A THEORY TO EXPLAIN ROOF SPLITTING BY ICE

ROGER G. RIEDEL
Portage, Wis.

Harsh northern winters have long been recognized as a major cause of roof splitting. Investigators have tried to pin down the relationship between cold climates and roof splitting. Work done at the U.S. Bureau of Standards attempted to solve this problem by testing the tensile strength and other characteristics of various materials. By establishing a "Thermal Shock Value" for various assemblies of roof membranes, the designer could, if the information was properly interpreted, select a stronger assembly over a weaker one.[1]

However, in field investigations, a clear understanding of the forces that cause splitting has been frustrated by the presence of weakening effects of insulation board joints and the condition of individual constituents within a roof system.

Some of these weakening effects are:

- Joints between insulation boards that create a line of weakness where splits normally occur.
- Insulation board joints allow moisture to condense on the underside of the membrane, softening and/or decaying it.
- Insulation must be firmly attached to the supporting structure to prevent movement of the roof system. When it is not, splitting is a normal result.
- Traditional paper roofing felts have only half the tensile strength in the crosswise direction as they have lengthwise.
- Incomplete cementing between felts produces lines of weakness where splits can originate.
- Leakage and soaking of all system components, combined with freeze/thaw cycles, drastically reduces their tensile strength.

The feeling that ice played a definite role in splitting was prevalent enough that members of ASTM Committee D8 were solicited by the chairman way back in the 1960s for evidence that would lead to an understanding of the relationship between ice formation and splitting. Most committee members agreed that ice was an important factor, but could not come forward with any useful evidence.

In 1961, the National Research Council of Canada said about ice:[2]

> *"It is very important that sufficient slope be provided to avoid standing pools of water. The combined attack of water or ice and sunshine on the membrane is a much greater hazard than either element alone."*

This was an important statement that recognized ice as a danger and led to eventual acceptance of the concept of removing this source of danger by designing slopes into roofs. Many individuals and organizations followed this recommendation in following years.

Drainage slope for roofs became an accepted requirement in the industry, because of the growing concern over roof splits. By the mid 1960s, virtually all manufacturers and roofing organizations concurred, and the requirement is included in the manuals of practically all manufacturers.

Splitting has not been totally overcome by designing drainage slopes into roofs, because of the weakening effects previously described. However, a better understanding of ice action has been made possible by the advent of sprayed urethane roofing systems.

Study of a damaged modified bitumen membrane which eliminates the weakening effects referred to is offered in support of this theory.

THREE INVESTIGATIONS

Investigations of splits in these newer roof systems, which are more homogeneous, or grainless, compared to conventional BURs (built-up roofs), re-evaluated this mechanism. The cases in point were:

1. A sprayed urethane roof system on a school in Winnipeg, Manitoba that failed by catastrophic splitting the first winter of its existence. *(Photo 1.)*
2. A similar system, behaving the same way in Elkhart, Ind. *(Photo 2.)*
3. An aluminum foil faced modified bitumen system nailed direct to plywood decking at Plover, Wis. *(Photo 3.)*

The urethane roofs had been applied over old insulated flat graveled roofs to overcome leaks and to improve insulation values. In both projects, provision was made in the contract to build in drainage slopes (at considerable expense for the additional urethane foam required) by applying up to 5 inches of foam at perimeters and 1½ inches at drains. This proved to be beyond the skill of the applicators, resulting in the roofs remaining about half ponded.

The coatings of both projects were acrylic latex emulsion claiming 280 percent elongation capability. Application rates were found to vary in thickness from nearly adequate to unacceptable, but in both cases the areas with greater coating thickness fared little better with regard to splitting than those with a thinner coHting.

The aluminum foil faced system had been mechanically attached to the plywood deck of a new refrigerated warehouse. Batt insulation was located below the deck. Random, wandering stress lines were found in which the embossments in the foil were stretched flat. Where stress exceeded the tensile strength of the foil, it split and the modified bitumen layer also split in places. None of the cracks were linear or related to the structural elements in any way. They seemed related entirely to the shape of snow drifts on the roof.

In all three cases, therefore, the new roofs did not contain the weakening factors that occur in traditional roofs that cause linear splitting. These roof splits took the direction of every imaginable geometric form, apparently determined by ice depths, snow patterns, or factors other than those of the roof system components. None of the splits were linear.

THE THEORY

A study of the cracking patterns on these new "grainless" roof systems reveals that the problem is less complex but the actual mechanism is still not obvious. The theory has often been advanced that *expansion* of the ice is what causes the splitting. This is a common concept based on observations of burst pipes or buckets caused by freezing water.

According to standard technical references[3] ice has the unique characteristic of expanding more and more as it becomes colder, while virtually all other solids contract upon falling temperatures. Water is most dense at 4C (39F) and expands both below and above that temperature. Ice is credited with having insulation value because of its lower density and crystalline structure. This prevents ponds from rapidly freezing their full depth.

Ice has a linear expansion coefficient more than double that of aluminum, one of the most active solids encountered in roof construction. Another property which has been revealed by studies of glacier movements[4] is that ice is compressible and, because of its crystalline structure, will deform in plastic cold flow under pressure.

If we accept the simple proposition that initial ice expansion causes splitting of traditionally insulated roofs, splits would occur along lines of gaps in the insulation, which would be forced to diminish as the ice expands. This would be accompanied by crushing of the ice plate and formation of a ridge in the membrane. This is commonly seen, and the ridges eventually crack from fatigue.

However, homogeneous systems such as sprayed urethane roofs require another explanation, because there are no voids in the insulation and no folds or ridges in the surface as a result of ice action.

Therefore, the complete roof cracking mechanism appears to be:

1. Pond freezes from top side downward. Because of expansion of the lower region as it freezes, there would be an uplifting force in the center of the area, which may cause loss of insulation bond to the substrate at the pond perimeter.
2. Further expansion of the upper region of the ice plate as temperature falls is absorbed in plastic flow under compression.
3. Upon warming, ice *contracts,* imposing tensile stress on itself. Cracks develop along lines of weakness which are controlled by ice depth, membrane strength and other factors. *(Figure 1.)*
4. As the ice warms, the gaps widen and leakage of melt water announces a roof split.

DISCUSSION

In retrospect, this type of curving, random splitting has been well known for 20 years in flat roofs employing some of the earlier types of glass fiber felts. These roofs also were essentially "grainless" with regard to differential tensile capabilities.

When roofs are sloped to drains even minimally, how does ice build to a depth that is capable of splitting roofs? The answer lies in a few words spoken at a University of Wisconsin seminar, the significance of which seem to have gone unnoticed. In an outline of the talk presented by David Schaeffer of the U.S. Army Cold Regions Research and Engineering Laboratory, March 25, 1972[5] Mr. Schaefer reported that CRREL research has found that:

> *"Snow is a fairly good insulation—hence if a roof has a sufficient snow cover the interface between the membrane and snow can be above freezing. An example: With approximately 2 inches of insulation (R = 10) and 3 inches of snow, the interface melts at an outside temperature of about −5F (inside temperature 70F). If the roof does not have a uniform snow cover the snow can melt in one place and refreeze at others." (Figure 2.)*

Actual conditions found in Wisconsin verify this. A school roof having about 1-inch-per-foot slope and better than R-10 insulation was found to have ankle-deep slush under a foot of snow on a cold day without sunshine. That this would become 4 inches of solid ice that evening was not realized at the time.

Yet another factor appears to be present—color or reflectivity. The superbly reflective aluminum foil system may have prevented much more extensive damage. The roof was repairable. The Elkhart and Winnipeg sprayed urethane systems were coated with grey material. Being less reflective, the coating would promote more thawing.

Coating manufacturers are well aware of the heat absorption characteristics of the darker coatings and utilize this to advantage during application. A dark primer or first coat over the sprayed urethane is recommended to produce a quick cure in cooler weather. This not only hastens the cure time for the first coat, but for the subsequent coat as well, because the first coat remains warmer. This makes the application of sprayed urethane systems possible in latitudes and seasonal conditions that may otherwise prevent their use.

Although only a few such examples have been investigated directly by the author, splitting failures of sprayed urethane roofs is quite widespread, according to technical discussions in meetings of the urethane contractors during their annual association conventions. Manufacturers have been asked for answers, and tests and surveys of contractors' experiences have been suggested. No recognition of splitting has been published or officially recognized, and an effective repair technique has not been found. *(Photo 4.)*

These two failed urethane roofs have been replaced with traditional BURs applied to new flat or tapered preformed foamed insulation of similar R value, and splitting has not occurred. This indicates that good tensile strength, rather than good elongation, should be sought in a roof membrane situated in cold regions.

CONCLUSION/RECOMMENDATIONS

Extensive studies of actual roofs under winter conditions are needed to determine which substrates and coatings or membranes are suitably resistant to ice action. It seems clear that high elongation is not the principle characteristic by which a roof covering should be judged.

Besides the urethane and coating branch of the roofing industry, makers of so-called single-ply modified bitumen systems, which are rapidly being accepted in the United States, need to determine whether their products should have high elongation properties or not.

The interests of roofing consumers and building owners would be well served by solutions to this growing problem.

REFERENCES

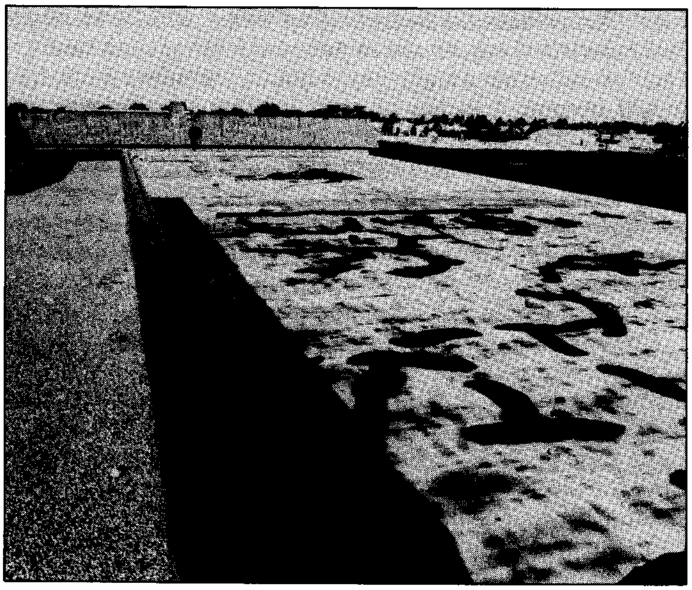
[1] National Bureau of Standards, Building Science Series 9 "Thermal Shock Resistance for Built-Up Membranes."

[2] CBD 24 December 1961.

[3] Handbook of Chemistry, Lange.

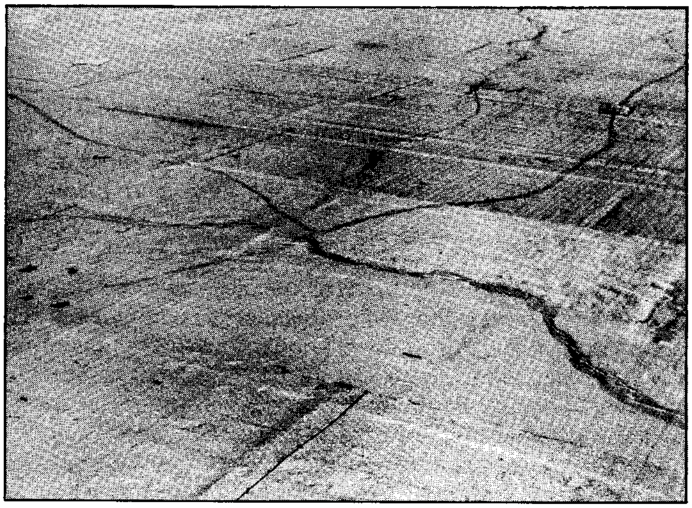
[4] Glacier, Time-Life Books.

[5] "Built-Up Roofing Problems in Cold Region," an outline of a talk by David Schaefer of the U.S. Army Cold Region Research and Engineering Laboratory (CRREL).



Photograph 1

Photograph 2



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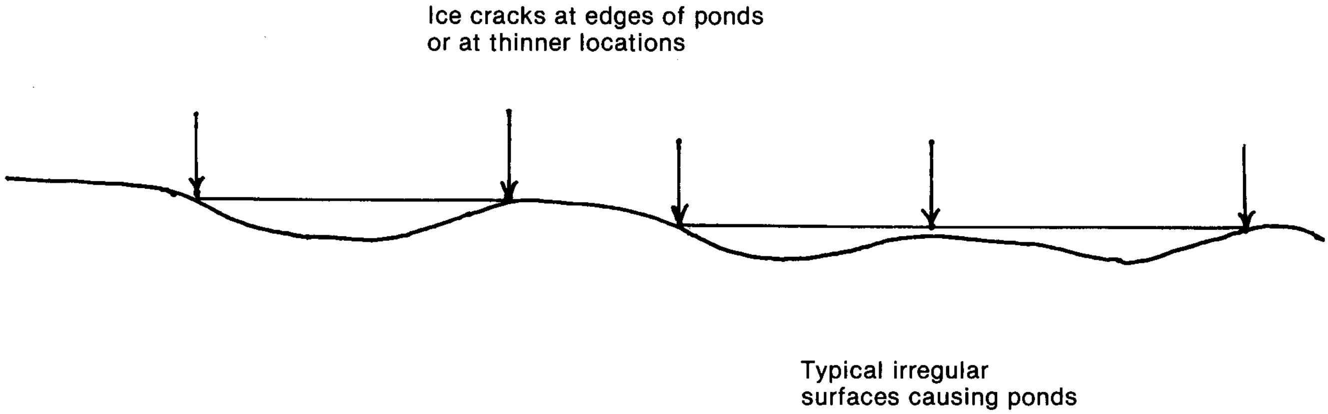
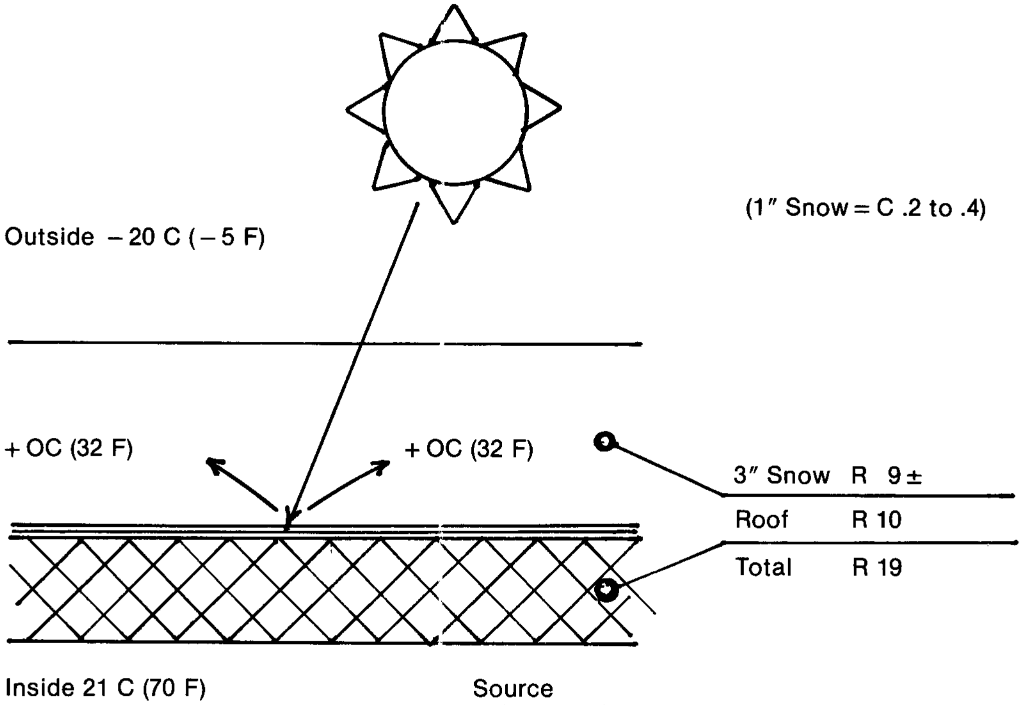


Figure 1



Source
U.S. Army Corps of Engineers
Cold Regions Engineering Laboratory

Figure 2