude an air/vapor retarder. Practical consideration still needs to be given to sealing the vapor retarder end laps over fluted steel decks, the tie-in of roof and wall air barriers and the long-term effects of fastener penetration.

Mineral Surfaced Button-Base Sheets

The use of button-base sheets in the recover of old roofing systems is popular in Europe. Beech[11] demonstrated that this material was useful to reduce stress transfer from unstable substrates and to equalize moisture vapor pressure within a roof.

Button-base sheets have not been widely used in Canada.Their use in new construction has caused some application problems: the granules on the underside of the sheet make it difficult to keep the sheets aligned and in-place, and the sheets are difficult to lay flat in cold weather. Other reasons for the lack of popularity of button-base sheets are lack of availability, the additional cost and concerns over the reduced area for adhesion.

Nevertheless, given the widespread use of button-base sheets in Europe, the potential benefit from the use of this material in Canada is worthy of research.

Perimeter Nailers

The shrinkage of unrestrained bituminous roofing membranes is well-known. Not only do unrestrained membranes shrink when cooled, they do so with significant force.[12,13]

The forces involved can be measured in the laboratory by simply clamping a specimen of roofing membrane between the jaws of a tensile tester and monitoring the build up of load as the specimen is cooled. It is common to see loads of 4kN/m (23 lbf/in) when membranes are cooled from 23°C to −40°C (70°F to −40°F).[14] This force is equivalent to having a hefty roofing applicator hanging from a 300mm (one foot)wide piece of roofing membrane.

Bituminous roofing membranes can pull away from roof perimeters if there is a plane of weak attachment between the membrane and insulation, insulation and vapor retarder, or vapor retarder and deck. It is of prime importance to secure all components to the roof deck.

In most of Canada perimeter nailers are not widely used(except for gravel stops and similar details), and roofs have not suffered from problems associated with membrane shrinkage (tented or split flashings, gaps between the roof edges and insulation). Perimeter nailing of bituminous membranes might be useful when roof attachment is marginal, but it is unnecessary when roofing systems are properly secured to the deck.

This is one area where roofing theory, although sound, is too cautious.

Roof Area Dividers

There are three types of roof area dividers: building expansion joints, roofing system control joints and membrane control joints. Building expansion joints start at the building foundation, roofing system control joints start at the roof deck and membrane control joints start at the insulation.

Membrane shrinkage forces are independent of the length of roofing membrane. Roof area dividers do not reduce the amount of force exerted by roofing membranes, but they can significantly reduce roofing problems. The division of large roof areas into smaller rectangular shapes is often desirable because:

- Membrane tears and splits which propagate from re-entrant corners are eliminated.
- Changes in deck material, slope or direction can be isolated. It should be noted that all building expansion joints must be continued through the roofing system.
- Future problems may be isolated to one section of the roof.

On the other side of the roof area divider discussion are those who argue that discontinuities in the roof membrane results in an increased number of flashing details and therefore should be avoided.

Standards

Standards are critical to successful roofing. In Canada, material standards are set nationally and building codes and practice are set provincially.

In the last decade many organizations have initiated their own material approval programs. These programs were started because compliance with many material standards do not necessarily indicate that materials are fit for their intended use. Changing any standard is a slow process, and changing from prescriptive-type standards to performance standards for materials is simply taking too long. In addition to meeting national standards and manufacturer's specifications, which are required to meet building codes and obtain material warranties, it is now common to have materials meet additional requirements prior to use. Roofing materials must be approved by the relevant roofing contractor association before being used on any roof which carries the association's warranty. In general, association standards are written so that successful field performance is necessary prior to material acceptance.

The Canadian Roofing Contractors Association (CRCA) is the umbrella group for the provincial associations and sets guidelines for good roofing practice.[15] Provincial associations set standards for what their members believe is necessary to provide good roofing.[16,17,18] Because of differences in climate, material preference and field experience, the standards of practice for some provincial associations vary from CRCA specifications. Perhaps the largest difference between provincial associations is that some have established technical standards in conjunction with the issuance of association-backed warranties.

Workmanship

Of the four necessary ingredients for a good roof—design, materials, workmanship and maintenance—it is workmanship which is most important. The best design and materials in the world rely on the skill and dedication of the applicator. Designs and materials that are straightforward and easy-to-use make the applicator's job easier and lead to more durable roofs.

There have been many technological changes in the last 10 years, both in materials and design. Some new materials (such as single-ply membranes) and designs (such as domed stadiums) have placed stringent requirements upon roofing applicators. Roofing application is more craft than science and it takes place outside, not in a laboratory. This should not be overlooked by designers and material manufacturers.

Roofing contractor associations exist to set codes of practice[15-18] which, when followed, result in quality roofs and a credible industry. These codes are based upon the cumulative and reasoned experience of all of the association's members. Codes of practice, together with experienced, qualified and reputable contractors and applicators, are essential for successful roofing.

CONCLUSIONS

Through the Canadian Roofing Contractors Association, the authors have drawn upon the combined expertise of the Canadian roofing industry. This paper has purposely concentrated on cold climate roof construction because it is an area where a valuable contribution to international roofing technology can be made.

This paper has stressed the need for an understanding of construction materials and practice at all stages of construction. Materials have application limits, beyond which great care must be exercised in their specification and use. The same can be said for construction workers. The best roofer in the world cannot construct a good roof out of newspaper and molasses, nor can he construct a roofing system to hold the building together should the design be wrong. Designers, material manufacturers and applicators must understand each others' role and work cooperatively to produce quality roofs.

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