INVESTIGATION OF THE POTENTIAL OF ICE LENSES UNDER BUILT-UP ROOFS ON LIGHTWEIGHT INSULATING CONCRETE

JOHN E. JOHNSON
University of Wisconsin
Madison, Wis.

ERIC N. JOHNSON
Engineering Research Corp.
McFarland, Wis.

Ice lenses have been reported to have been found in the field between a built-up roof membrane and the supporting substrate below. As a result, concern has been voiced as to what effects such lenses have on the performance of the BUR.

The types of supporting substrates include a range of different materials such as structural concrete, lightweight insulating concrete, insulation boards, gypsum concrete, plus many others. One of these substrate materials, namely lightweight insulating concrete, was selected for study due to its initial high water content upon mixing.

The work reviewed in this paper reports on the potential of an ice lens bonding lightweight insulating concrete (LIC) to a built-up roof membrane (BUR). An ice lens is defined as a build-up of ice at the interface of the LIC and BUR in a nailed system which bonds the LIC to the BUR. The ice lens phenomenon reported in this work determines if an ice lens bond could exist, and if so, what effects it would have.

RESEARCH OBJECTIVES

The purpose of the work reported in this paper was to determine by laboratory tests if the potential for bonding exists. Also, in the event a bond does develop, does it have any detrimental effects on the LIC/BUR composite system. The tests concerning the ice lens phenomenon were separated into two areas. These areas were:

- tests performed under severe laboratory conditions.
- tests performed simulating realistic field conditions.

TESTS PERFORMED UNDER SEVERE LABORATORY CONDITIONS

The LIC/BUR composite was subjected to severe temperature gradients in order to form an ice lens which bonded the LIC to the BUR. The temperature gradient was established by using heat lamps to keep the bottom of the LIC slab at room temperature and using solid CO_2 (dry ice) to cool the top of the BUR. It should be noted that the temperature gradient across the test set-up was very severe and was approximately 150F. Once an ice lens bonded the LIC to the BUR, the effect of this bond was investigated. This involved testing a LIC/BUR composite which was bonded by an ice lens according to three combinations of loading which could take place in this composite system. These combinations of test loading conditions are:

1. Pulling on the BUR while holding the LIC fixed when the LIC/BUR composite is bonded by an ice lens.
2. Pulling on the BUR only when the LIC/BUR composite is bonded by an ice lens.
3. Pulling on the LIC only when the LIC/BUR composite is bonded by an ice lens.

Loading Condition 1

The purpose of this set of tests was to determine the effect of the bond created by an ice lens when the LIC is held fixed and the BUR is pulled. The moisture content of the LIC varied from 50 percent by weight to 149 percent by weight. Figure 1 is a diagram of the loading test set-up for this test. In each test, the bond strength of the ice lens was recorded for each moisture content. Table 1 shows the results of this test. At a 50 percent moisture content, eight out of 10 times the LIC did not bond to the BUR. Figure 2 is a graph showing the bond shear strength vs. moisture content for this test. The bond shear strength of the ice lens to the LIC is to a great extent a function of the shearing strength of the LIC itself. Even if an ice lens would be present under this loading condition, the ice lens bond in the interface fails in shear before any significant detrimental effects to the BUR or the LIC take place.

Loading Condition 2

The purpose of this test was to determine the effect of the bond created by an ice lens when the BUR was loaded in tension. Figure 3 is a diagram of the loading test set-up for this test. Ten samples were tested and the results are shown in Table 2.

As can be observed from the data shown in Table 2, the LIC slab falls off the BUR before the membrane fails. In other words, the ice lens bond fails before the membrane fails in tension and the LIC falls off undamaged.

Loading Condition 3

The purpose of this test was to determine the effect of the bond created by the ice lens when the LIC is loaded in tension. Figure 4 is a diagram of the loading test set-up for this particular test. Ten samples were tested and the results can be seen in Table 3. The LIC was loaded in tension and failed at the indicated stress. As the LIC failed in tension at the stress indicated, the BUR fell off the LIC undamaged. In other words, with an ice lens bond present, the LIC fails in tension prior to any significant detrimental effects to the BUR.

TESTS PERFORMED SIMULATING REALISTIC FIELD CONDITIONS

Tests were performed to determine the ranges of temperature gradients that are more realistically found in the field. Subjected to these less severe temperature gradients, the potential of an ice lens bonding the LIC to the BUR was investigated. The two areas tested were:

1. The determination of the temperature gradient profile across the LIC/BUR composite when subjected to more typical field temperature conditions.
2. Subjected to these less severe temperature conditions, what was the potential of an ice lens bonding the LIC to the BUR.

Test 1

Tests were performed determining the temperature gradient profile across the LIC/BUR composite when subjected to more realistic field temperatures. Temperatures were measured across the LIC/BUR composite. Figure 5 is a diagram of the test set-up. Various thicknesses of insulation were placed beneath the LIC to simulate various field conditions. The moisture content of the LIC in these tests varied between 0 percent moisture by weight and 100 percent moisture by weight. Preliminary results indicate that the temperature gradient across the LIC/BUR composite is greatly reduced when insulation is present and LIC has moisture.

Test 2

Tests were performed determining the potential of an ice lens bonding the LIC to the BUR when subjected to more typical field temperature conditions. In the performance of this test an environmental chamber test set-up was used. Twelve LIC/BUR composite samples of the LIC was varied between approximately 50 percent to 100 percent by weight. In all twelve cases, an ice lens did not bond between the LIC and the BUR.

CONCLUSIONS

The results of the research reported in this paper lead to these basic conclusions. They are:

1. In theory, and through severe conditions in laboratory experiments, the potential for bonding of the LIC and BUR by an ice lens caused by the temperature gradient across the LIC/BUR composite can develop.
2. Under field conditions, however, bonding by an ice lens rarely if ever exists when subjected to the normal temperature gradients which actually occur across the LIC/BUR composite.
3. Even if bonding would occur, it has no significant detrimental effects because the bond created by the ice lens will fail in shear in the LIC prior to any significant detrimental effects to the BUR or LIC.

The above results indicate that it is highly improbable that an ice lens bond of any kind develops as a result of the mixing water used in the LIC. However, the fact that ice lenses have been found, points to the need of establishing the source of the moisture required and the mechanism by which it enters the interface between the roof membrane and the LIC. Although this problem is currently being studied, the results are premature at this time and is beyond the scope of the work presented in this paper.

REFERENCES

[1] Griffin, C. W., *Manual of Built-Up Roof Systems*, Second Edition (1982), McGraw-Hill, Inc.

[2] Leiff, M., and Trechsel, H. R., "Moisture Migration In Buildings," ASTM Publication Code Number (PCN) 04-779000-1-, 1982.

[3] Reichard, T. W., "Mechanical Properties of Insulating Concretes," Tri-Service Projects-Departments of Army, Navy, and Air Force, 1961.

[4] Valore, R. C., Jr., "Insulating Concretes," Journal of the American Concrete Institute, 1956.

[5] Yen, Yin-Chao, "Review of Thermal Properties of Snow, Ice and Sea Ice," CRREL Report 81-10, United States Army Corps of Engineers, June, 1981.

SAMPLE	% MOISTURE	BOND STRENGTH (lbs/in²)
1	50	0
2	51	1
3	51	0
4	51	0
5	51	0
6	52	0
7	52	0
8	52	0
9	52	0
10	53	6
11	72	0
12	72	14
13	73	10
14	75	5
15	75	14
16	77	11
17	78	13
18	82	10
19	85	18
20	87	8
21	95	12
22	96	13
23	96	17
24	96	21
25	97	12
26	98	13
27	98	11
28	99	11
29	99	15
30	100	18
31	129	31
32	131	28
33	133	26
34	135	19
35	144	27
36	149	26

Table 1 Results of Loading Condition 1
(Pulling on the BUR while holding the LIC fixed when the LIC/BUR composite is bonded by an ice lens)

SAMPLE	ULTIMATE LOAD OF BUR (lbs)	LOAD AT WHICH ICE LENS BOND FAILED AND LIC SLAB FELL OFF (lbs)
1	645	522
2	655	305
3	602	406
4	669	120
5	622	170
6	595	60
7	659	659
8	618	618
9	566	476
10	785	750

Table 2 Results of Loading Condition 2 (Pulling on the BUR only when the LIC/BUR composite is bonded by an ice lens)

SAMPLE	ULTIMATE LOAD OF LIC (psi)
1	48
2	21
3	61
4	115
5	106
6	122
7	132
8	81
9	101
10	76

Table 3 Results of Loading Condition 3 (Pulling on the LIC only when the LIC/BUR composite is bonded by an ice lens)

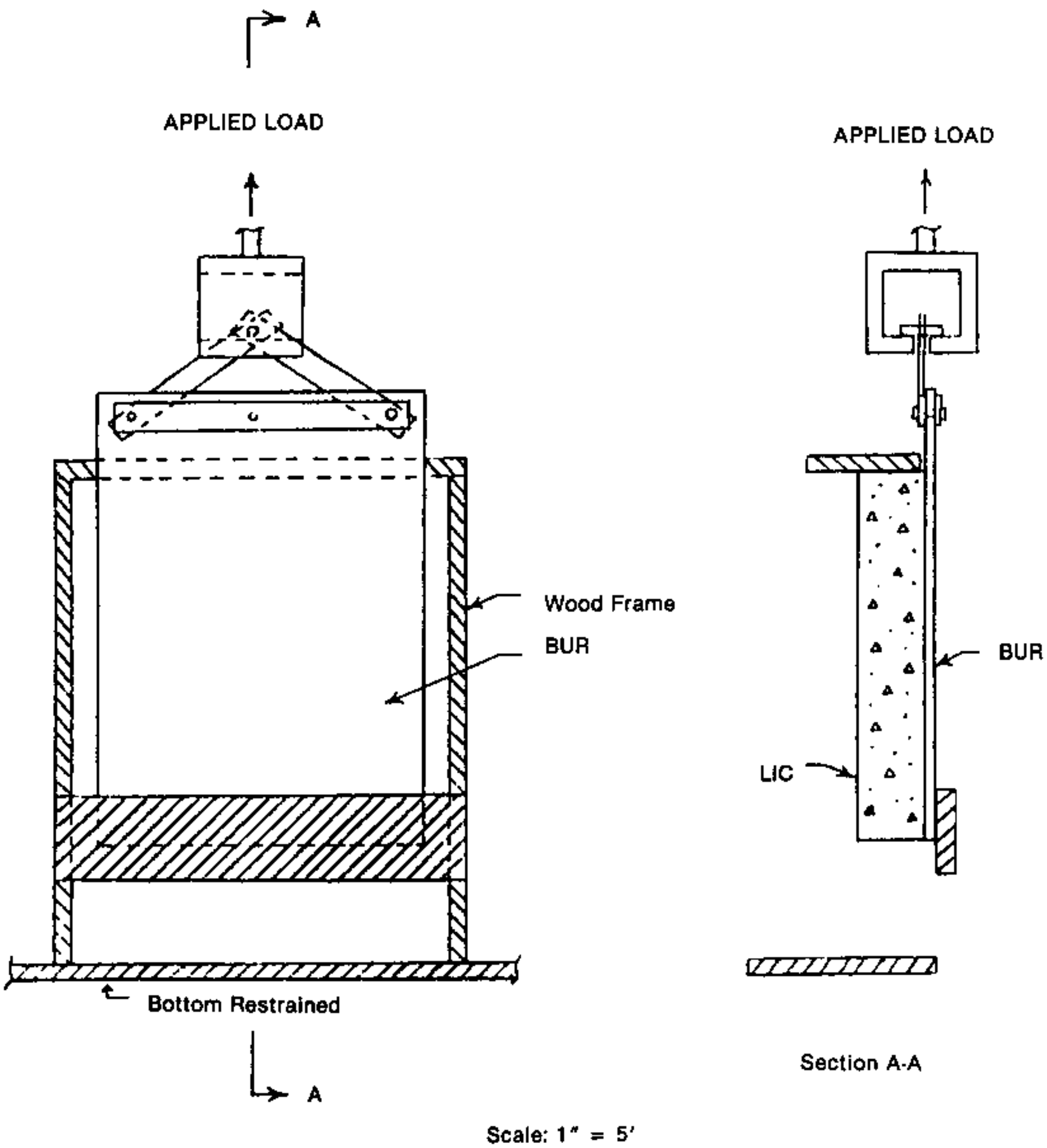

Figure 1 Diagram of the LIC/BUR composite ice lens bond shear strength test

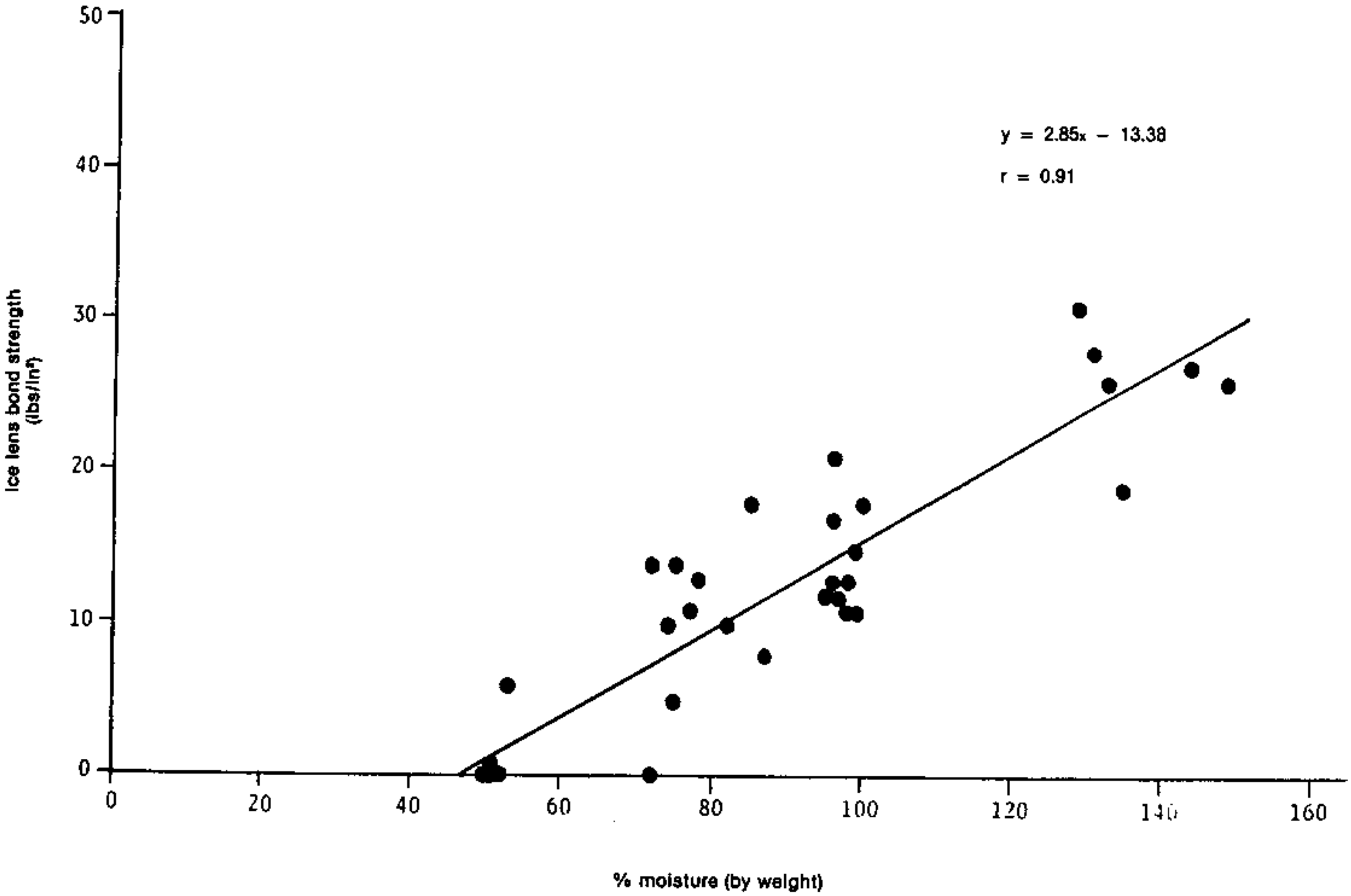

Figure 2 Ice lens bond strength vs. moisture content (tests performed under severe laboratory conditions)

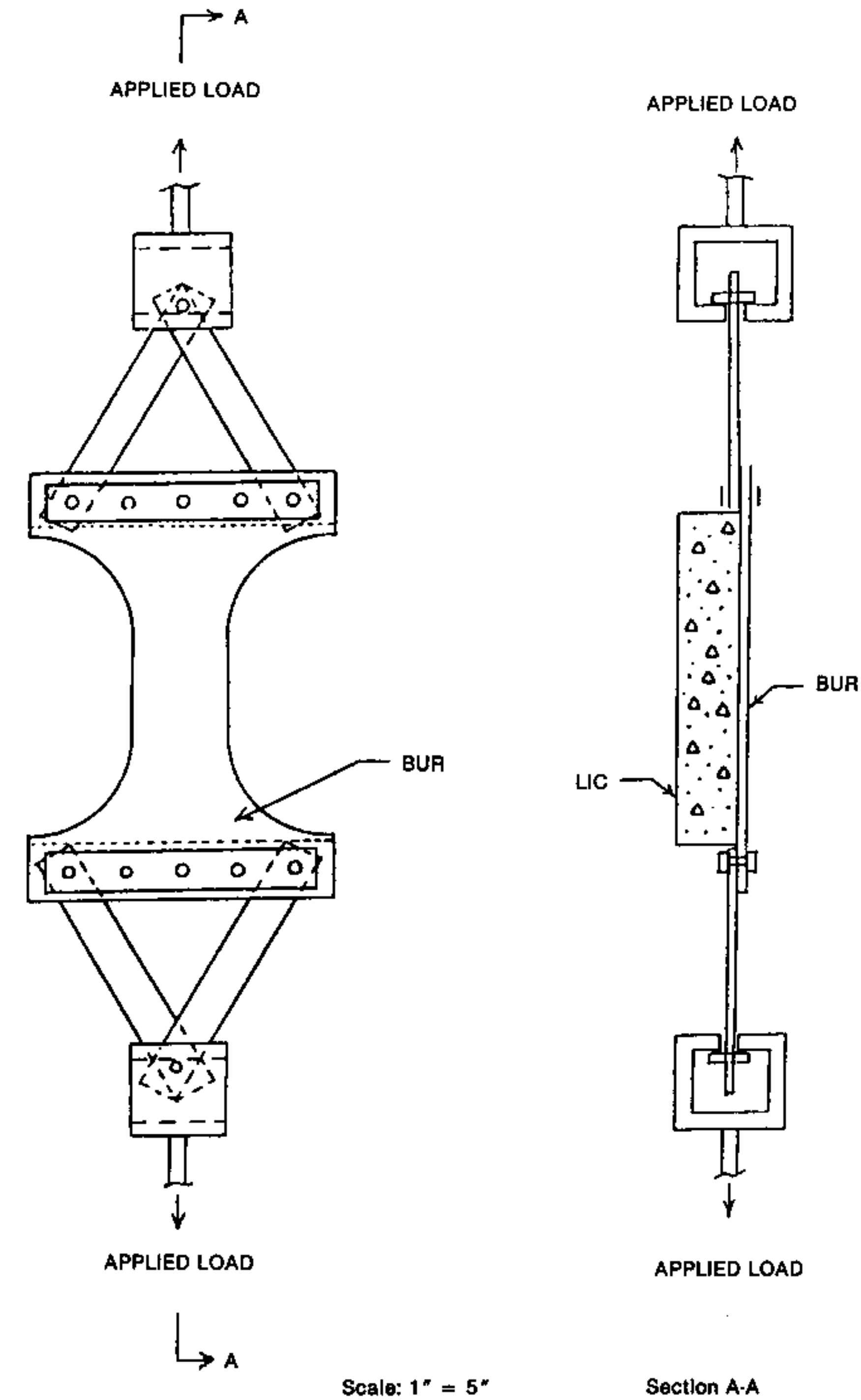

Figure 3 Diagram of the test set-up where the BUR only is loaded in tension when the LIC/BUR composite is bonded by an ice lens