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CONCRETE BLOCK PAVEMENTS ON ASPHALT HIGHWAYS

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SUMMARY

This paper introduces a method of paving with thin concrete blocks, and compares it to conventional asphalt paving commonly used in Hokkaido, Japan's northernmost main island. Located just southwest of the Kuriles, Hokkaido experiences some of the severest climatic conditions in the country, ranging from -35 degrees C in winter, to 35 degrees C in summer. These extremes in temperature are only partially responsible for the strain on roads, however. Pavements also take a beating because vehicles are required to use studded tires in winter. For all their advantages in improving traction, studded tires introduce almost as many problems as they solve, increasing the burden on road maintenance, for instance. And recently, environmentalists and those concerned with public health have expressed alarm over the increase in air pollution resulting from asphalt dust, a byproduct of studded tire wear on regular pavements.

Concrete, if used as is, carries its own set of problems, particularly in a cold region. The proposed remedy discussed here is to reduce the concrete surface down to an orderly mosaic of small blocks, applied directly to the existing asphalt road surface with an adhesive. The blocks are limited in size to 150 mm x 150 mm. The size and method of placement are critical to the success of this system, and set it apart from conventional road construction technology using concrete.

NOMENCLATURE

SYMBOL	VARIABLE	TYPICAL UNITS
a	block thickness	cm
b	block length	cm
c	subgrade coefficient	kg/cm^2
e	thermal expansion coeffcient	degree C
h	elastic depth of foundation	cm
S	normal loading stress	kg/cm^2
S_0	tire pressure	kg/cm^2
S_t	thermal stress	kg/cm^2
E	elastic modulus of concrete	kg/cm^2
G	shear modulus	kg/cm^2
M	bending moment	kgcm
I	secondary moment of section	cm^4
T	temperatures	degreeC
P	concentrated load	kg
Q	shear force	kg

other symbols,not listed here,are defined at an appropriate point.

I. INTRODUCTION

In a region like Hokkaido, where a combination of heavy snowfall and narrow but well-trafficked roads necessitate the use of studded tires, concrete clearly is preferable to asphalt. Road maintenance costs are higher with asphalt, which tends to soften into ruts in summer, and erode from the punishment inflicted by studded tires in winter. The dust created also poses a major pollution problem.

Several major drawbacks must be overcome, however, for concrete to become a vialbe alternative to asphalt:

——Initial higher construction costs for concrete;

——Time-consuming construction and maintenance, putting roads out of comission for longer periods of time;

——Less flexibility in relation to shifts or movement in the road foundation, and

——Lower ability to absorb vehicular noise.

These obstacles can be overcome by using small thin blocks instead of the standard solid concrete surface.The scope of this study was to determine the optimal block size and adhesive layer and to assess the thermal effects of this method of road construction.

1.Block Size;Small is Better

a)The size of the block directly determines its ability to absorb stress.The smaller the block, the greater its capacity to bear high levels of vehicle weight.This relationship was determined according to the stress function equation.In calculating stress loads,it was assumed that adverse was not distributed evenly over the block surface(B.S.),but rather,was concentrated at one point.The maximum stress for a vehicle load is is determined by the ratio of the block's thickness to its width.

b)Smaller blocks also possess a greater capacity to absorb thermal stress,since they do not expand as much as large blocks and are therefore less susceptible to breaking.

c)A concrete overlay is useful for lowering temperatures of foundation asphalt in summer,and good results are achieved even if the concrete layer is thinner than that used in conventional pavement.

d)Small blocks are easier to install than large blocks,which usually must be cut to fit the road surface in the corner.This is useful both during initial installation,and later on,during extraneous road work such as the laying of sewer lines,which necessitates the removal of the road surface.With conventional road surfaces, such repairs leave an uneaven or marred face.But small blocks can be replaced leaving no trace of sewer or other work below.

2. Adhesive Instead of Sand

a) Traditional maintenance work on roads with blocks involves replacing the damaged road portion in part or completely with a wide band of sand, placing blocks on top. But the proposed system saves time and money by avoiding that step altogether. The injured road surface is simply covered with a thin asphaltic adhesive, laying blocks on top.

Experimental results demonstrate that the adhesiveis an effective means of holding the blocks in place, thus proving groundless any psychological fears drivers may have that the vacuum caused by passing traffic could send blocks flying as dangerous projectiles.

b) The adhesive layer also prevents water from seeping into the roadbed and causing damage associated with expansion and contraction during freezing and thawing. This is particularly important in cold areas like Hokkaido.

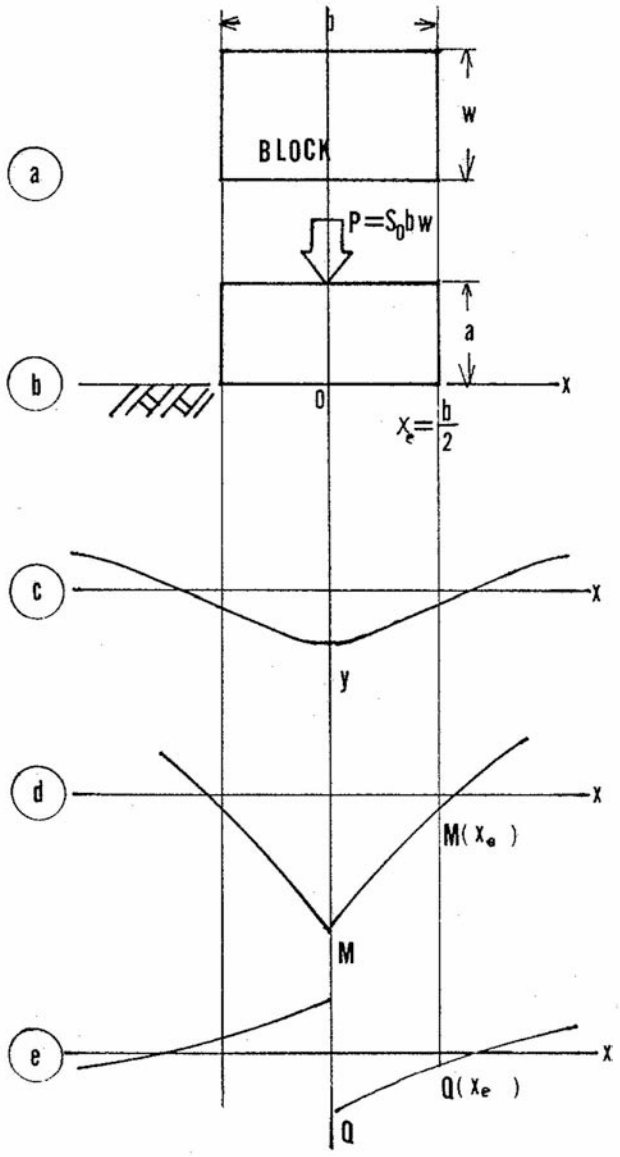


Fig.1.Bending behaviour of a block subjected to a traffic load.

II. STRENGTH OF BLOCKS

The strength of the blocks is dependent on a host of factors, such as block size and the condition of the foundation. This study assumed traffic loads exerting 5.5 kg/cm² of the maximum pressure on the road surface, a subgrade coefficient greater than 1,000 kg/cm², and an elastic modulus of concrete of 400,000 kg/cm². The most adverse case was assumed to be a concentrated load, wheel pressure multiplied by wheel area, as if the tire were on a stiff rod on the block. Since experience testifies that cracks in thin plates on the road surface usually occur at the center of the plate, fracture of the block may be calculated from the stress value at the center. The stresses can vary according to the state of the foundation, particularly the condition of the adhesive between the block and the foundation. Blocks placed on an elastic foundation are subject to tensile stress; blocks joined to the foundation are subject to compressive stress.

1. Blocks on Elastic Foundation

The calculation steps are shown in Fig.1. Stress value is derived by itteration. The first step is to calculate the deformation and other section forces, with block length at infinity. Then the differential equation with deflection y is

$$d^4y/dx^4 + 4v^2 y = 0 \quad \text{.....(1)}$$

where $v = \sqrt[4]{(cw/4EI)}$

Boundary conditions are

$$dy/dx = 0 \text{ and } d^3y/dx^3 = 0 \text{ at } x = 0 \quad \text{and}$$

$$y = 0 \quad \text{at } x = \infty$$

Thus the first approximations can be obtained as follows;

$$y=(w S_0/2c) \exp(-vx) (\cos vx + \sin vx) \quad \text{...(2)}$$

$$M=(bwS_0/4v) \exp(-vx) (\cos vx - \sin vx) \quad \text{...(3)}$$

$$Q=-(bwS_0/2) \exp(-vx) \cos vx \quad \text{.....(4)}$$

Since the block length is not infinite,both the bending moment and the shear force should be zero at both ends of the block,$x_e = b/2$.

The next step is to apply the negatives of the bending moment ,$M(x_e)$,and the shear force,$Q(x_e)$, obtained at the block ends,to calculate the deformations and section forces again.The itteration must be continued until the calculated results approach the previous results.The calculated results for varying subgrade coefficients are shown in Table 1,where the assumptions are made as follows;E=140,000kg/cm² and S_0 =5.5kg/cm²

Table 1.Tensile stress due to bending moment

a	b	C=1000 (kg/cm)	C=2000 (kg/cm)	C=3000 (kg/cm)	C=4000 (kg/cm)	C=5000 (kg/cm)	C=10000 (kg/cm)
1	5	102.564	95.5817	90.9296	87.3689	84.4602	74.6646
2	5	29.327	28.3196	27.6361	27.1037	26.6616	25.1115
3	5	13.6422	13.3204	13.1022	12.9322	12.7908	12.2925
4	5	7.85678	7.71319	7.61599	7.5403	7.47739	7.2558
5	5	5.10244	5.02547	4.97345	4.93298	4.89938	4.78111
1	10	269.924	225.897	200.285	182.676	169.539	132.972
2	10	95.5817	87.3689	81.9913	77.9352	74.6646	63.9669
3	10	47.5902	44.8721	43.0459	41.6375	40.4793	36.5165
4	10	28.3196	27.1037	26.2805	25.641	25.1115	23.2686
5	10	18.7492	18.1003	17.66	17.3171	17.0324	16.0342
1	15	379.854	297.871	258.366	234.485	218.274	179.01
2	15	167.579	143.482	128.938	118.653	110.801	87.9261
3	15	90.9296	81.9913	76.2216	71.9205	68.487	57.504
4	15	56.4325	52.2737	49.5168	47.4157	45.706	39.9983
5	15	38.286	36.033	34.521	33.3562	32.3993	29.133
1	20	451.172	361.36	322.716	299.865	284.047	241.355
2	20	225.897	182.676	159.238	143.933	132.972	104.643
3	20	134.141	115.217	103.741	95.5964	89.3595	71.0782
4	20	87.3689	77.9353	71.9205	67.4809	63.9669	52.9308
5	20	61.0057	55.7221	52.2651	49.6592	47.5591	40.6981
1	25	533.242	446.349	405.683	379.233	359.661	303.439
2	25	267.046	209.526	181.673	164.79	153.311	125.494
3	25	171.231	140.652	123.478	111.976	103.574	81.0918
4	25	117.214	100.535	90.4417	83.29	77.8208	61.8336
5	25	84.4602	74.6646	68.487	63.9669	60.4157	49.4373
1	30	637.212	541.458	491.311	457.776	433.021	363.835
2	30	297.871	234.485	206.433	190.051	179.01	151.125
3	30	200.285	159.238	138.042	124.663	115.322	92.0895
4	30	143.482	118.653	104.522	94.9634	87.9261	68.8222
5	30	106.741	91.2869	81.9752	75.3996	70.3849	55.8083

2. Blocks Joined to Foundation

The proposed system postulates the effective adhesion of the blocks to the foundation. When the blocks adhere tightly to the foundation, as if projecting from it, a wedge-shaped core of the block bears the entire amount of the stress. The most adverse scenario is chown in Fig.2.

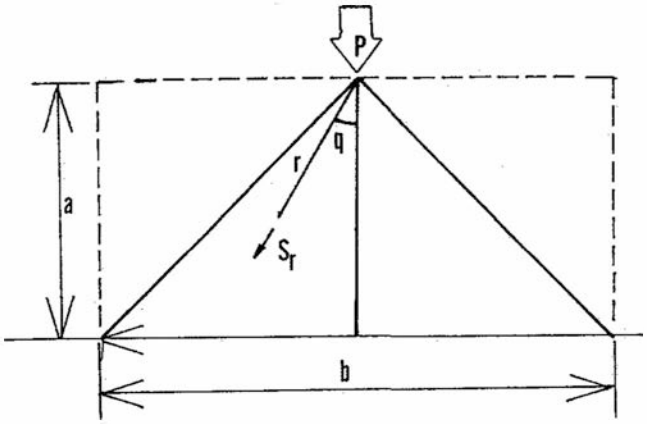


Fig.2.Adverse condition to perfect adhesion.

Assuming the stress function as Airy's stress function $\phi = r \cdot F(q)$, the stress can be derived from

$$\nabla^4 \phi = 0$$

Thus

$$S_r = (b/a) \cdot \cos^2 q \cdot (-2b) \cdot S_0 / (2t + \sin 2t) \quad \ldots(5)$$

where $t = \tan^{-1}(a/2b)$

The maximum stress, taking place at q=0, is

$$S = -2bS_o (b/a) / (2t + \sin 2t) \quad \ldots\ldots\ldots\ldots(6)$$

The actual conditions occur between these two extremes. Consequently, the actual principal stress at the bottom central portion of the block may fall between the values obtained above. Fig.3 shows the stresses with the flatness ratio b/a, when the block is 2 cm. thick.

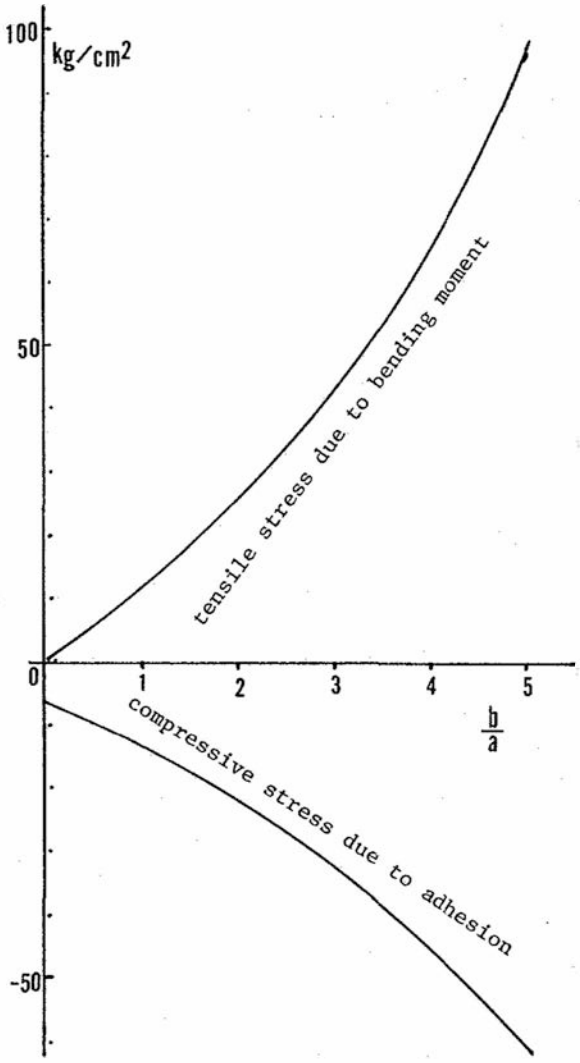


Fig.3.Stress range in block.

Table 2.Design of concrete mixture

slump	air	W/C	s/a	W	C	S	G	mx. ag
6 cm	3.5%	60%	35.5%	146kg	243kg	689kg	1265kg	10mm

*river aggregates, average compressive strength=450 kg/cm^2.

3. Adhesion Effects

As the block sustains daily wear, the adhesive has to be strong enough both to prevent the block from flying into the air and to prevent air pockets from developing underneath. Yet too strong a bond also is undesirable, since it interferes with the free movement of thermal expansion and shrinkage. The stress due to the constraints is calculated as follows:

It is assumed that the temperatures are uniform both in the block and the foundation asphalt, and that the thermal stresses are concentrated at the center, diminishing toward the edges, as shown in Fig.4.

The distribution equation with S_T is assumed as

$$S_T = S_{TC}\cos(\pi x/l) \quad \cdots\cdots(7)$$

Since the distributions are similar in both halves, the center can stay fixed.

Thus the free movement at the block end is

$$\Delta_T = \varepsilon \, dT(b/2) \quad \cdots\cdots(8)$$

where dT is the differential temperature between the blocks and the foundation.

The shear constraints will push back the movement by

$$\Delta_S = \int_0^{b/2} (S_T/E)dx \quad \cdots\cdots(9)$$

The tangential stress τ_e at $x=b/2$ is

$$\tau_e = G\gamma = G(\Delta_T - \Delta_S)/h \quad \cdots\cdots(10)$$

The equilibrium equation at an arbitrary point is

$$aw \cdot dS_T + \tau \cdot w \cdot dx = 0 \quad \cdots\cdots(11)$$

Thus

$$\tau = -a \, dS_T/dx \quad \cdots\cdots(12)$$

Then from the equation (7),

$$\tau = (a\pi S_{TO}/b)\sin(\pi x/b) \quad \cdots\cdots(13)$$

When $x=b/2$, $\tau_e = \pi S_{TO}(a/b)$ $\cdots\cdots(14)$

From the equation (9),

$$\Delta_S = (S_{TO}/E)\cdot\int_0^{b/2}\cos(\pi x/b)\,dx$$

$$= S_{TO}\, b/(\pi E) \quad \cdots\cdots(15)$$

Consequently,

$$S_{TO} = (\pi \cdot \varepsilon \cdot dT \cdot E/2)\left\{1 - \eta/(b^2 + \eta)\right\} \quad \cdots\cdots(16)$$

where $\eta = (h/G)\pi^2 E a$.

If the tangential stress at the end is given as the friction τ_f, which is constant between two materials, the equation (14) gives the thermal stress as

$$S_{TO} = (\tau_f/\pi)\cdot(b/a) \quad \cdots\cdots(17)$$

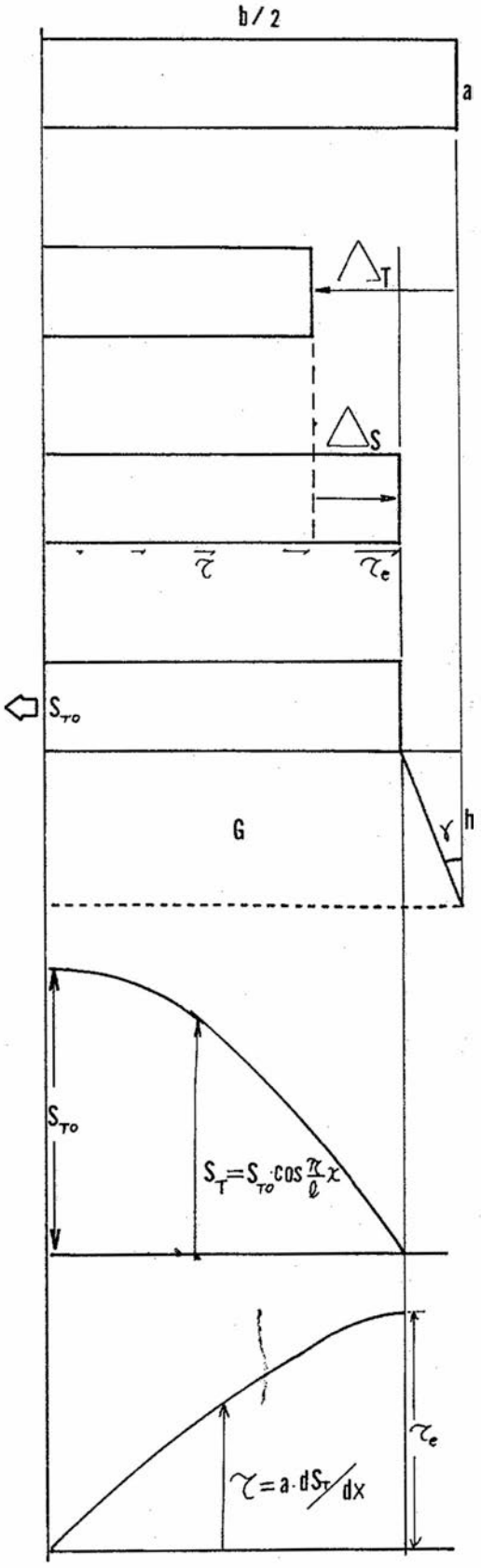


Fig.4.Thermal stress in block

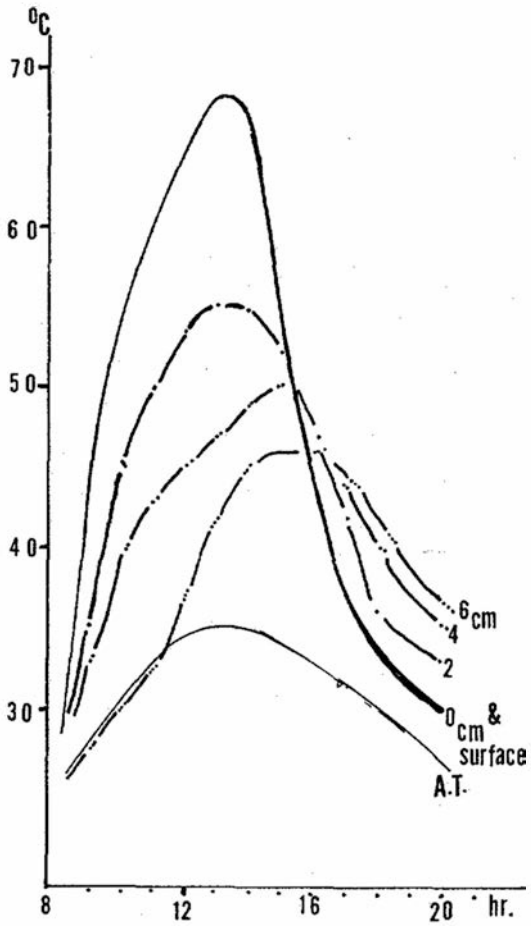


Fig.5.Asphalt temperatures variation in naked asphalt pavement.

B.S. indicates temperatures at block surface
A.T. indicates temperatures of atmosphere.

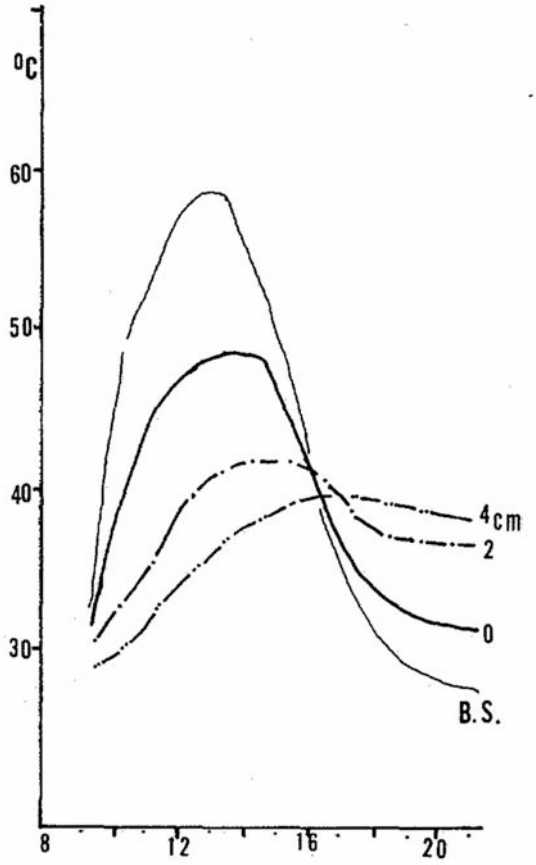


Fig.6.Asphalt temperatures variation under 2cm thick block.

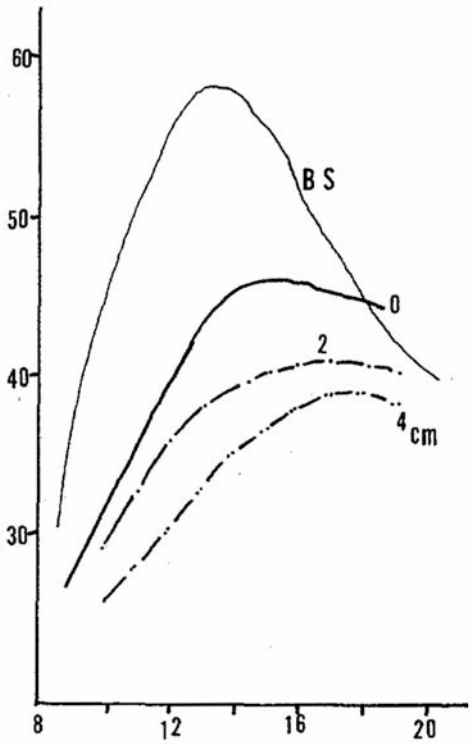


Fig.7.Asphalt temperatures variation under 4cm thick block.

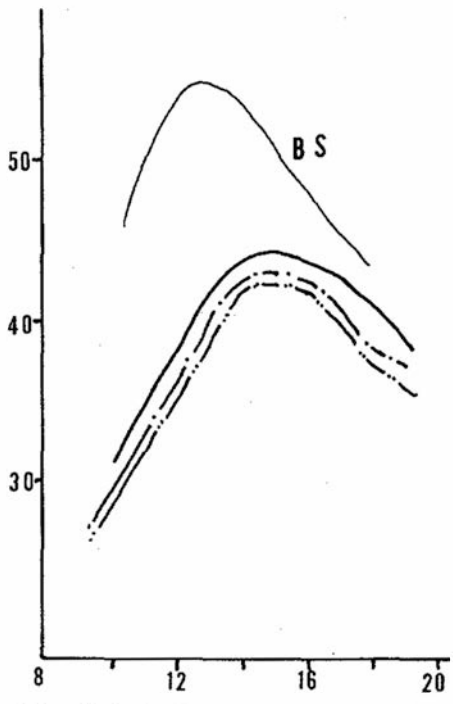


Fig.8.Asphalt temperatures variation under 6cm thick block.

4. Cover Effects on Asphalt Temperatures

Asphalt rutting can be prevented by keepping the asphalt under a concrete layer, which has a cooling effect. Variables are the thickness of the block and the ingredients of the mixture. When the mixture is given as shown in Table 2, the temperature distributions measured on the hottest day in 1983 are as shown in Fig.5 through 8. The relationship between the concrete thickness and the highest asphalt temperature is shown in Fig.9.

III. DISCUSSION

The critical stress caused by a given amount of traffic on block, either tensile or compressive, increases directly in proportion with the flatness ratio, as shown in Fig.3. The maximum flatness ratio the block can sustain without fracturing is indicated by the material strength and the subgrade coefficient. Conversely, the flatness ratio indicates the degree to which a conventional concrest overlay will crack into small pieces. In other words, when the pieces reach a size determinable by the flatness ratio, fracturing will cease. "Pre-fracturing," or cutting up the concrete overlay into blocks before appliction, prevents this form of destruction to the road surface.

From an economical point of view, the blocks should be as thin and as long as possible. Thinner blocks are cheaper than thick ones, and the longer the block, the less labor time involved in installation. Desired thickness also is determined by the block's capacity to withstand thermal rutting, calculated by a given subgrade coefficient for the foundation.

The optimal size for blocks in this system, in other words, rests largely on three factors -- mechanical strength, handling costs, and the thermal cover effect.

One trial was made as follows:

The tensile strength of concrete in Table 2 was 50 kg/cm^2. The allowable temperature for rutting was assumed to be 50 degrees C for the asphalt used. The minimum thickness, then, is 2 cm., and the subgrade coefficient was 1,000 kg/cm^2. The block size should be to an actual road surface with a daily traffic load of over 15,000 vehicles a day. The procedures are shown in Plates 1 through 6.

The adhesive strength of asphalt is approximately 6 kg/cm . In addition to normal vehicular wear, several experiments were run using trucks over 5 tons braking while traveling at speeds of up to 60 km per hour, to test the adhesive and block strength. No damage has been apparent either to the adhesive or to any of the blocks during the tests and over six months of actual traffic wear.

IV. CONCLUSIONS

1. Theoretical work indicates that cracks in the thin concrete overlay on the existing asphalt concrete pavement can be avoided by sizing the blocks according to their thickness and the foundation.

2. A minimum thickness for the blocks can be determined in relation to the effects of thermal cover, to prevent asphalt rutting from high temperatures. Thickness should be kept to the minimum necessary to sustain wear. A thickness of 2 cm. can lower the asphalt temperature by 20 degrees C on the hottest day.

3. The asphalt adhesive can also prevent water seepage into the foundation. This is particularly important in cold areas to keep the road surface from buckling. Since both block and adhesive layer are thin, the degree of evenness and the transverse profile depend entirely on the quality of the existing finished pavement surface.

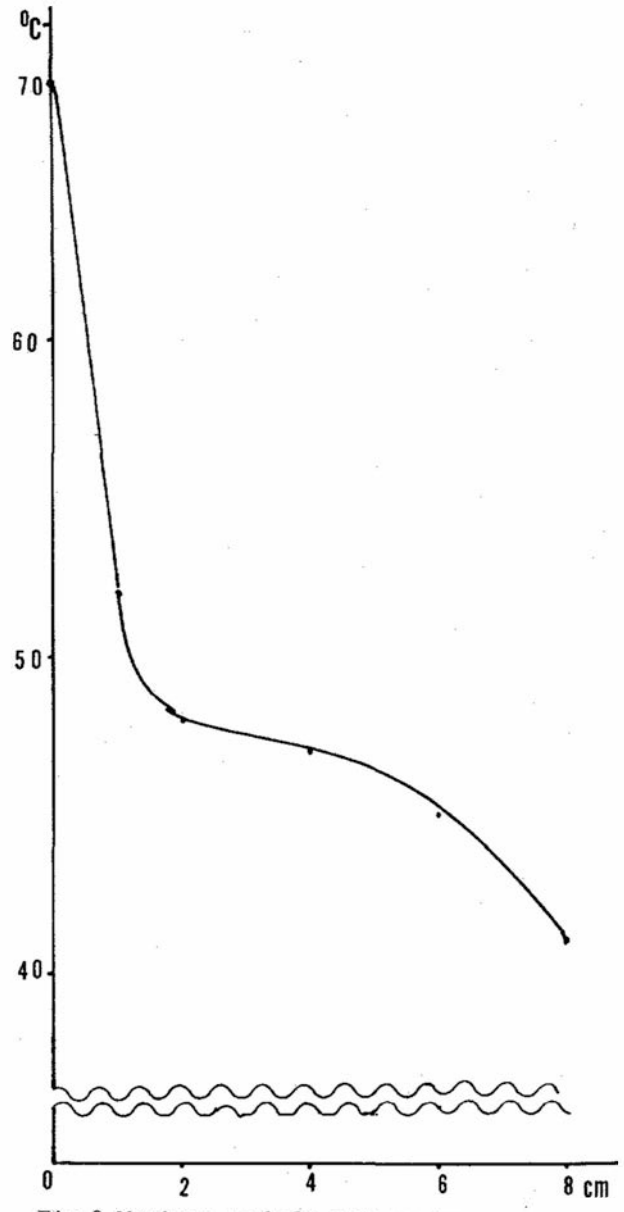


Fig.9.Maximum asphalt temperatures to block thickness variation.



Plate 1.Preheating of asphalt pavement



Plate 2.Blocks on an adhesive



Plate 3.Arranged blocks

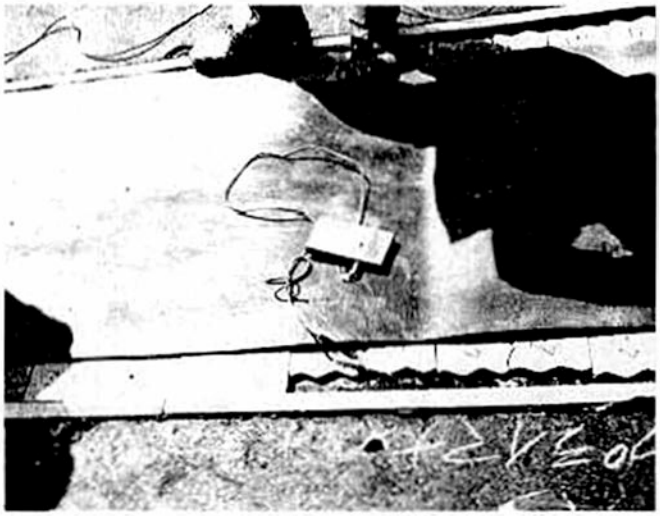


Plate 4.Preparation for pressing blocks

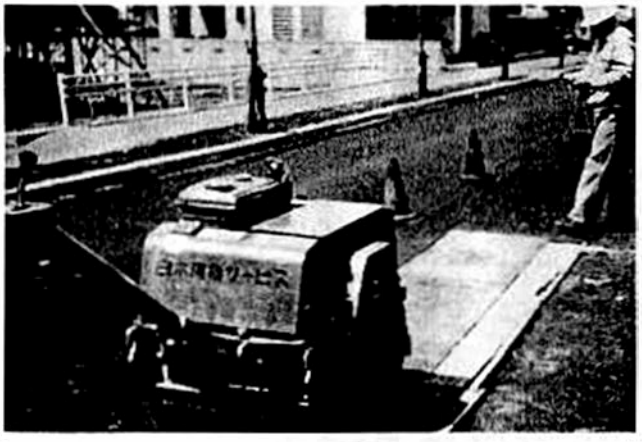


Plate 5.Block pressing for adhesion



Plate 6.Completed overlay