EXPERIMENTAL DETERMINATION OF TEMPERATURE INDUCED LOADS IN BUR SYSTEMS

J. W. Lee, R. M. Dupuis, and J. E. Johnson
Engineering Research Consultants, Inc., Madison, Wisconsin, U.S.A.

INTRODUCTION

Forces generated in built-up roof systems due to temperature changes have been of special interest to groups involved in the production, design and construction of built-up roof systems. The contribution of thermally generated forces in different built-up roof systems is a well discussed subject throughout the industry. In order to better understand the behavior of built-up roof systems in relation with temperature changes, a research program was conducted to study the coefficient of expansion, the temperature induced load in membranes, as well as the temperature induced load in composite built-up roof systems.

In this paper, different types of organic felt membranes will be examined. The coefficient of expansion obtained by the strain gauge method will be presented. Experimental results of temperature induced loads for membrane alone as well as membrane-insulation built-up roof systems will be reported.

Four types of organic felts were considered in this report. They are listed as follows:

Asphalt saturated felt with perforations - Type I (ASTM D 226-75)
Asphalt cóated sheet (ASTM D 3158-72T)
Asphalt coated base sheet - Type I (ASTM D 2626)
Asphalt coated base sheet - Type II (ASTM D 2626)

The four types of felts are commonly referred to as the 15 pound vented felt, the 30 pound felt, and the 43 pound CBS, respectively, with the 43 pound CBS applying to both TYPE I and TYPE II of asphalt coated base sheet.

Two-ply and 4-ply membranes were constructed from the above felts with interply moppings of steep asphalt, plus glaze coat of steep asphalt. Note in table 1, that TYPE IIA and IIB samples are 2-ply membranes with CBS TYPE I and TYPE II respectively and TYPE IV samples are 4-ply membranes. All samples tested are uniform samples in the transverse direction of the roofing felt.

This research project indicates that the thermal characteristics of felts vary among rolls of similar felts. Therefore, even though the results define more quantitatively some of the membrane properties relating to temperature, relative results should be viewed more keenly between different types of membranes and built-up roof systems.

COEFFICIENT OF EXPANSION

In 1974, Mathey and Cullen (1) investigated the linear thermal expansion and contraction characteristics of different types of built-up roof membranes. They used a Whittemore Extensometer and reported results for built-up roof membranes constructed with a wide range of felt and asphalt/tar combinations. Since then, relatively little work has been published in that area.

In an effort to substantiate our temperature induced load data (presented later), the co-efficient of linear thermal expansion was determined for different types of membranes constructed with different types of organic felts and asphalt. Strain gauges were used to measure the change in the strain for different temperature ranges. Proper considerations were given to minimize any possible bending effect, and correlations made to account for the apparent strain induced by the temperature sensitivity of the strain gauges. A full bridge circuit was used for the strain determination.

It was found that the thermally induced strain can be described by means of an exponential curve with an arbitrary base strain of 1000 μ/in./in. Exponential regression analysis was used to determine the best fit curve for the thermally induced strain for different built-up roof membranes. The coefficient of expansion is then the differential of the thermally induced strain with respect to temperature.

The thermally induced strain for sample TYPE IIB and TYPE IV, together with the regression analysis curves are plotted in Figure 1. The resulting coefficients of expansion are tabulated in Table 2. The thermally induced strain for an asphalt coated base sheet - TYPE I is plotted in Figure 2. The CBS TYPE I was used in the construction of TYPE IIA samples. The resulting coefficients of expansion are tabulated in Table 3.

Figure 3 shows a plot of coefficients of thermal expansion for a different but representative felt, membrane, and asphalt. Qualitatively, it shows that the asphalt has a much higher coefficient of thermal expansion than the felt, which has a coefficient of thermal expansion close to that of the built-up roof membrane. It is evident that the coefficient of expansion of the built-up roof as relating to the asphalt and the felt follows some simple mathematical rules. However, the applicability of the law of mixtures cannot be verified due to the lack of information on the mechanical properties of the asphalt.

In view of the above observation it is interesting to note that the coefficient of thermal expansion for the coated base sheet – TYPE I is quite different from that for TYPE IIB membrane which utilizes asphalt coated base sheet – TYPE II. Based on the fact that 43 pound coated base sheet could be ASTM D 2626 CBS TYPE I or TYPE II, the difference in coefficient of thermal expansion reported herein suggested that the thermal expansion properties of similar felts could be vastly different.

TEMPERATURE INDUCED LOAD IN ORGANIC MEMBRANES

Temperature Induced Load Tests

The temperature induced load experiments were designed to investigate the amount of forces generated in a specimen due to temperature changes. During the experiment, the ends of a specimen were held at constant lengths while a drop in temperature was effected. The restraint at the ends of the specimen, coupled with the specimen's natural tendency toward shrinkage produced the induced forces. The magnitude of the forces is dependent on the coefficient of expansion as well as the modulus of elasticity of the specimen.

To approximate the boundary conditions of a typical element in a large roof, loads are induced into the test specimens by keeping their lengths constant and lowering the temperature. Practically, however, the load measuring dynamometer will deflect as the loads are being induced. Therefore, to keep the specimen's length constant, corrections must be made to account for the dynamometer head deflections.

Schematically, we could consider the dynamometer as an elastic spring with a specimen hooked up in series. As shown in Figure 4, while the temperature is dropping, the specimen tends to contract and at the same time the dynamometer head will deflect a certain amount. The first deflection correction is then made equal to the deflected amount of the dynamometer head. The final correction is derived as follows:

Denoting the spring constant of the dynamometer head as K and that of the specimen as K with deflection noted in Figure 4 we get

$$K_s = \frac{P_2 - P_1}{2\Delta_1 - d_2} \qquad (1)$$

where:

$$d_2 = \frac{P_2 - P_0}{K_d} \qquad (2)$$

and the final correction, Δ_2:

$$\Delta_2 = \frac{K_s}{K_d}\Delta_1 \qquad (3)$$

$$\text{Total Induced Load} = P_3 - P_0 \qquad (4)$$

To check the correction, the dynamometer head deflection and the correction applied can be compared:

$$\text{Head Deflection} = \frac{P_3 - P_0}{K_d} \qquad (5)$$

$$\text{Total Correction} = \Delta_1 + \Delta_2 \qquad (6)$$

$$\%\ \text{Difference} = \frac{\text{Head Deflection} - \text{Total Deflection}}{\text{Head Deflection}} \qquad (7)$$

The loads were induced by lowering the temperature from 70°F to – 20°F.

TEST RESULTS FOR 2-PLY AND 4-PLY BUILT-UP ROOF SPECIMENS

Load inducement experiments were conducted on 2-ply and 4-ply built-up roof membranes. These specimens were designated as Sample Type IIB and Sample Type IV for 2-ply and 4-ply built-up roof membranes respectively. The sample membranes were tested in the transverse (cross) direction of the felts. Starting at approximately 70°F, temperature was stabilized at approximately 30°F, 0°F and - 20°F. The previously described procedures were applied and the resulting loads recorded.

The resulting loads induced at various temperatures for the Type IIB samples (2-ply) and Type IV samples (4-ply) are plotted in Figure 5. Note that in Fig. 5, temperature **decreases** from left to right. To visually define the pattern of the induced load, straight lines were used in joining the averages of each group of experimental points. Averages of the experimental results are listed in Table 4.

It is interesting to note that Sample IIB and Sample IV have similar slopes as well as similar induced load magnitudes for temperatures of 30°F and 0°F. However, the load induced from 0°F to - 20°F indicates a considerably higher magnitude for the 4-ply samples as compared to the 2-ply samples. The one important result from this experiment is that on a **force per ply** basis, the 4-ply samples have a much lower induced load as compared to the 2-ply samples.

The effects of the thickness of interply asphalt moppings on the magnitude of temperature induced load were also investigated. The 2-ply results reported in Figure 5 and Table 4 were normal Type IIB samples with an average sample thickness of 0.266". Two other groups of samples of Type IIB were constructed to the thickness of 0.359" and 0.196", each group consisting of three samples. Figure 6 shows the average magnitude of the induced load with the average thickness of the samples. As shown in Figure 6, the induced load for the normal and thin samples were similar. However, the increase in the induced load was significant for the thick sample. It is, therefore, apparent that up to a certain thickness, the presence of interply asphalt in a 2-ply membrane will have little effect on the temperature induced load. However, for membranes with thick interply asphalt, the presence of the excessive asphalt will prompt $ significant increase in the temperature induced load.

TEMPERATURE INDUCED LOAD IN COMPOSITE BUR SYSTEMS

To investigate the forces induced in built-up roof systems with various insulations, composite samples of 2-ply and 4-ply BUR together with various insulations attached to the BURs by means of steep asphalt, were tested using the temperature induced load procedure. The samples were approximately 20" in length, with the transverse (cross) direction of both the felts and the insulations as the longitudinal directions of the samples. The geometric dimensions of the samples are shown in Figure 7.

The BUR membranes used in the composite construction are similar to the ones reported earlier as TYPE IIA and TYPE IV for the 2-ply and 4-ply membranes respectively. However, the BUR membranes are made from different rolls of felts which had thermal expansion characteristics similar to that reported earlier for the CBS TYPE I. Therefore, the induced load results of the composites should not be compared directly with the induced load results of the membranes reported previously.

To simulate the field condition, a hardwood board was used as a substrate to restrain lateral movements of the samples. The arrangements resembled the reaction of a BUR system with the insulation **not attached** to the substrate. However, uniform temperature change was induced into the entire sample as contrast to a temperature gradient through the vertical cross sections for BUR systems on an actual roof.

Five types of insulations were used in the sample construction. Both 2-ply and 4-ply samples were tested. The sample types are listed in Table 5.

Average loads induced in various samples as a result of temperature drop from 70°F to - 20°F are listed in Table 6. For comparison purposes, two bar charts showing the magnitude of loads in the 2-ply and 4-ply samples are presented in Figure 8. For 2-ply systems, the composite samples with fiber glass, wood fiber board and bare polyurethane as insulating materials all had similar induced loads. The 2-ply extruded expanded polystyrene composite had a slightly lower induced load while the 2-ply perlite composite had the lowest induced load. The same can be observed for the 4-ply composite samples except for the fiber glass composite. Two different boards were used in constructing the 4-ply fiber glass composite samples and the 2-ply fiber glass composite samples. The two boards behaved quite differently although they bear the same identification. Therefore, the result for 2-ply composite with fiber glass should not be compared directly with that of the 4-ply composite. The other interesting aspect of the results is that in general, (except for the fiber glass composite) the 4-ply composites only generated slightly higher induced loads. Therefore, the **load per ply** generated within the 4-ply composites is actually lower than that of the 2-ply composites.

CONCLUSIONS

As a result of this study on thermally induced loads, the behaviors of 2-ply and 4-ply built-up roof membranes as well as composites with various insulation materials were documented. From the data presented in this paper, together with the qualitative evaluations of various felts and insulating materials, the following observations were made:

1. The variation in the coefficient of thermal expansion could be large between different rolls of felts with similar identifications.
2. With care, the strain gauge technique can be applied to roofing studies. Proper precautions, however, must be taken to guard against erroneous results generated from using the wrong type of gauges, inadequate adhesion between gauge and specimen, the apparent strain induced due to temperature, etc.
3. A reduction from the normal amount of asphalt used as interply moppings between felts will not alter significantly the magnitude of load induced by temperature change. However, an excessively thick coat of asphalt used as interply moppings could magnify the induced load in the membrane significantly.
4. On a **per ply** basis, the 4-ply membranes produced much lower induced loads than the 2-ply membranes.
5. Except for the perlite composite, all other composite samples with similar built-up roof membranes had similar induced loads with the 1" extruded expanded polystyrene composite exhibiting a slightly lower induced load.

The temperature induced load experiments presented herein illustrate the behavior of built-up roof systems due to thermal effects. The experiments conducted on membranes alone and on composite samples both indicated lower induced loads for the 4-ply system on a **per ply** basis. Note that the weight of desaturated felt for each of the 15 pound organic felts used in the 4-ply system is similar to the 30 pound organic felt used in the 2-ply system. Therefore, the resistance to the thermal generated loads is far better for the 4-ply system than the 2-ply built-up roof system. Due to the variations in felt properties, it is felt that the results presented herein should be viewed more appropriately in a relative sense rather than in an absolute sense.

Obviously, there are other factors which affect the behavior of built-up roof systems and should be investigated. Topics such as moisture effects, creep studies, strength and moduli studies are currently on the authors' agenda of continuing research work in the roofing area.

ACKNOWLEDGEMENT

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REFERENCE

1. R. G. Mathey and W. C. Cullen, "*Preliminary Performance Criteria for Bituminous Membrane Roofing,*" U.S. Department of Commerce, National Bureau of Standards, November, 1974.

TABLE 1
MEMBRANE SAMPLES

SAMPLE TYPE	BASE PLY	TOP PLY(S)
IIA (2-PLY)	ASTM D2626 - Type I Asphalt Coated Base Sheet (43 lb)	ASTM 3158 - 72T Asphalt Coated Sheet (30 lb)
IIB (2-PLY)	ASTM D2626 - Type II Asphalt Coated Base Sheet (43 lb)	ASTM 3158 - 72T Asphalt Coated Sheet (30 lb)
IV (4-PLY)	Asphalt Coated Base Sheet (43 lb)*	ASTM D226-75 - Type I Asphalt Saturated Felt With Perforations (15 lb)

* This felt is commonly called a coated base sheet by the manufacturer, and is commonly used as a base sheet. However, it did not meet ASTM D2626.

NOTE: All materials were randomly selected from roofer's warehouse stock.

TABLE 2
COEFFICIENTS OF THERMAL EXPANSION FOR SAMPLE TYPE II B AND TYPE IV IN THE TRANSVERSE DIRECTION

T, TEMPERATURE (°F)	α, COEFFICIENT OF THERMAL EXPANSION (X 10^{-6} IN/IN/°F)	
	SAMPLE TYPE IIB	SAMPLE TYPE IV
	$\alpha = 31.30e^{-0.0124T}$	$\alpha = 26.16e^{-0.0116T}$
70	13.14	11.61
50	16.84	14.65
30	21.58	18.47
10	27.65	23.29
0	31.30	26.16
-10	35.43	29.38
-30	45.40	37.05

NOTE: NEGATIVE SIGN INDICATES EXPANSION IN RESPONSE TO A TEMPERATURE DROP.

TABLE 3
COEFFICIENT OF THERMAL EXPANSION
FOR CBS TYPE I IN THE TRANSVERSE DIRECTION

T, TEMPERATURE (°F)	α, COEFFICIENT OF THERMAL EXPANSION ($\times 10^{-6}$ IN/IN)
70	8.94
50	10.51
30	12.36
10	14.53
0	15.75
-10	17.08
-30	20.08

$$\alpha = 15.75e^{-0.0081T}$$

TABLE 4
AVERAGE INDUCED LOAD DUE TO TEMPERATURE CHANGE IN 2-PLY
AND 4-PLY SAMPLES IN THE TRANSVERSE DIRECTION

SAMPLE TYPE IIB		SAMPLE TYPE IV	
TEMPERATURE (°F)	INDUCED LOAD (LBS/IN)	TEMPERATURE (°F)	INDUCED LOAD (LBS/IN)
70	0	72	0
30	9.1	29	9.8
3	27.8	0	30.2
-17	52.3	-19	71.4

TABLE 5
SAMPLE TYPE CONSTRUCTION

TYPE OF INSULATION	THICKNESS	C*	BUR	
			2-PLY	4-PLY
1) WOOD FIBER BOARD	1-1/2"	.26	II A 1	IV 1
2) EXTRUDED EXPANDED POLYSTYRENE	1"	.19	II A 2	IV 2
3) FIBER GLASS	1-7/8"	.13	II A 3	IV 3
4) PERLITE	2"	.19	II A 4	IV 4
5) BARE POLYURETHANE	1-1/2"	.11	II A 5	IV 5

* BASED ON DATA FROM ASHRAE HANDBOOK OF FUNDAMENTALS, 1972, 1977. (BTU/HR FT^2 °F)

TABLE 6
TEMPERATURE INDUCED LOADS IN COMPOSITE SAMPLES (LBS/IN)

TYPE OF INSULATION	BUR	
	2-PLY	4-PLY
1) WOOD FIBER BOARD	14.3	17.1
2) EXTRUDED EXPANDED POLYSTYRENE	10.1	11.8
3) FIBER GLASS	15.8	7.67
4) PERLITE	4.94	7.67
5) BARE POLYURETHANE	14.7	16.0

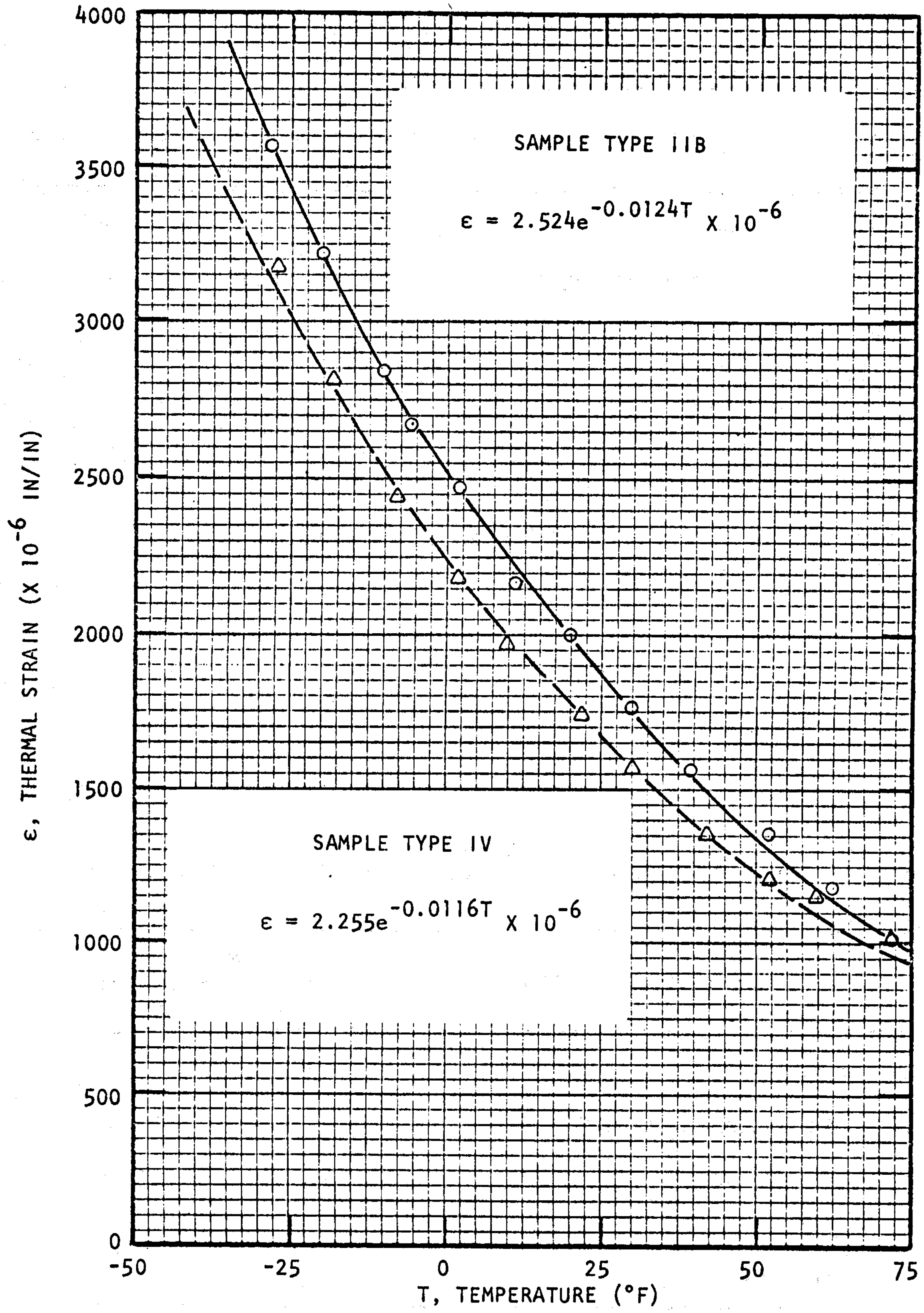

FIGURE 1 - THERMALLY INDUCED STRAIN FOR SAMPLE TYPE IIB AND IV IN THE TRANSVERSE DIRECTION

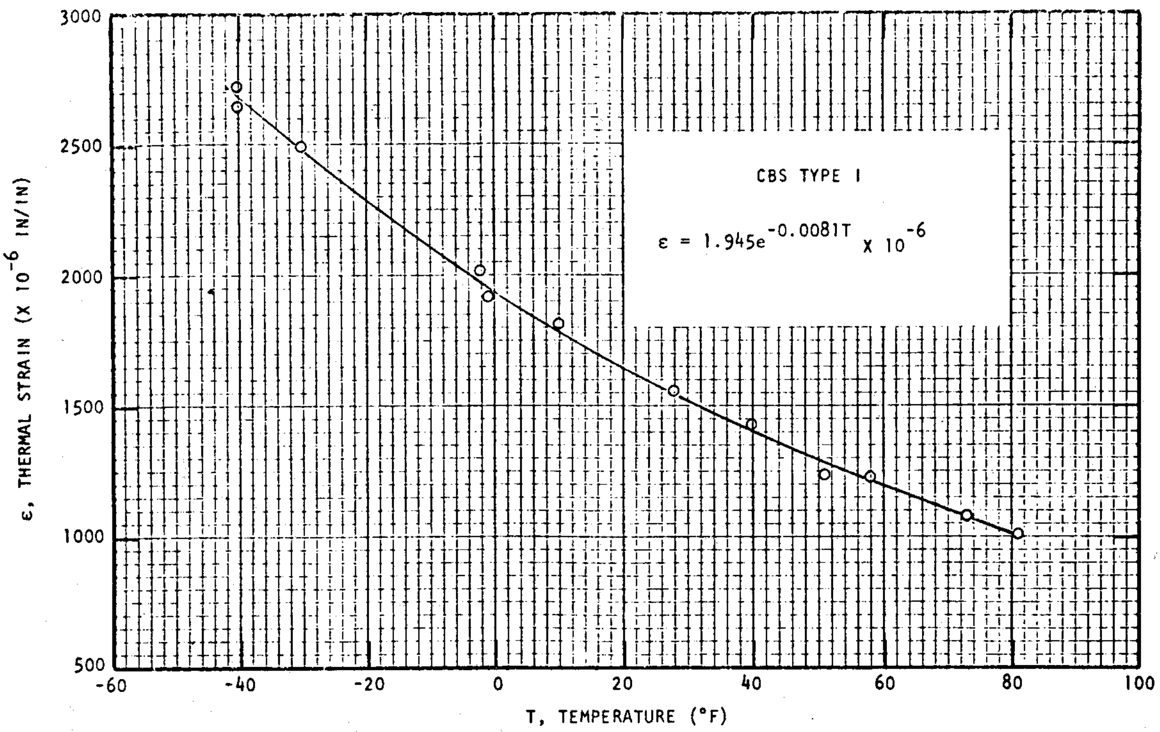

FIGURE 2 - THERMALLY INDUCED STRAIN FOR ASPHALT COATED BASE SHEET (CBS) - TYPE I IN THE TRANSVERSE DIRECTION

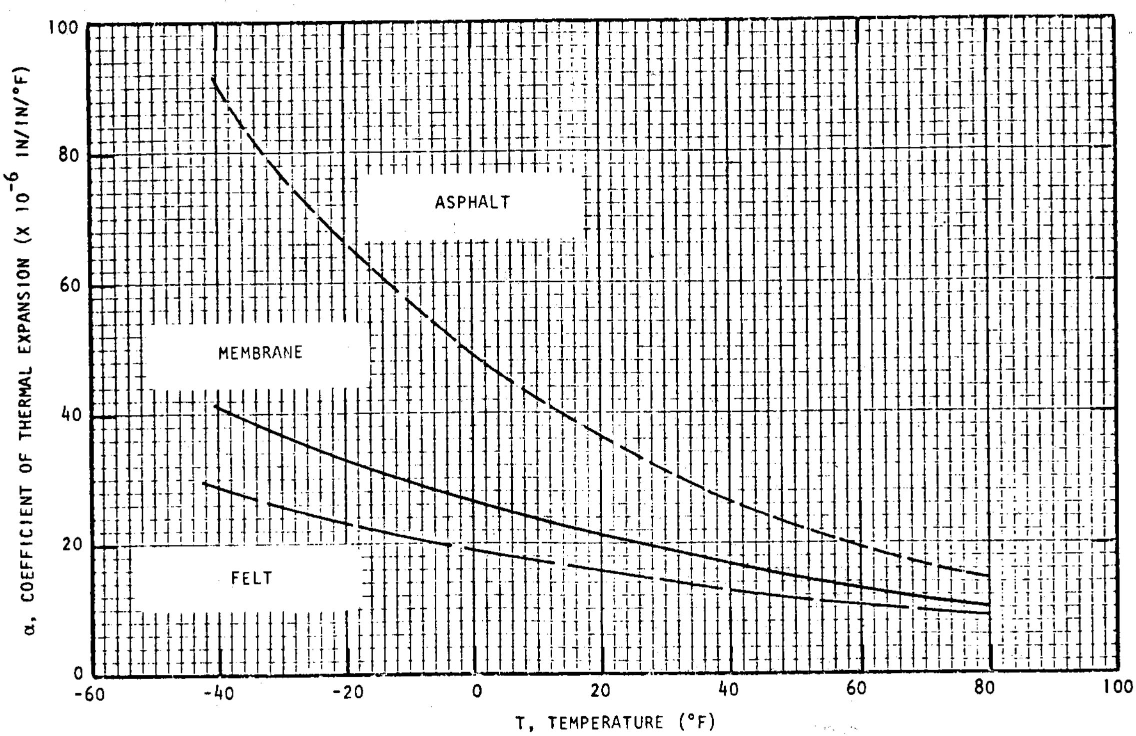

FIGURE 3 - COEFFICIENT OF THERMAL EXPANSION FOR FELT, MEMBRANE AND ASPHALT

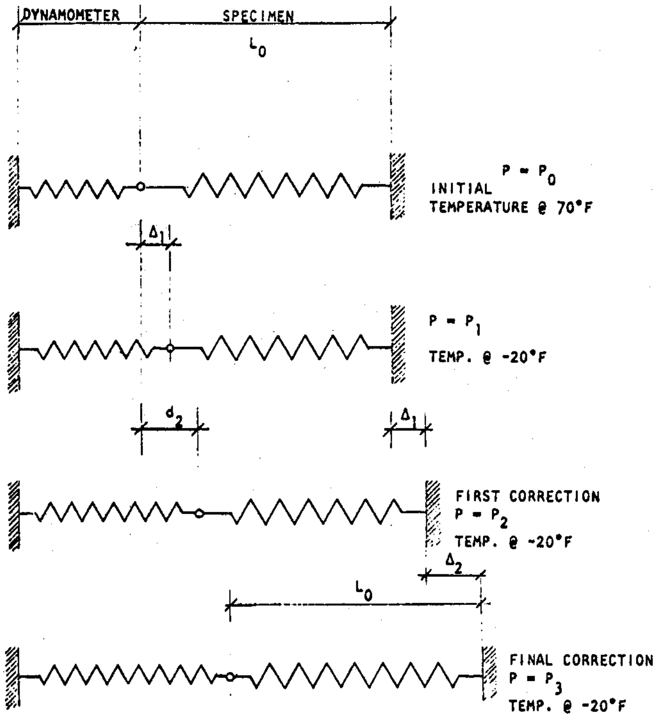

FIGURE 4 - TEMPERATURE INDUCED LOAD MODEL

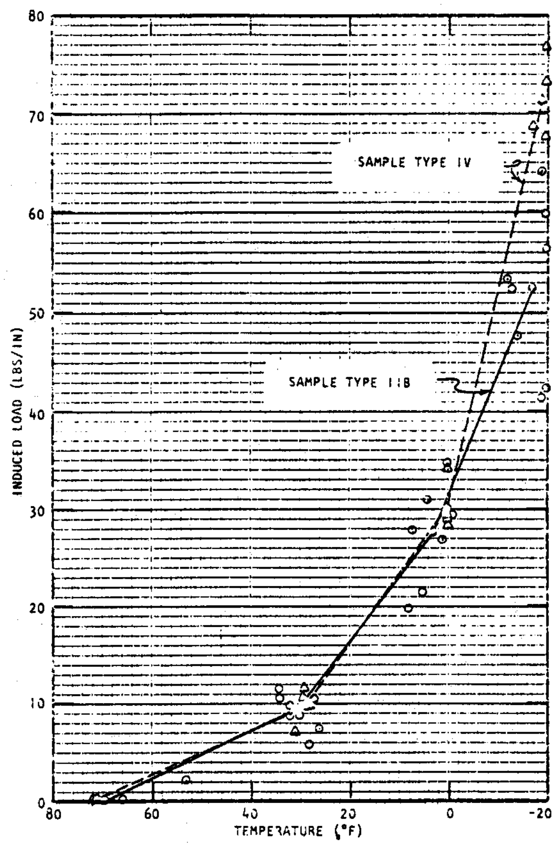

FIGURE 5 - LOAD INDUCED BY TEMPERATURE CHANGE FOR 2-PLY AND 4-PLY SAMPLES IN TRANSVERSE DIRECTION

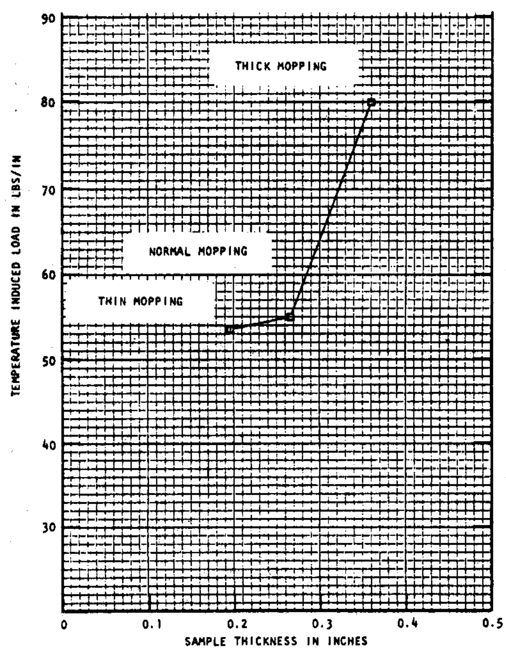

FIGURE 6 - EFFECT OF AMOUNT OF INTERPLY ASPHALT ON INDUCED LOAD FOR 2-PLY MEMBRANES

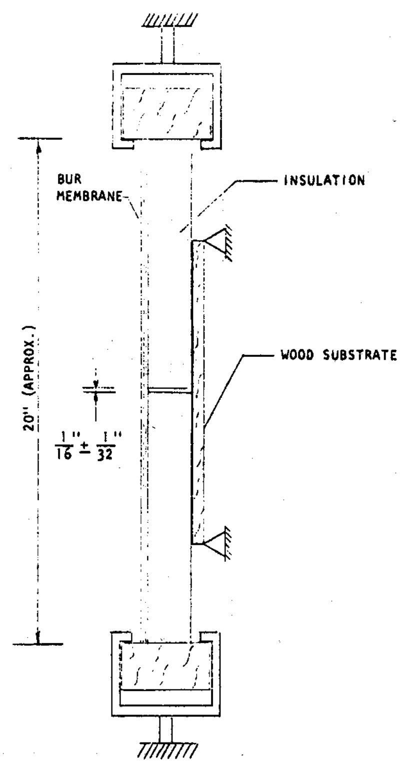

FIGURE 7 - COMPOSITE SAMPLE

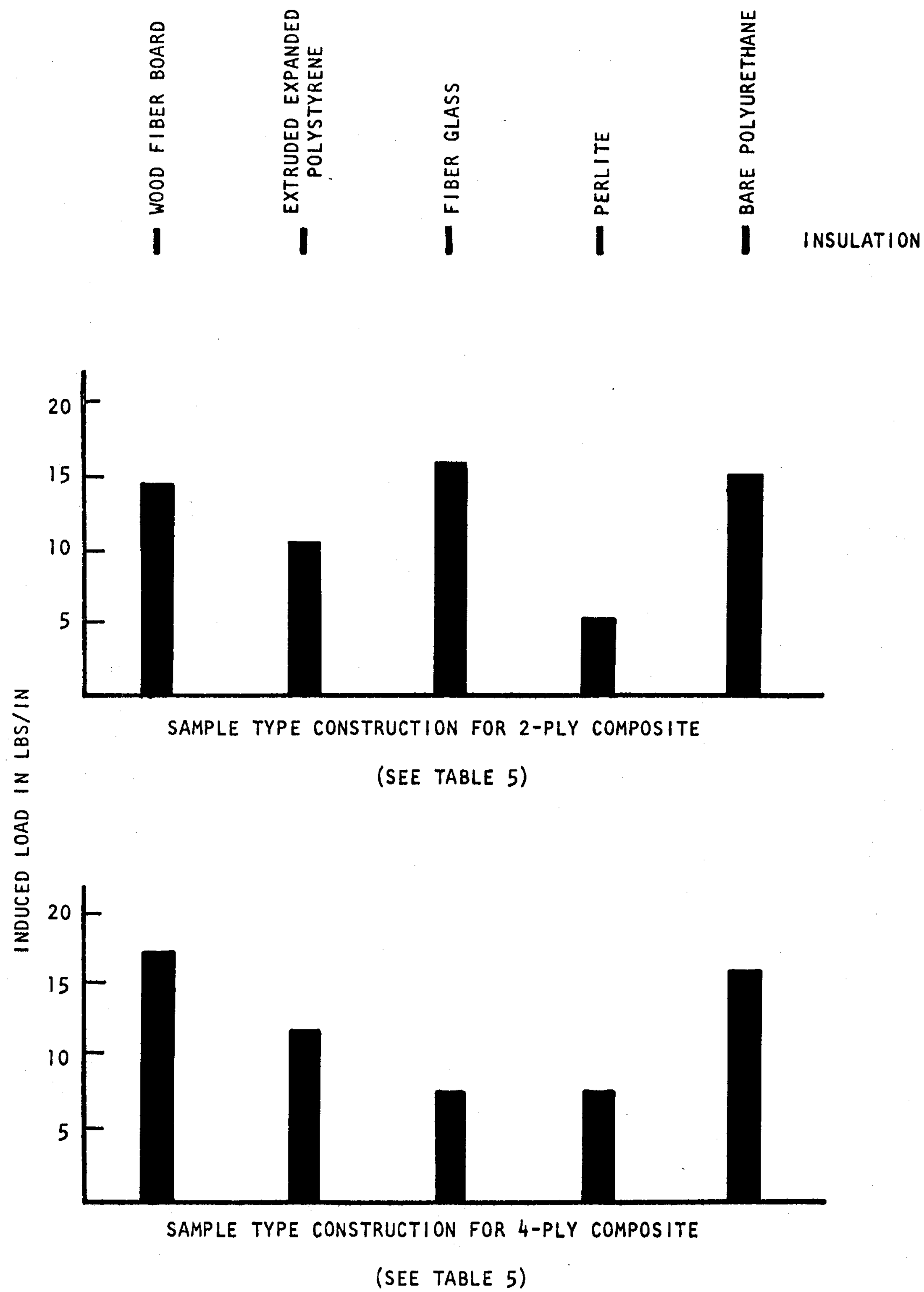

FIGURE 8
TEMPERATURE INDUCED LOAD COMPARISON CHARTS