Dynamic Tests on the Stability of Bituminous Mixtures for Pavement at Low Temperature.

By

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CONTENTS

Synopsis

Using several techniques developed by the authors, determination was made of the physical properties of bituminous mixtures for road pavement at various low temperatures, the sensitivity of mixtures to those temperatures and the resistance against freezing and thawing actions.

Observations were made on the effects of drop hammer impact using a modified Page impact testing machine; other dynamic tests using an Izod and a Charpy impact testing machines and a sonic apparatus were performed. For comparison a Hubbard stability static test was also made.

As to the results, it has been found that the toughness, stability, and dynamic modulus of elasticity of bituminous mixtures varied according to variation of temperature, and each machine typically indicates these characteristics, but there were considerable differences between the dynamic tests and the static tests.

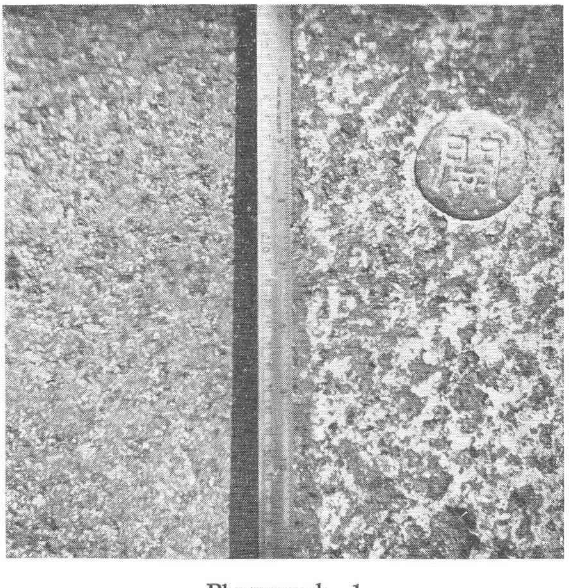
It was found that the sonic apparatus was highly suitable for estimation of stability of bituminous mixtures, and that dynamic tests were a most reasonable procedure for determination of the composition of mixtures in their use for highway pavements.

The ultimate objectives of this work in testing of bituminous mixtures were to establish suitable procedures for testing bituminous mixtures at low temperatures, to find out the optimum asphalt content, to determine bituminous mixtures suitable for pavement in cold districts and to develop adequate practices for overcoming failures under the impact of high speed traffic and the other basic damages done to pavement in cold weather.

Chapter 1 General description

In cold weather bituminous pavements are extensively damaged by the frost action and frost heaving of the base and roadbed, change in physical properties caused by falling of temperature of mixtures, freezing and thawing actions and special winter traffic conditions.

Among these, causes of damages due to base and roadbed were not taken into consideration but those due to properties of surface course were simply considered. Scaling or ravelling of bituminous pavement damaged by the beating action of chains attached to pneumatic tires to prevent the slipping of running vehicles has been found in cold regions. The amount of this scaling on bituminous pavement, sometimes, may reach to a depth of 2 to 3 cm. Photograph—1 illustrates damage to the asphalt pavement surface of National Highway No. 36, between Sapporo City and Chitose Air Port in Hokkaido, Japan. This roadway was constructed in 1952 and 1953, and has been in



Photograph 1
Scaling of seal coat of asphalt concrete.

service for just one winter. This highway pavement is constituted of asphalt concrete and Topeka; both types of pavement were damaged by abrasion and ravelling caused by the beating action of tire chains in winter. These phenomena suggest both the necessity and the suitability of performing dynamic tests on bituminous mixtures.

The sensitivity of bituminous cement and bituminous mixtures is a most important factor in their application on highway pavement. It has been recognized that the bituminous cement and bituminous mixtures are easily affected, as to their chemical constitution and physical and mechanical properties, by temperature variation. Moreover it is recognized that the range of this temperature variation within which the mechanical properties of mixtures make them ideally available for pavement purposes are within not more than 30°C to 40°C.

In general the toughness of bituminous mixtures is transformed into brittleness as temperature drops. The mixtures show liquid properties at temperatures higher than 30°C to 40°C, plastic properties at moderate temperatures and elastic or brittle at lower than about 5°C.

For the analysis of rheological properties of bituminous cement, conventional methods have been developed. They include the determination of softening point and penetration. The softening point is the temperature at which the mixture possesses a consistency conforming to conventional standard, such as the Ring and Ball method. The penetration is the depth to which the needle of standard size penetrates into bitumen within specified time under a standard load at given temperature. The ductility, and others have also been used to measure the rheological properties of bituminous cement.

Some methods[1) 2)] concerned with the determination of the temperature sensitivity of bituminous cement such as "Penetration Index" based upon penetability, have also been presented.

Several methods and apparatuses for determining the stability or temperature sensitivity of bituminous mixture have been offered, but these techniques are not always adequate for the explanation of properties of highway materials because they are static tests.

Several methods and apparatuses for explanation of properties of bituminous mixtures as affected by temperature variation were tried by the authors. Observations were made on the effect of drop hammer impact in which use was made of a Page impact testing machine. Other dynamic tests were made using an Izod and a Charpy impact testing machines, and a sonic apparatus. On the other hand for comparison, a

Hubbard stability static test and compression tests were made.

Chapter 2 Dynamic tests by Izod and Charpy impact testing machines.

1. Apparatuses and preparation of specimens.

(1) Impact shear test with Izod testing machine.

An Izod impact testing machine with a 20 kg.cm capacity was used. The pendulum consists of a hammer weighing 1.205 kg with a pivot swinging in ball bearings in a vertical stand that is bolted down to a cast iron bed plate. The pendulum strikes against a specimen, which is clamped to act as a vertical cantilever, but in this test the clamping equipment was reconstructed in order to make clear to develop the dynamic shearing action.

If friction losses in the swinging pivot are not considered, the energy consumed in rupturing the specimen may be computed as follows:

Initial energy $= WH = WR\ (1-\cos A)$

Energy after a specimen ruptures $= WH' = WR\ (1-\cos B)$

Energy to rupture a specimen $= W(H-H') = (WR)(\cos B - \cos A)$

where W: weight of pendulum.
H: height of fall of center of gravity of pendulum.
H': height of rise of center of pendulum after hitting a specimen.
A: angle of fall.
B: angle of rise.
R: distance from center of gravity of pendulum to axis of swing 0.

The principle of this testing machine is shown in Fig. 1.

(2) Impact flexure test with Charpy testing machine.

A Charpy impact testing machine having capacity of about 30 kg.cm was used. The principle of this machine is illustrated in Fig. 2. The pendulum consists of a relatively light but rigid bar on the end of which is a heavy disc; the pendulum is suspended from a short shaft that rotates in ball bearings and swings midway between two rigid upright stands, close to the base of which the specimen is supported on an anvil. The flexural test specimen mounted on the support accepts the impact energy of the pendulum at the bottom of a

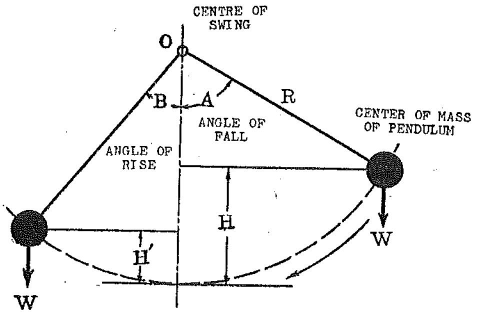


Fig. 1 Space relation for pendulum machine.

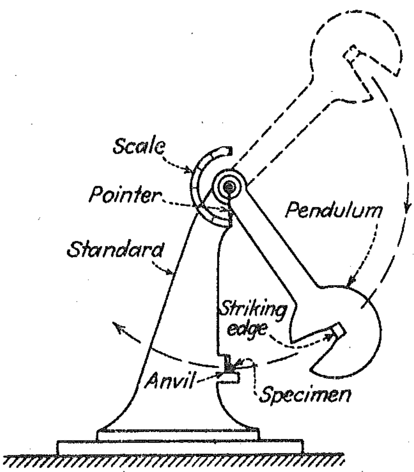


Fig. 2 Charpy impact testing machine

notch cut in it. As specimens, 25 by 15 by 90 mm pieces of asphalt mortar were prepared.

(3) Materials.

Asphalt: In these experiments two kinds of asphalt, Trinidad Lake asphalt and Akita straight asphalt produced in Akita, Japan, were used; their characteristics are shown in Table-1.

TABLE 1 Characteristics of bituminous cement

Items	Trinidad Lake asphalt	Akita straight asphalt
Specific gravity	1.212	1.003
Softening point	41°C	36°C
Penetration at 25°C	37	101
Ductility	24 (15°C)	14 (5°C)

Sand : Crushed quartz sand having specific gravity 2.63, and the grading of which 99% passes 0.3 mm sieve and is retained on 0.15 mm sieve.

Composition: As shown in Table 2.

TABLE 2 The composition of bituminous mixtures

No.	Asphalt content			Sand content		
	by weight (%)	by volume (%)		by weight (%)	by volume (%)	
		Trinidad	Akita		Trinidad	Akita
1	5.0	10.2	12.2	95.0	89.8	87.8
2	7.5	15.0	17.6	92.5	85.0	82.4
3	10.0	19.5	22.6	90.0	80.5	77.4
4	12.5	23.6	27.3	87.5	76.4	72.7
5	15.0	27.7	31.7	85.0	72.3	68.3
6	20.0	35.2	39.7	80.0	64.8	60.3
7	50.0	68.5	72.5	50.0	31.5	27.5
8	100	100	100	0	0	0

(4) Preparation of specimens.

The specimens were molded in a steel framed form. All specimens were pressed under a load intensity of 8 kg per sq cm. by Amstlar compression testing machine of 500 kg capacity.

2. Test results.

The impact tests of asphalt mixtures were made at 10 different temperatures: −20°C, −15°C, −10°C, −5°C, 0°C, 5°C, 10°C, 15°C, 20°C, 30°C. At lower than 0°C the specimens were thoroughly cooled in a low temperature room.

Test results by an Izod and a Charpy impact testing machines are shown in Table–3 and Table–4. The asphalt content of mixture having maximum absorbed energy measured by the Izod impact testing machine was 15% asphalt content at test temperature of 30°C; 20% at test temperatures of 20°, 10°, 5°, −10°, −15° and −20°C; and 50% at 0°C.

As the result the optimum asphalt content measured by the Izod was determined to be 20% at the various temperatures. At the various test temperatures, the maximum absorbed energy of each mixture was, 0.647 kg.cm/cm^2 on 5%, 1.197 kg.cm/cm^2 on 7.5%, 1.783 kg.cm/cm^2 on 10%, 4.830 kg.cm/cm^2 on 15%, at test temperature of 30°C; 1.707 kg.cm/cm^2 on 12.5% at 5°C; 3.703 kg.cm/cm^2 on 20%, 3.220 kg.cm/cm^2 on 50% and 1.583 kg.cm/cm^2 on 100% at 20°C. On the last three of 20%, 50% and 100% mixtures, the absorbed energy could not be determined at 30°C. Then the mixture having 20% asphalt except three kinds of compositions above mentioned which might not be usable in field, may have the maximum absorbed energy.

TABLE 3 Absorbed energy of bituminous mortar at each temperature by an Izod impact testing machine

Asphalt content (%)	Absorbed energy at each temperature kg·cm/cm²									
	30 °C	20 °C	15 °C	10 °C	5 °C	0 °C	− 5 °C	−10 °C	−15 °C	−20 °C
5.0	0.647	0.603	0.540	0.643	0.617	0.540	0.537	0.580	0.567	0.400
7.5	1.197	0.923	0.900	1.057	1.000	0.773	0.750	0.910	0.813	0.693
10.0	1.783	1.410	1.560	1.467	1.390	1.360	1.340	1.187	1.067	0.893
12.5	1.643	1.277	1.473	1.657	1.707	1.680	1.497	1.430	0.910	0.720
15.0	4.830	2.570	2.260	2.123	1.720	1.930	1.793	2.137	1.880	1.310
20.0	—	3.703	3.343	2.210	2.623	1.717	2.067	2.330	1.907	1.457
50.0	—	3.220	1.843	1.610	1.683	1.820	1.093	1.377	1.843	1.197
100.0	—	1.583	1.070	0.923	0.973	0.687	0.683	0.580	0.413	0.520

TABLE 4 Absorbed energy of bituminous mortar at each temperature by a Charpy impact testing machine

Asphalt content (%)	Absorbed energy at each temperature kg·cm/cm²									
	30 °C	20 °C	15 °C	10 °C	5 °C	0 °C	− 5 °C	−10 °C	−15 °C	−20 °C
5.0	0.920	0.803	1.666	0.993	0.993	1.067	1.303	1.190	1.067	0.953
7.5	1.497	0.980	1.500	1.220	1.100	0.889	1.260	1.260	1.220	4.132
10.0	1.060	1.146	—	2.170	1.493	1.533	1.916	1.570	1.533	1.570
12.5	1.170	1.510	1.100	1.453	2.139	2.960	2.140	1.609	1.453	0.960
15.0	2.630	1.810	1.810	1.690	2.353	1.453	1.650	1.413	1.410	1.613
20.0	3.143	4.360	—	2.143	1.770	1.733	—	2.686	1.970	1.050
50.0	—	4.630	1.465	1.610	1.010	1.170	1.223	1.743	1.493	2.283
100.0	—	1.510	1.423	1.140	1.150	1.180	1.110	1.066	0.840	0.950

In the tests using the Charpy impact testing machine, the regular relation of asphalt content and composition could not be obtained, but the absorbed energy showed the higher value than on the Izod testing machine, by the amount of approximately 20%, and these values have the same tendency as those obtained by the Izod test, i.e. the mixture having maximum absorbed energy at each test temperature was 20% asphalt content excepting a few cases.

Chapter 3 Dynamic test by a modified Page impact testing machine.

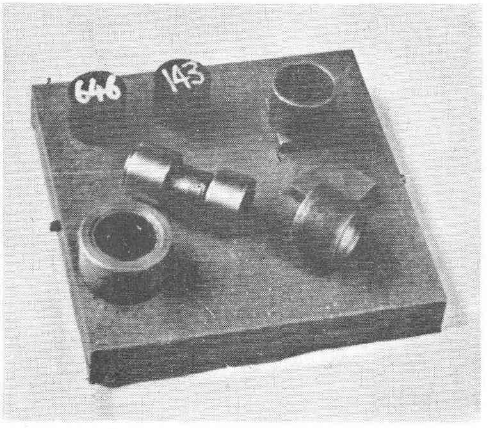
1. Apparatus[3).

A Page impact testing machine used for measuring the toughness of stones was reconstructed to make it suitable in type and capacity for determining the brittleness of bituminous mixtures. The Page impact testing machine commonly used for determining the brittleness of stones has a drop hammer weighing 2 kg. However this hammer weight is too large for tests of the bituminous mixtures, so it was reduced to 710 gr. The apparatus was arranged so that the hammer weight fall freely between suitable guides. A plunger made of hardend steel with spherical surface, was placed directly on the specimen. In the test a specimen immersed in a small water bath for temperature control was put on a steel anvil. Specimens were kept for several hours in a water bath as desired test temperature and care was taken to make sure that they were 10 uniform temperatures throughout. The 710 gr. hammer was released by a tripping mechanism and its falling height was increased by 1 cm each time when it was dropped.

It was considered a failure of the specimens if they broke into two or three pieces at low temperature, while it was so considered when remarkable deformation of specimen took place at high temperature. Judgement of the occurrence of such failure was rather difficult problem, so the reliability in accuracy of toughness value was low at 30°C on mixture with richer than 20% in asphalt content on account of difficulty of measurement at that temperature. When the failure of breaking or deformation at which cracking occurred on specimen, was recorded. Those values were taken to indicate the brittleness of the specimens.

2. Preparation of the specimens.

Materials and composition of specimens was the same as that of specimens used in the Izod and the Charpy impact test. The size of specimen was determined according to the capacity of the testing machine, after the tests on selection of the suitable size. As the result the specimens in the form 35 mm$\phi \times$30 mm cylinder was used. The forms were made of steel pipe, and steel bar was used for pressing of mixture and removing the specimen. All specimens were pressed under a load intensity of 8 kg per sq.cm. This load intensity was considered the same as that produced with a road-roller on road paving in a field project. All specimens removed from the form, were stored in low temperature room in which the temperature was maintained at 0°C until the test. Photograph-2 shows the molding and removing devices.



Photograph 2
Molding device and removing device.

3. Test results.

The impact tests of mixtures were made at 10 different temperatures: −20°, −15°, −10°, −5°, 0°, 5°, 10°, 15°, 20°, 30°C, at lower than 0°C the specimens throughly cooled in a low temperature room. Results of these tests are shown in Fig. 3—Fig. 12, Fig. 13—Fig. 22, Fig. 23—Fig. 29 and Fig. 30—Fig. 36.

Fig. 3—Fig. 12 show the relationship of asphalt content and toughness on Trinidad Lake asphalt mixtures, Fig. 13—Fig. 22 show that on Akita straight asphalt. Fig. 23—Fig. 29 shows the relation between test temperature and toughness at each temperature on Trinidad Lake asphalt mixtures, and Fig. 30—Fig. 36 show that on Akita straight asphalt mixtures, respectively.

4. Conclusion.

From the above tests by the Page impact testing machine the following conclusions were reached.

(1) Although the hardness was increased in both Trinidad Lake asphalt and Akita straight asphalt, the toughness was generally reduced in accordance with lowering of temperature as shown in the Figures; in some temperature variation ranges, these reduction rates of brittleness showed the parabolic relation. Although general shapes of relationship between temperature and toughness were the same in each composition as shown in Fig. 23—Fig. 36, there were considerable differences in absolute value of toughness in each composition of mixtures. The temperature range in which the relation between toughness and temperature shows the parabolic relation was higher than 5°C but lower than normal atmospheric temperature.

Fig. 3—Fig. 12 Relation between asphalt content and toughness of Akita straight asphalt by the modified Page impact testing machine.

Y: Toughness. X: Asphalt content in percent.

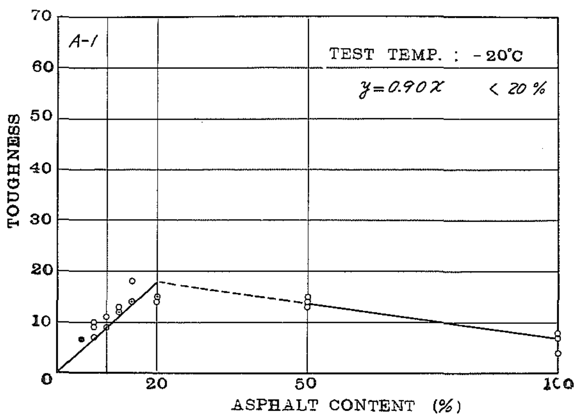


Fig. 3

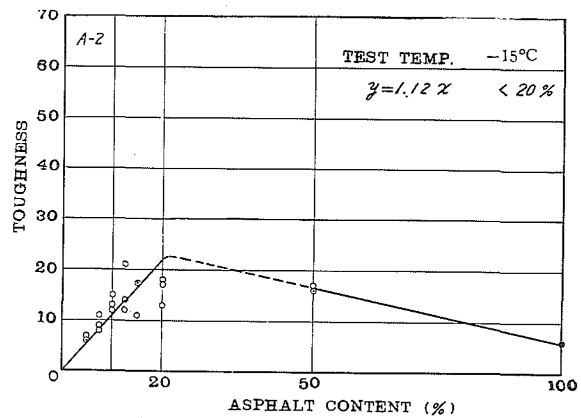


Fig. 4

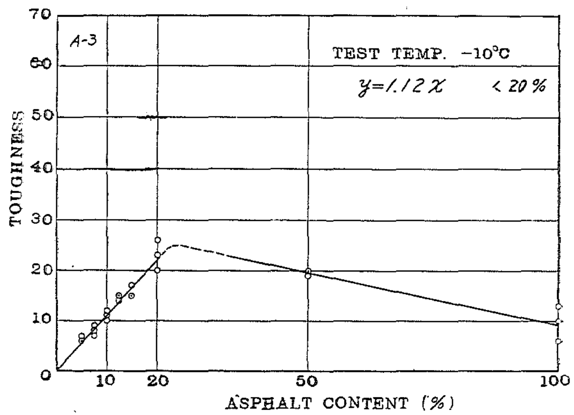


Fig. 5

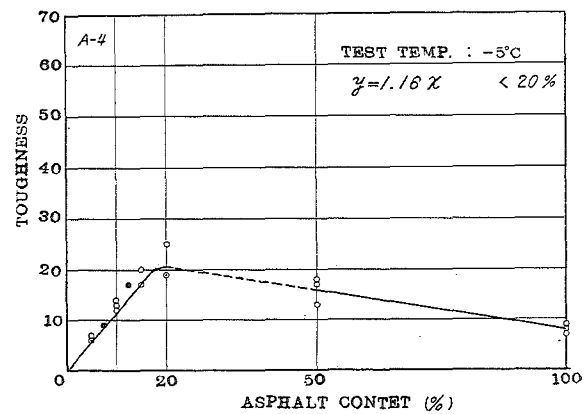


Fig. 6

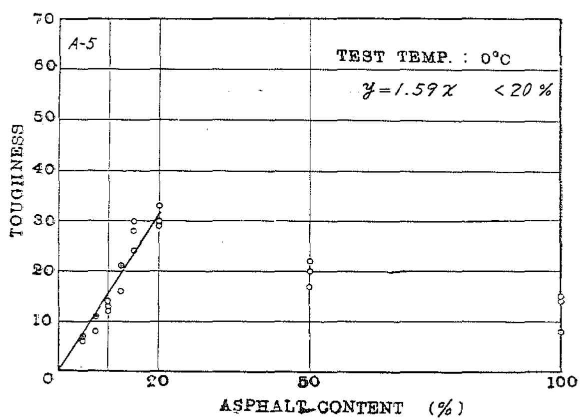


Fig. 7

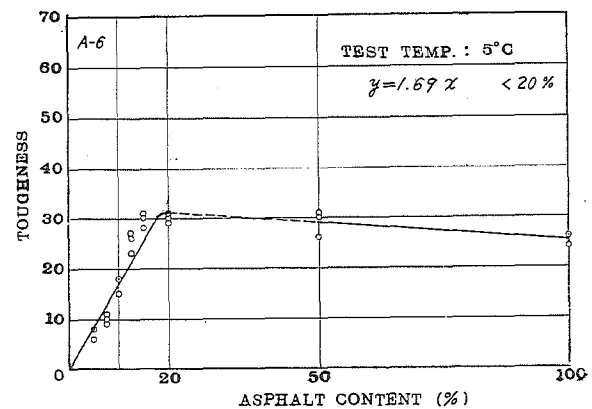


Fig. 8

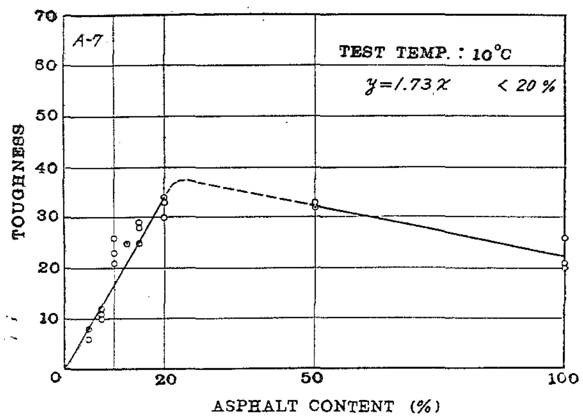


Fig. 9

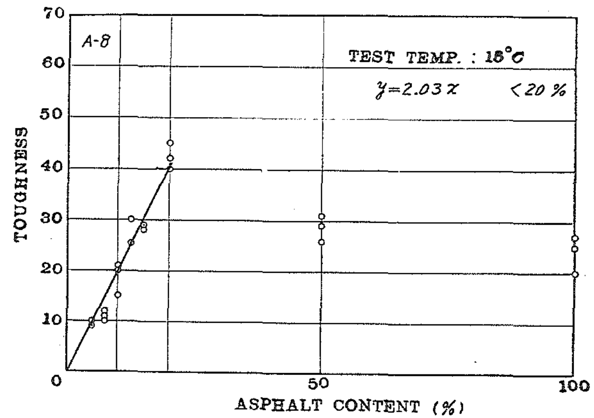


Fig. 10

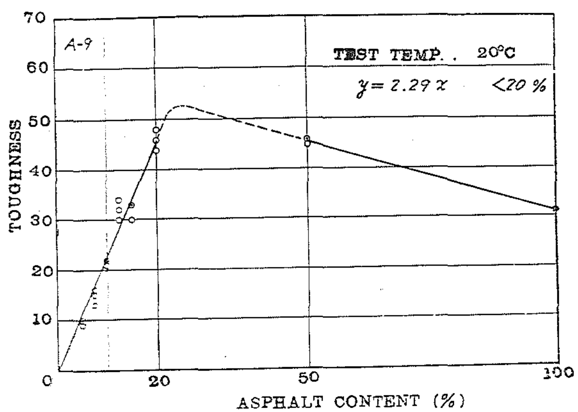


Fig. 11

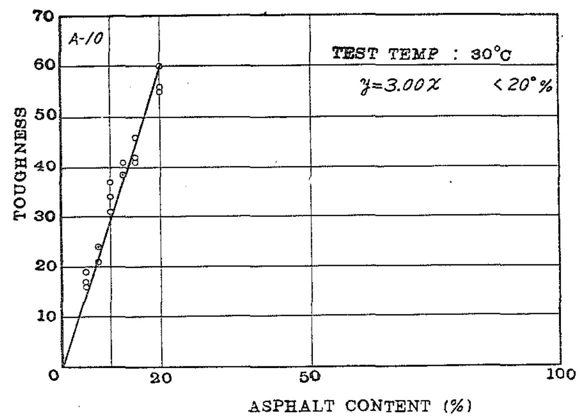


Fig. 12

Fig. 13–Fig. 22 Relation between asphalt content and toughness of Trinidad Lake asphalt by the modified Page impact testing machine.

Y: Toughness at each temperature. X: Asphalt content in percent.

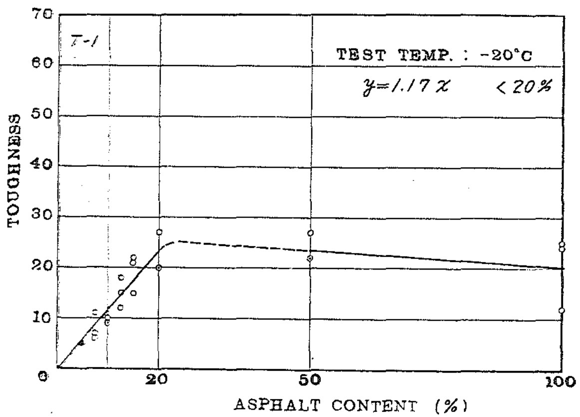


Fig. 13

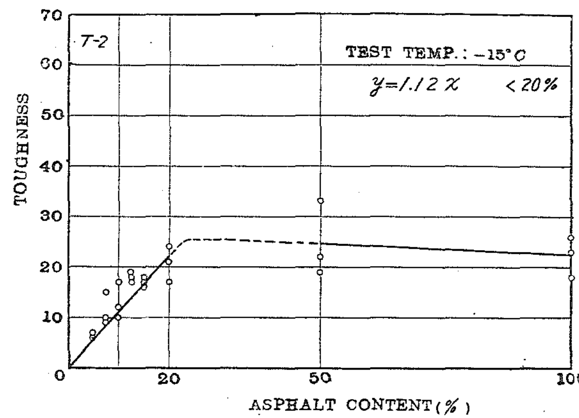


Fig. 14

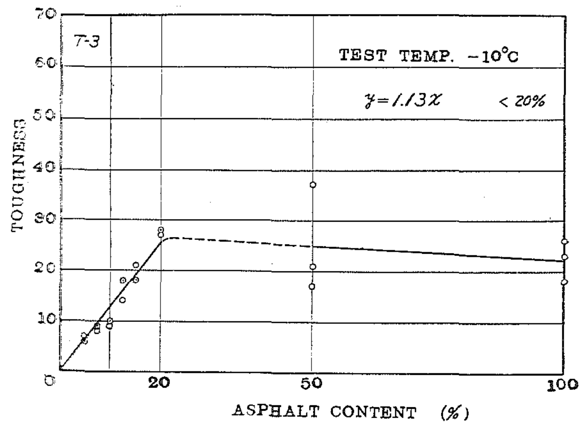


Fig. 15

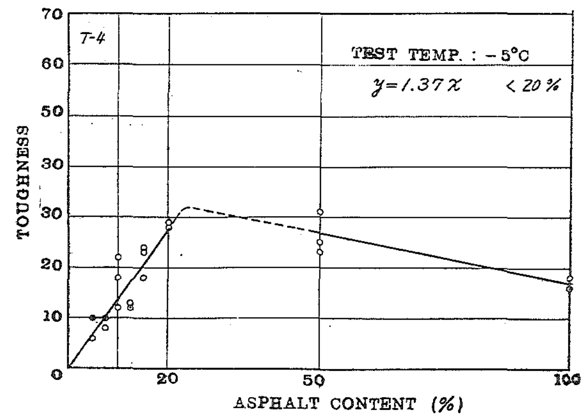


Fig. 16

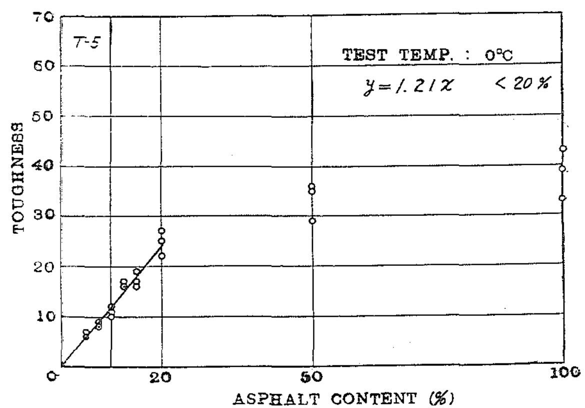


Fig. 17

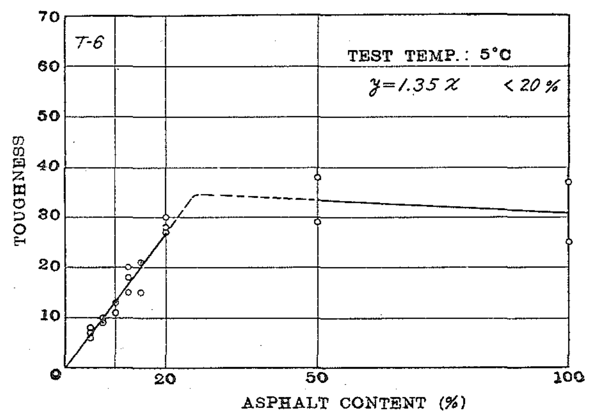


Fig. 18

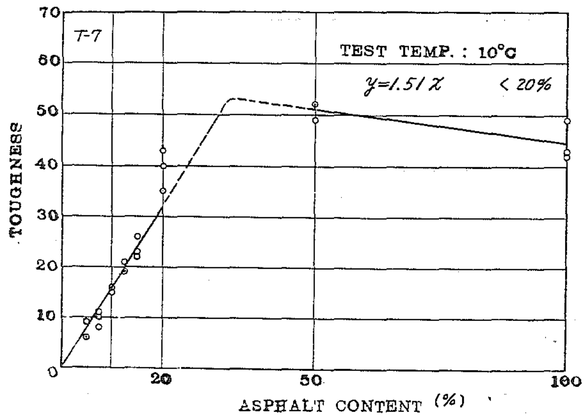


Fig. 19

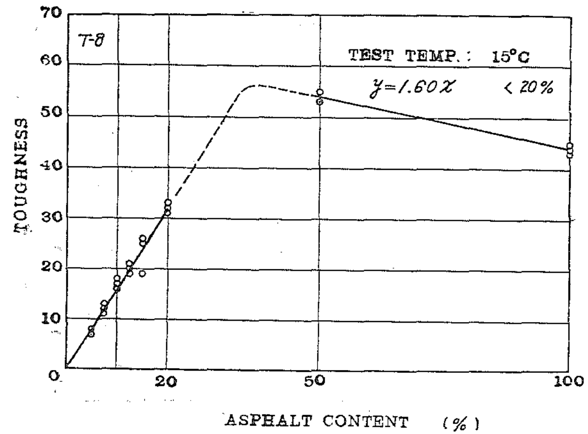


Fig. 20

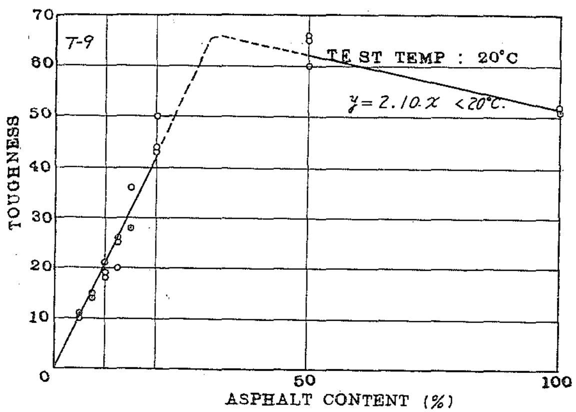


Fig. 21

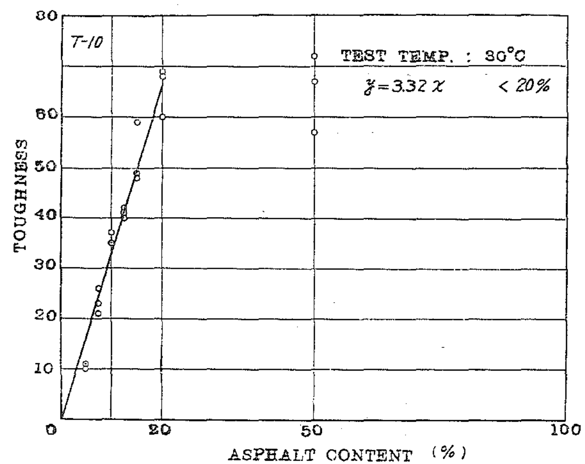


Fig. 22

Fig. 23—Fig. 29
Relation between test temperature and toughness of Akita straight asphalt by the modified Page impact testing machine.
(percent shows the asphalt content)

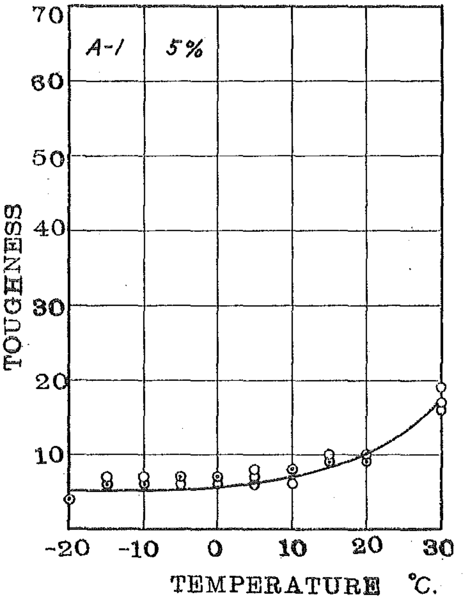


Fig. 23

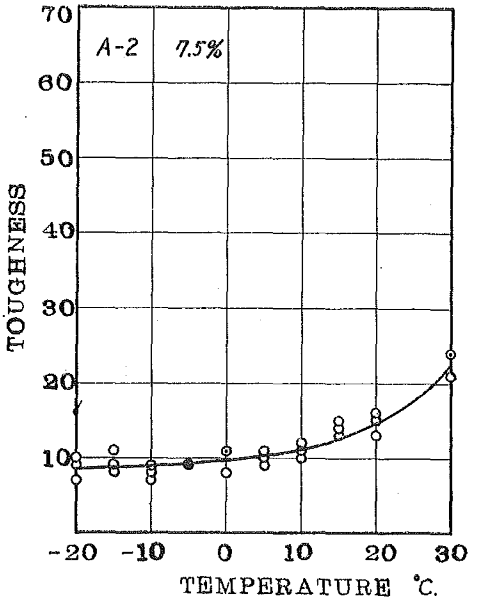


Fig. 24

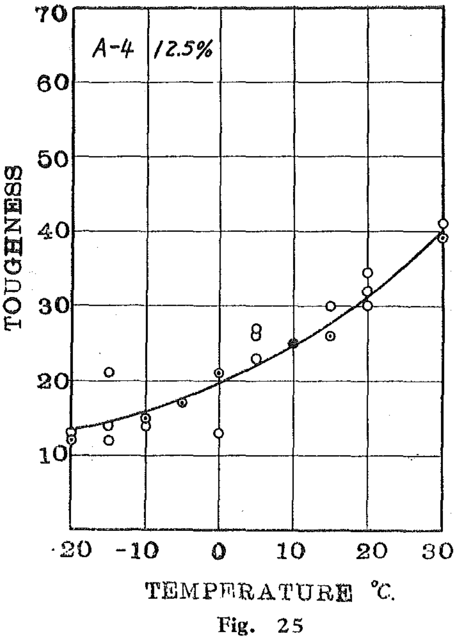


Fig. 25

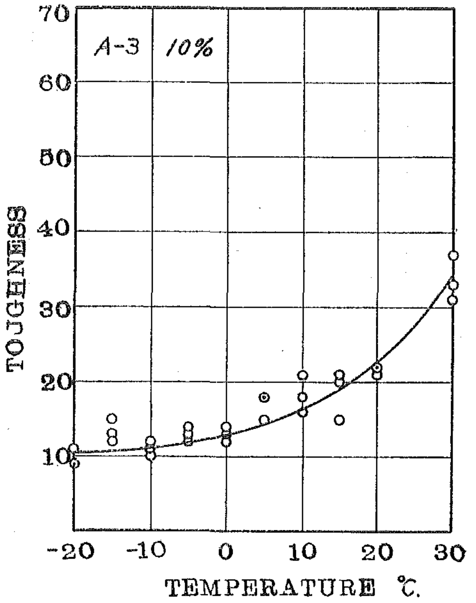


Fig. 26

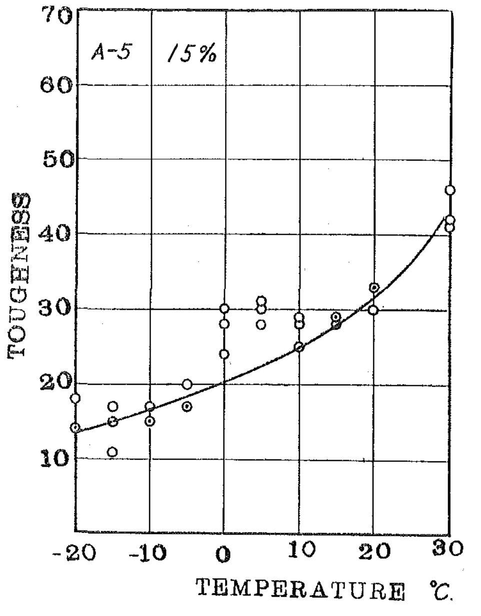


Fig. 27

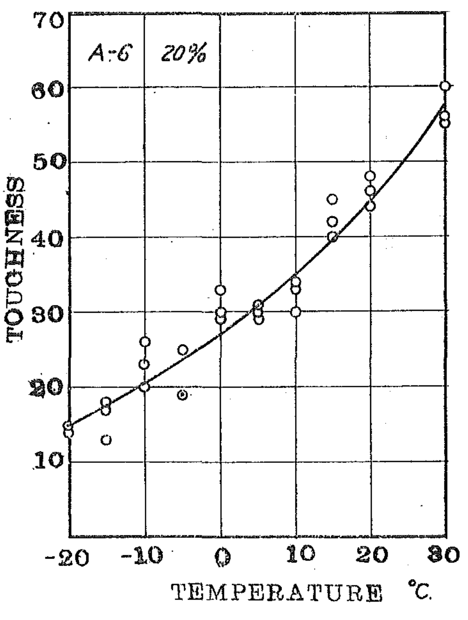


Fig. 28

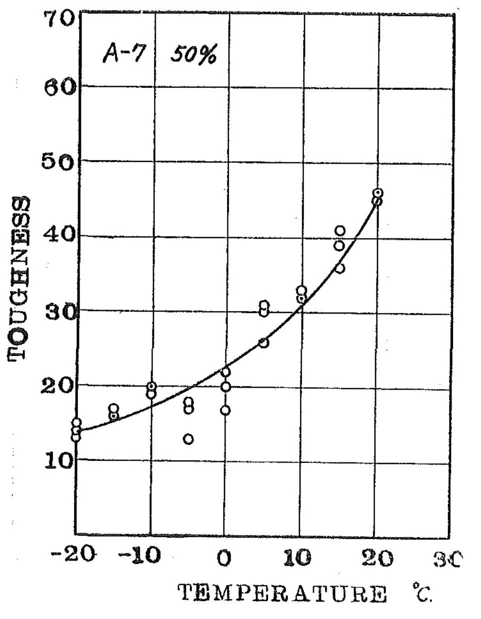


Fig. 29

Fig. 30—Fig. 36
Relation between test temperature and toughness of Trinidad Lake asphalt by the modified Page impact testing machine.
(percent shows the asphalt content)

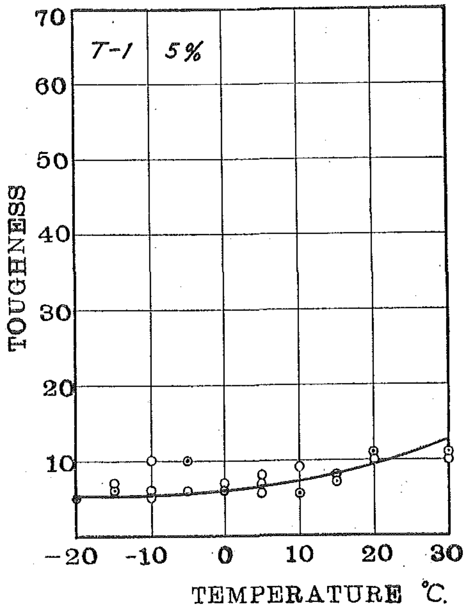


Fig. 30

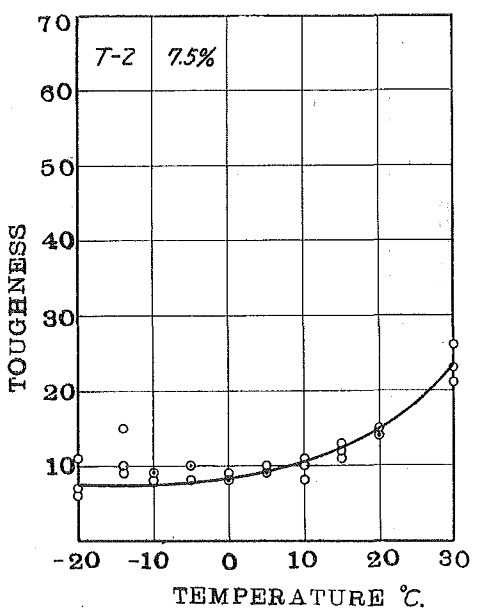


Fig. 31

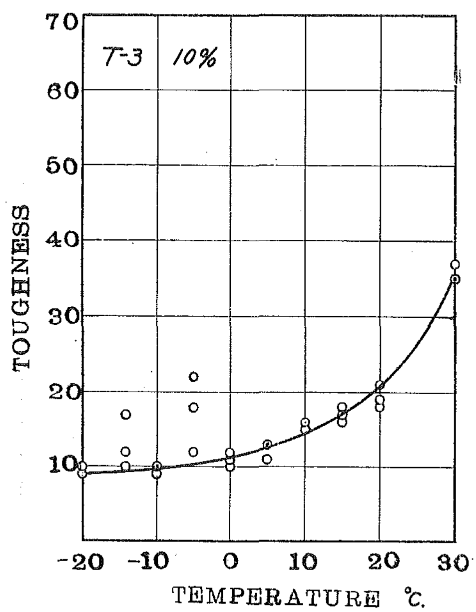


Fig. 32

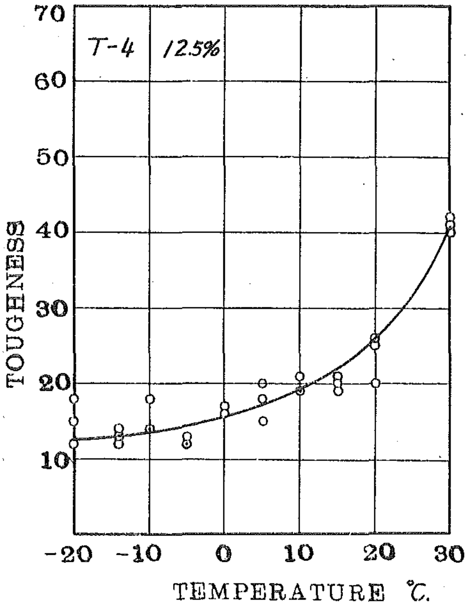


Fig. 33

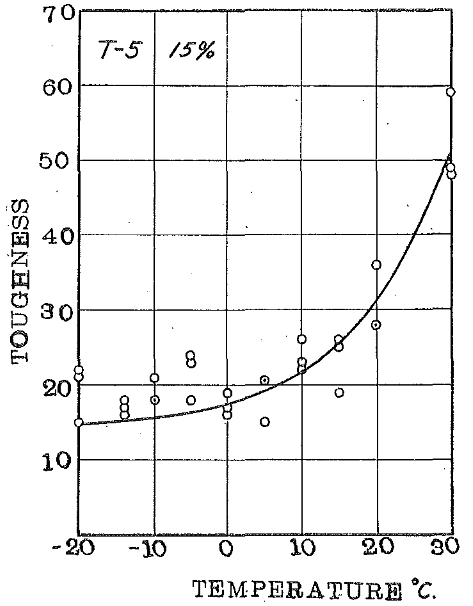


Fig. 34

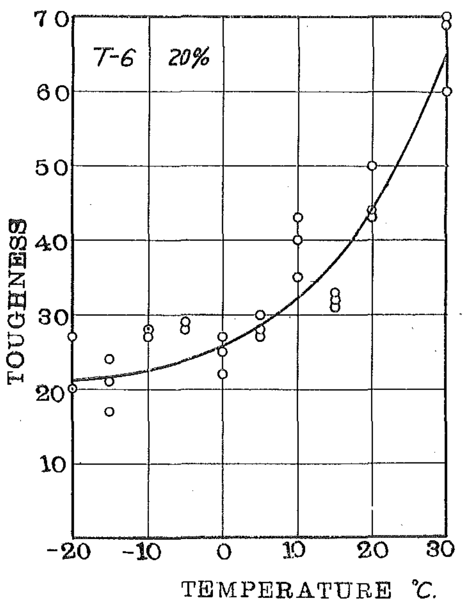


Fig. 35

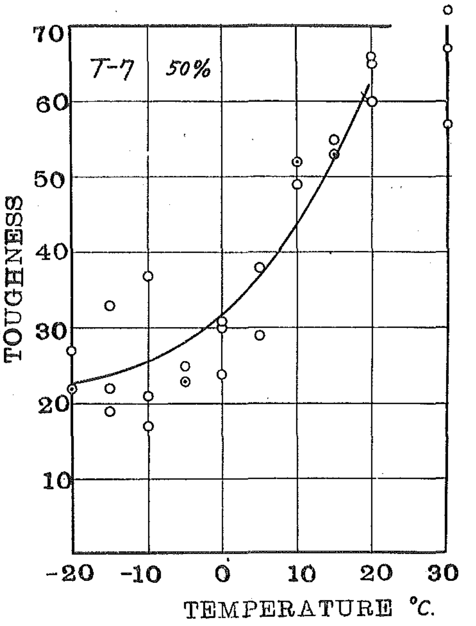


Fig. 36

(2) The values of toughness ratio at the two different test temperatures 20°C and 0°C were calculated. These values of toughness ratio were 0.67 on 5%, 0.53 on 7.5%, 0.52 on 10%, 0.61 on 12.5%, 0.58 on 15%, 0.59 on 20% and 0.51 on 50% in mixtures made of Trinidad Lake asphalt. On mixtures made of Akita straight asphalt the values were 0.60 on 5%, 0.67 on 7.5%, 0.56 on 10%, 0.65 on 12.5%, 0.63 on 15%, 0.61 on 20% and 0.49 on 50%.

As shown in the above, there were no considerable differences on values of toughness ratio calculated at the two different temperatures, and this range of these values was between 0.49 and 0.67.

These facts show that the temperature sensitivity of mixtures depends on temperature sensitivity of bituminous cement, and toughness ratio (referred as to log. penetration Index) at two different temperatures did not vary although any composition of mixtures was selected. Further, there were no remarkable differences in log. toughness-temperature slopes. Then if high stability at some high or low temperature is wanted, the bituminous cement having low sensitivity should be selected; the high stability can not be obtained without the selection of an appreciate bituminous cement.

(3) The mixtures generally showed viscous-liquid properties at temperatures higher than normal atmospheric temperatures in summer, and the temperatures in the mixtures attained the maximum toughness were different in each specimen. These temperatures may depend on compositions, in fact the relation of bituminous content and temperature resulting in the maximum toughness, showed a regular relation in each. This temperature limit was higher in specimens with rich asphalt content than in those with lower asphalt content.

(4) A value of toughness of Trinidad Lake asphalt mixtures was higher than those of Akita straight asphalt at lower than 0°C on mixtures constituted of lower than 20% asphalt content.

(5) In proportion to asphalt content the toughness increased within a certain range of asphalt content; the limits were 20 to 25% in both kinds of asphalt, but at points higher than this limit the toughness was reduced.

(6) At lower than 5°C the mixtures, generally, showed a non-plastic character.

(7)[4] It was found that the elasticity influenced the relationship between penetration and temperature. It was also found that the differences in the slopes of penetration-temperature lines[1] in semi-log.

scale shown in bitumens of different types were principally determined by this property. This means that the characterization of the bitumen according to its rheological type can also be based on the slope of the log. penetration-temperature curves. So this slope was expressed by an Index figure, the penetration index. In these tests of bituminous mixtures, similarly, the same regular toughness relation were obtained within certain ranges of temperature.

Finally it may be said that these test may be satisfactorily used for determination of stability and temperature sensitivity of bituminous mixtures. Especially, the Page impact testing machine clearly shows the value of stability. In these experiments, tests of bituminous mortar only were made, and if a suitable Page impact testing machine having larger capacity can be provided, the stability of asphalt concrete and other materials may surely be determined satisfactorily.

Chapter. 4 Freezing and thawing test of bituminous mortar.

For tests the Page impact testing machine was used to determine the resisting power of bituminous mixtures against freezing and thawing.

Although bituminous mixtures have commonly been regarded as non-absorbing material, it has been made clear[5] that some kinds of bitumen absorb considerable quantities of water. Bitumen may be considered to absorb the water in the following ways:

a. Bitumen is generally soluble in water even in small amount.

b. If water soluble are contained in bitumen, the salt will be dissolved in water and water will entrain in bitumen itself.

c. As the result of presence of filler in bitumen.

Of the above three ways the last two occur to a considerable degree. Furthermore the water absorption of bituminous mixtures may be increased by the presence of fine and coarse aggregates. It is not at all hard to understand that the durability under the influence of freezing and thawing actions is reduced proportionally with increase of water absorption.

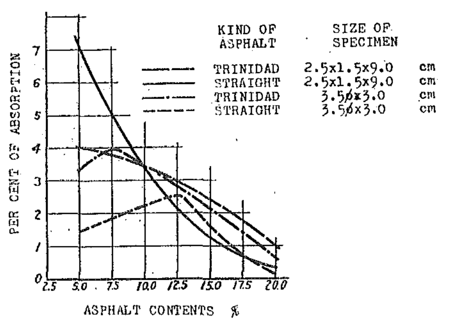


Fig. 37

Relation between asphalt content and percent of absorption of specimens after 96 hours immersion.

Having these points in mind, the present freezing and thawing tests were made. The compositions and other characters of specimens are similar to those used in the dynamic test with the Page impact testing machine. The specimens made of two kinds of asphalt, Akita and Trinidad, were immersed in water of 10°C before tests. After 96 hours immersion, specimens were taken out from the water bath and the surface water was wiped off with a clean towel. Specimen weighed; the weight of specimen was increased by soaking in water, then it was assumed that the weight increase was due to absorption.

Fig. 37 shows the relation between bituminous content and percent of absorption, after 96 hours' immersion. Specimens were frozen in low temperature room in which the temperature was maintained at −15°C to −20°C, for 1.5 hours, and they were thawed in water of 10°C, and these procedures were repeated. The weight and toughness were measured at 10, 20, 30, 40, 50 and 60 cycles of freezing and thawing; the toughness testings were made at temperature of 10°C in all specimens. The toughness were determined by the Page impact testing machine, accordingly the toughness value is indicated by a drop height. Fig. 38 and Fig. 39 show the relation of weight variation and cycles of freezing and thawing of the specimen of each kind of composition. In these Figues each axis shows the weight variation based on initial reading of weight of each mixtures and cycles of freezing

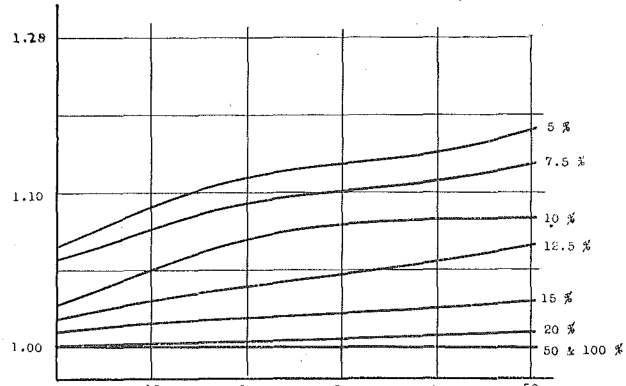


Fig. 38 Relation Between variation of weight of Akita straight asphalt mortar and cycles of freezing and thawing.

and thawing. Fig. 40 and Fig. 41 show how the toughness is affected by freezing and thawing. Table–5 is a tabulation of these results. From these tests the following conclusions were attained.

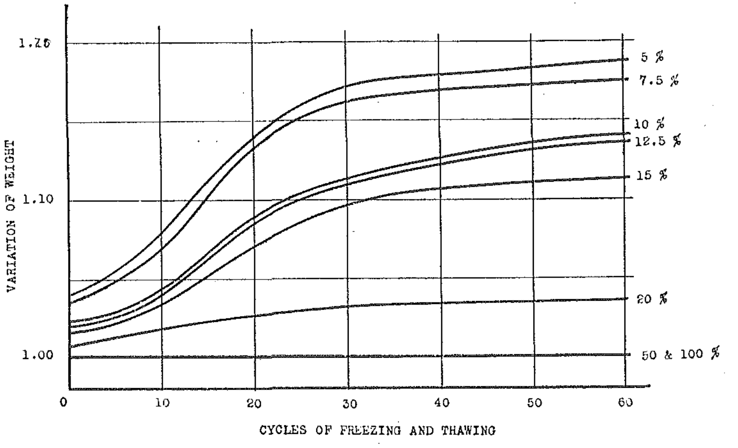


Fig. 39 Relation between variation of weight of Trinidad Lake asphalt mortar and cycles of freezing and thawing.

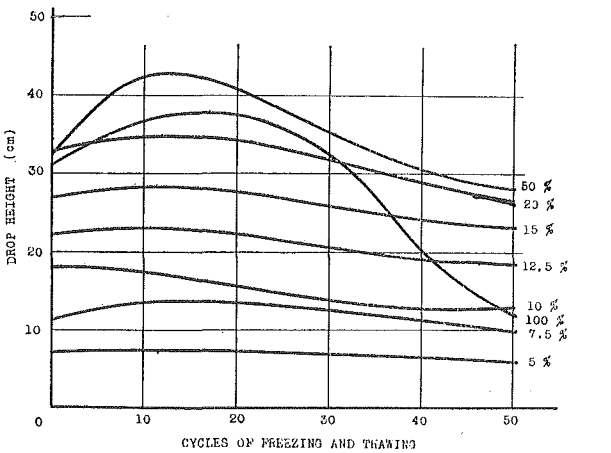


Fig. 40 Relation between toughness of Akita straight asphalt mortar and cycles of freezing and thawing.
(by page impact testing machine)

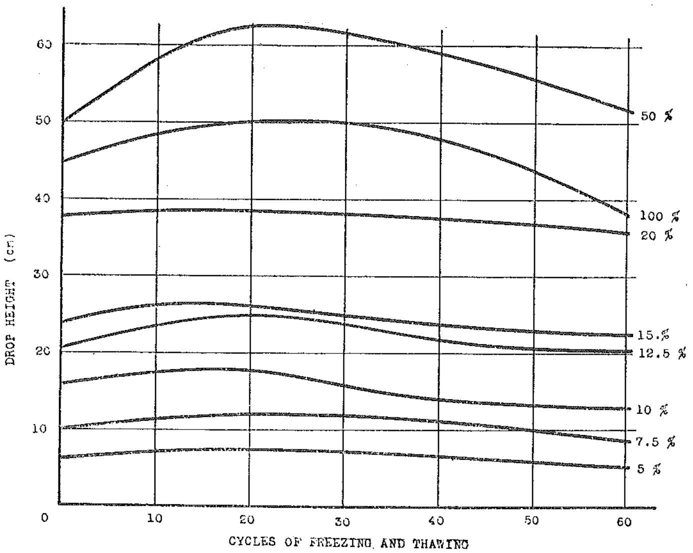


Fig. 41 Relation between toughenss of Trinidad Lake asphalt mortar and cycles of freezing and thawing. (by Page impact testing machine)

1. Variation of weight.

a) The water absorption of bituminous mortar was, to certain extent, inversely proportional to bituminous content.

b) The rate of weight increase was rather rapid within 30 cycles of freezing and thawing. The weight increase showed a constant proportion in the Akita straight asphalt mixtures.

c) There were no remarkable weight variations caused by freezings and thawings, in either bituminous cement or in mixtures constituted of 50% bituminous cement, but such phenomena did not always indicate the non-absorbing character, because the specific gravity of bituminous cement is quite close to that of water.

d) In these tests only 60 cycles of freezing and thawing test were made, but if these actions are repeated more times, it may be concluded that the weight increase would surely be greater.

e) As the weight of mixtures increases because of water absorption or because of freezing and thawing action, the texture of the mixtures becomes rough. This phenomenon indicates that the durability may be affected by that action.

Table 5

Kind of Asphalt	Asphalt content	Weight variation													
		Cycles of freezing and thawing and weight variation							Cycles of freezing and thawing and percent of weight variation						
		0	10	20	30	40	50	60	0	10	20	30	40	50	60
Trinidad Lake Asphalt	5.0	4.0	8.0	14.0	17.2	18.0	18.4	18.8	1	2.00	3.50	4.30	3.50	4.60	4.70
		(0)	(4.0)	(10.0)	(13.2)	(14.0)	(14.4)	(14.8)							
	7.5	3.5	7.0	13.2	16.2	17.0	17.2	17.5	1	2.00	3.77	4.60	4.86	4.91	5.00
		(0)	(3.5)	(9.7)	(12.7)	(13.5)	(13.7)	(14.0)							
	10.0	2.4	4.4	9.0	11.4	12.6	13.6	14.1	1	1.83	3.75	4.75	5.25	5.67	5.87
		(0)	(2.0)	(6.6)	(9.0)	(10.2)	(11.2)	(11.7)							
	12.5	2.5	4.0	8.5	11.0	12.2	13.2	13.6	1	2.00	4.25	5.50	6.10	6.60	6.80
		(0)	(2.0)	(6.5)	(9.0)	(10.2)	(11.2)	(11.6)							
	15.0	1.6	3.4	7.0	9.6	10.8	11.2	11.4	1	2.13	4.38	6.00	5.75	7.00	7.13
		(0)	(1.8)	(5.4)	(8.0)	(9.2)	(9.6)	(9.8)							
	20.0	0.8	1.8	2.7	3.2	3.4	3.5	3.6	1	2.25	3.38	4.00	4.25	4.38	4.50
		(0)	(1.0)	(1.9)	(2.4)	(2.6)	(2.7)	(2.8)							
Akita straight Asphalt	5.0	7.0	9.1	11.0	11.9	12.6	14.0	—	1	1.30	1.57	1.70	1.80	2.00	—
		(0)	(2.1)	(4.0)	(4.9)	(5.6)	(7.0)								
	7.5	5.7	7.6	9.3	10.1	10.8	12.0	—	1	1.33	1.63	1.77	1.89	2.10	—
		(0)	(1.9)	(3.6)	(4.4)	(5.1)	(6.3)								
	10.0	2.7	5.0	7.0	8.0	8.3	8.4	—	1	1.85	2.59	2.96	3.07	3.11	—
		(0)	(2.3)	(4.3)	(5.3)	(5.6)	(5.7)								
	12.5	1.8	3.0	4.0	4.8	5.6	6.6	—	1	1.67	2.22	2.67	3.11	3.67	—
		(0)	(1.2)	(2.2)	(3.0)	(3.8)	(4.8)								
	15.0	1.0	1.6	2.0	2.2	2.6	3.0	—	1	1.60	2.00	2.20	2.60	3.00	—
		(0)	(0.6)	(1.0)	(1.2)	(1.6)	(2.0)								
	20.0	0.3	0.5	0.7	0.8	0.9	1.0	—	1	1.67	2.33	2.67	2.99	3.33	—
		(0)	(0.2)	(0.4)	(0.5)	(0.6)	(0.7)								

( ) shows the weight increase.

Figs. 42 and 43 show the relation of bulk specific gravity, variation of weight, void ratio and asphalt content of mixtures.

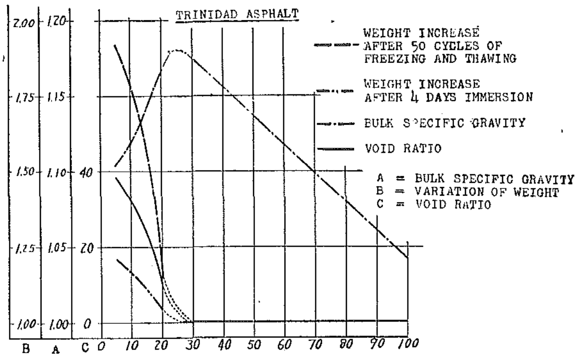


Fig. 42 Relation of Bulk specifif gravity, variation of weight, void ratio and asphalt content.

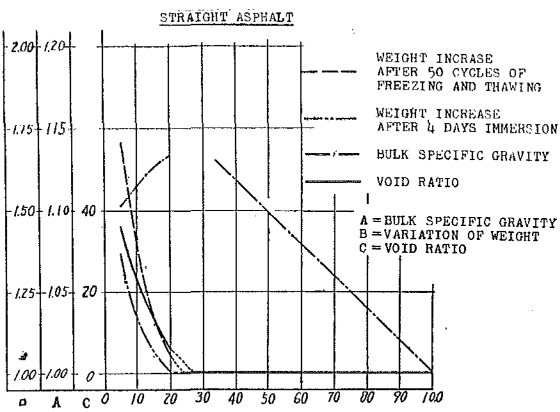


Fig. 43 Relation of bulk specific gravity, variation of weight, void ratio and asphalt content.

2. Variation of toughness.

The toughness of bituminous mixture was affected by freezing and thawing actions. As shown in the Figs. 40 and 41, from these tests some interesting results were obtained, for example, the repetition of freezing and thawing resulted in some increase of toughness within 10 to 20 cycles. This fact led to the consideration that this action might cause some settlement in the constitution of the mixtures. And in spite of the fact that some kinds of non-absorptive specimens contained 50 and 100% of bituminous cement, their toughness was reduced, when they were subjected to repetition of freezing and thawing over 10 to 20 cycles. As a result of this test, the toughness of mixture was considered to be reduced by the repetition of freezing and thawing.

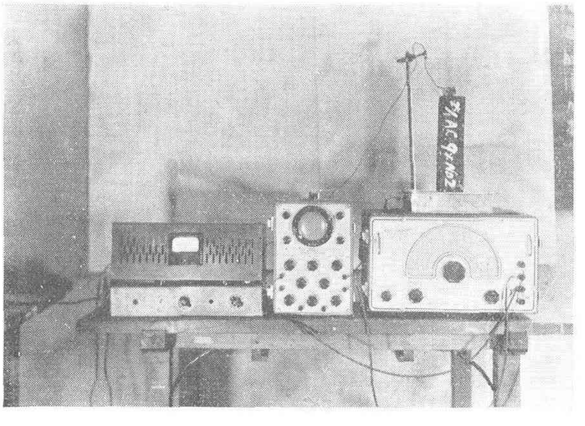
Chapter 5 A sonic method of studying the temperature sensitivity and stability of bituminous mixtures.

1. General.

Several conventional methods have been used for studying of temperature sensitivity or stability of paving materials. Generally, those methods are subjected to considerable difficulties as mentioned in the preceding chapters. It has become clear that the sonic method is most suitable for studying the interior behaviour of cement concrete and other materials. The sonic method may also be satisfactorily used for determination of stability of bituminous mixtures just as of concrete, and many of the difficulties mentioned may be eliminated. Accordingly the sonic apparatus was applied to bituminous mixtures, and was used for the purpose of checking compatibility and ability of experiment on stability of bituminous mixtures.

2. Sonic apparatus (photograph-3).[6),7),8),9),10)]

The constitution of this equipment is schematically shown in Fig. 44. The driving unit consists of variable audio-oscillator, an amplifier and a driver. The oscillator, so-called "Audio frequency oscillator



Photograph 3

Sonic apparatus.

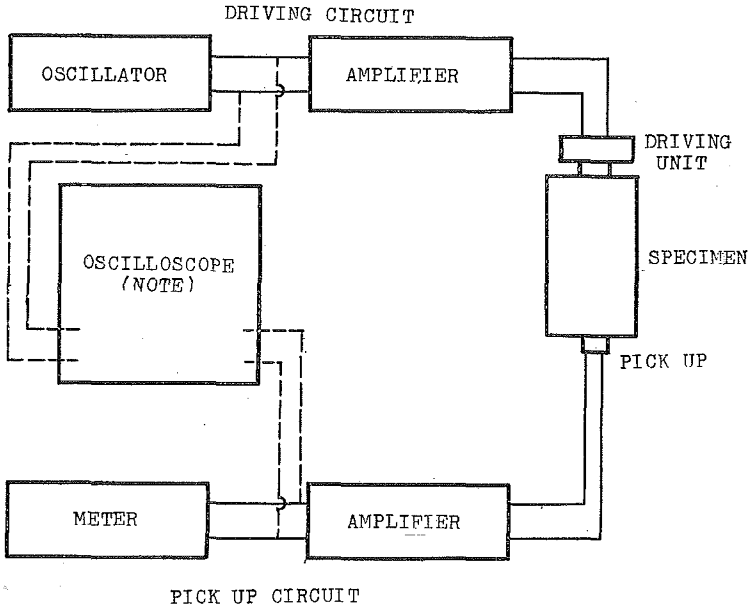
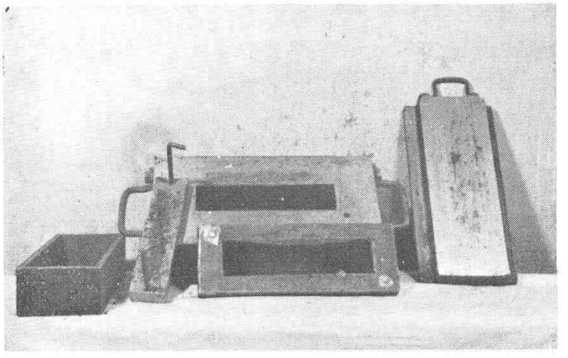


Fig. 44 Schematic diagram of a sonic device.

Model RC–2K (made by the Matsushita Electric Industrial Co. Ltd.) has three frequency ranges of 20–200, 200–2,000, 2,000–20,000 cycles per second; the accuracy of this oscillator is within 1% of frequency.

The pick-up circuit consists of a Rochelle salt crystal pick-up (produced by Nihon Denshi Sokki Co. Ltd), an amplifier and indicator. The indicator consists of micrometer and cathode-ray oscilloscope so-called "A National CT–75 Cathode Ray Oscilloscope" (produced by the Matsushita Electric Industrial Co. Ltd.).

The dynamic modulus of elasticity was obtained on three 6 by 6 by 25 cm bars of each sort of composition. The coarse aggregates were well-graded crushed stones and the fine aggregates devided into two gradings, were crushed quartz sand. The cement used as mineral filler, amounted to five percent by weight of total amount of the material; the composition of mixtures is shown in Table–6. Photograph–4 shows the molding devices. The molding form was made of wrought iron, because the form made of cast iron of the same size broke upon application of tamping pressure of 200 kg per sq.cm (about 3,000 psi). From this accident it was realized that the propagation of pressure in hot bituminous mixtures is approximately the same as in



Photograph 4

Molding device.

TABLE 6 Compositions of mixture (dy weight)

Kind	Asphalt content (%)	Filler (%)	Crushed stone (%)					Sand (%)	
			mm 30–20	mm 20–15	mm 15–10	mm 10–5	mm 5–0	mm 1.2–0.6	mm 6.3–0.15
Asphalt Mortar	7.5	5	—	—	—	—	—	43.75	43.75
	9.0	5	—	—	—	—	—	43.00	43.00
	10.5	5	—	—	—	—	—	42.25	42.25
	12.0	5	—	—	—	—	—	41.30	41.30
Topeka	7.5	5	—	—	20.21	17.02	2.17	24.05	24.05
	9.0	5	—	—	19.85	16.72	2.13	23.65	23.65
	10.5	5	—	—	19.49	16.41	2.09	23.25	23.25
	12.0	5	—	—	19.19	16.16	2.06	22.85	22.85
Asphalt Concrete	7.5	5	23.17	11.58	—	4.65	—	24.05	24.05
	9.0	5	22.75	11.38	—	4.57	—	23.65	23.65
	10.5	5	22.34	11.17	—	4.48	—	23.25	23.25
	12.0	5	21.95	10.97	—	4.40	—	22.85	22.85

liquid substances, so that the final molding device was designed with-regard to Pascal's law.

Brittle bituminous mixture was changed to liquid state by application of high pressure, and this phenomenon might occur originally in heat exchange of bituminous cement. Then it was suggested that the mixtures might be completely compacted by application of a suitable compacting machine, if obtainable even in low temperature. The pressure applied in making specimens was 210 kg per sq.cm.

3. Determination of dynamic modulus of elasticity.

The dynamic modulus of elasticity is calculated from the fundamental transverse frequency, weight and dimensions of test specimens by the following equation:

$$E = \frac{4l}{S} W f^2$$

where E: dynamic modulus of elasticity in kg per sq.cm
W: weight of specimen in grams
l: length of specimen in cm
S: cross sectional area of test specimen in sq.cm
f: frequency in cycle per second

Tables–7, 8, and 9 show the relation between the bituminous content in mixtures and the dynamic modulus of elasticity of them obtained by this sonic apparatus. Figs.–45, 46, and 47, show the relation between the bulk specific gravity and dynamic modulus of elasticity of the same mixtures at various temperatures.

TABLE 7 Dynamic modulus of elasticity of bituminous mortar

Asphalt content (%)	No.	Dynamic modulus of elasticity (kg/cm²)		
		−10°C	0°C	20°C
7.5	1	221,000	132,000	129,000
	2	205,000	149,000	126,000
	3	205,000	148,000	123,000
	aver.	210,300	143,000	126,000
9.0	1	217,000	166,000	126,000
	2	199,000	154,000	125,000
	3	230,000	181,000	158,000
	aver.	215,300	167,000	136,300
10.5	1	199,000	178,000	154,000
	2	196,000	177,000	156,000
	3	204,000	177,000	131,000
	aver.	199,700	177,300	147,000
12.0	1	187,000	125,000	122,000
	2	169,000	124,000	119,000
	3	159,000	126,000	126,000
	aver.	171,700	125,000	122,300

TABLE 8 Dynamic modulus of elasticity of Topeka

Asphalt content (%)	No.	Dynamic modulus of elasticity (kg/cm^2)		
		−10°C	0°C	20°C
7.5	1	290,000	206,000	199,000
	2	294,000	211,000	212,000
	3	270,000	257,000	239,000
	aver.	284,700	224,700	216,700
9.0	1	263,000	257,000	202,000
	2	253,000	231,000	199,000
	3	268,000	198,000	194,000
	aver.	261,300	228,700	198,300
10.5	1	292,000	214,000	212,000
	2	292,000	255,000	244,000
	3	256,000	201,000	202,000
	aver.	280,000	223,300	219,300
12.0	1	250,000	187,000	172,000
	2	270,000	193,000	191,000
	3	251,000	193,000	171,000
	aver.	257,000	191,000	178,000

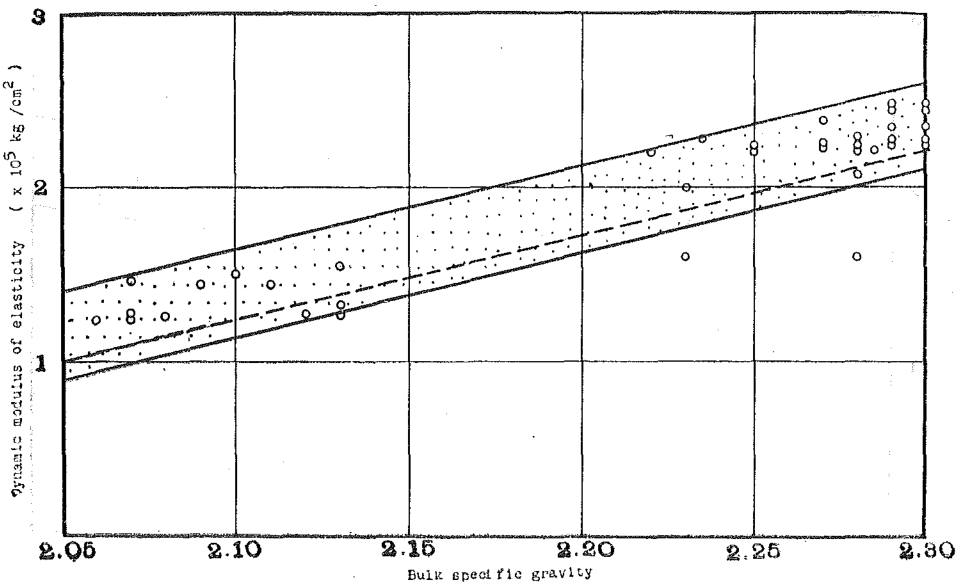


Fig. 45 Relation between bulk specific gravity and dynamic modulus of elasticity at test temperature 20°C.

TABLE 9 Dynamic modulus of elasticity of asphalt concrete

Asphalt content (%)	No.	Dynamic modulus of elasticity (kg/cm²)		
		−10°C	0°C	20°C
7.5	1	281,000	192,000	179,000
	2	230,000	176,000	162,000
	3	251,000	179,000	174,000
	aver.	254,000	182,300	171,700
9.0	1	271,000	237,000	197,000
	2	233,000	200,000	194,000
	3	272,000	192,000	169,000
	aver.	258,700	209,700	186,700
10.5	1	294,000	196,000	177,000
	2	283,000	194,000	170,000
	3	—	—	—
	aver.	288,500	195,000	173,500
12.0	1	280,000	180,000	197,000
	2	280,000	188,000	192,000
	3	247,000	180,000	178,000
	aver.	269,000	182,700	189,000

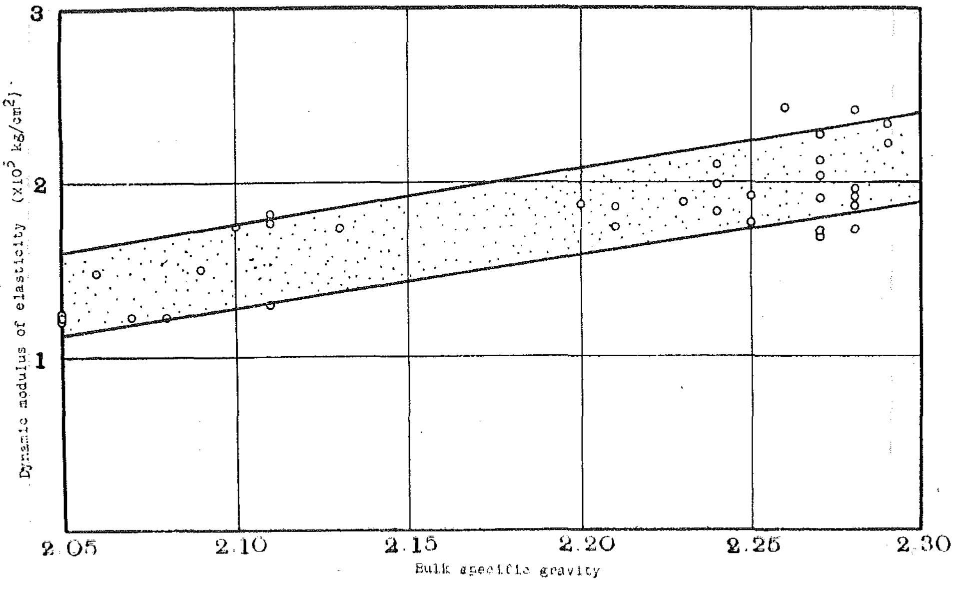


Fig. 46 Relation between bulk specific gravity and dynamic modulus of elasticity at test temperature 0°C.

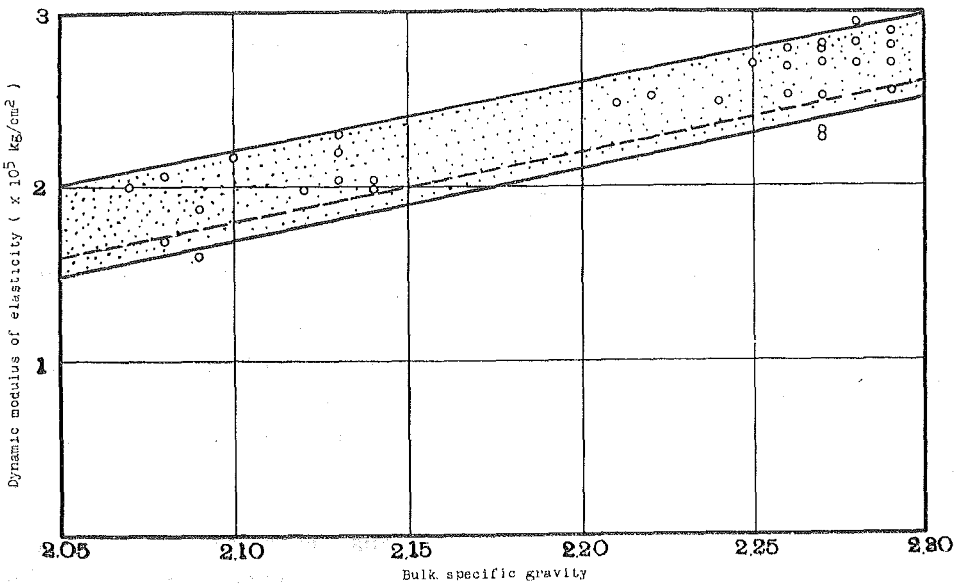


Fig. 47 Relation between bulk specific gravity and dynamic modulus of elasticity at test temperature $-10°C$.

4. Conclusions.

The method and apparatus described are believed by the present authors to be suitable for the determination of temperature sensitivity or stability of bituminous mixtures. As the results of these preliminary experiments, the following conclusions were reached.

a) The dynamic modulus of elasticity of various bituminous mixtures is affected by temperature and composition.

b) It was considered to be certain that constant relationship exists between stability and temperature, and bulk specific gravity and dynamic modulus. Accordingly the temperature sensitivity and stability of bituminous mixtures may be determined accurately and satisfactorily by the sonic apparatus.

c) The dynamic moduls of elasticity of the bituminous mixture of three kinds were 1.2 to 1.7×10^5 kg per sq.cm in asphalt mortar, 1.8 to 2.6×10^5 kg per sq.cm in Topeka and 1.7 to 2.0×10^5 kg per sq.cm in asphalt concrete in normal temperature respectively.

d) As shown in Figures, these results formed bands 92% of the measured values at 20°C, 87% at $-10°C$ and 80% at 0°C were included respectively and the width of the bands was 0.5×10^5 kg per sq.cm; while their upper and lower limits were shown by the equations:

at −10°C	upper limit	$Y=(4.00\,X-6.20)\times10^5$
	lower limit	$Y=(4.00\,X-6.70)\times10^5$
at 0°C	upper limit	$Y=(3.20\,X-4.95)\times10^5$
	lower limit	$Y=(3.20\,X-5.45)\times10^5$
at 20°C	upper limit	$Y=(4.80\,X-8.44)\times10^5$
	lower limit	$Y=(4.80\,X-8.94)\times10^5$

where Y: dynamic modulus of elasticity in kg per sq.cm.
X: bulk specific gravity of a specimen.

But if the width of the bands was reduced to 0.4×10^5 kg per sq.cm as shown by dotted lines inside the band shown in the Figures, the percentage of values falling within the bands would be reduced to 82% at 20°C and 81% at −10°C.

e) The authors are planning to continue the stability measurements with greater accuracy by the preparing more suitable specimens in respect to size and by providing a device capable of controlling the temperature variation of specimens and testing apparatuses.

Chapter 6 Static test by Hubbard stability test apparatus.

A Hubbard stability test apparatus of 6 inch inner diameter was used to make tests on temperature sensitivity of both kinds of bituminous mixtures of bituminous concrete and of bituminous mortar. In these tests the Akita straight asphalt was used. In studies of bituminous concrete four kinds of mixture 7.5%, 10%, 12.5% and 15% of asphalt cement content with mineral filler were tested. In bituminous mortar using three gradings of sand in proportion 1 (0.15 to 0.3 mm) to 1 (0.5 to 1 mm) to 1 (1 to 2 mm) by weight, five kinds of mixture were tested 5%, 7.5%, 10%, 12.5% and 15% of bituminous cement content without mineral filler. These sensitivity tests were performed at −5°C, 5°C, 10°C, 15°C, 20°C, 25°C and 30°C with both types of mixtures.

The test results are shown in Figs.-48 and 49. Each line shows the relation between crushing strength (commonly this value indicates the stability) and temperature.

On the other hand Tables-10 and 11 show the percentages of stability of each kind of mixture in which 10% bituminous cement content and 15°C test temperature used as the base. The results obtained from the above may be stated as follows:

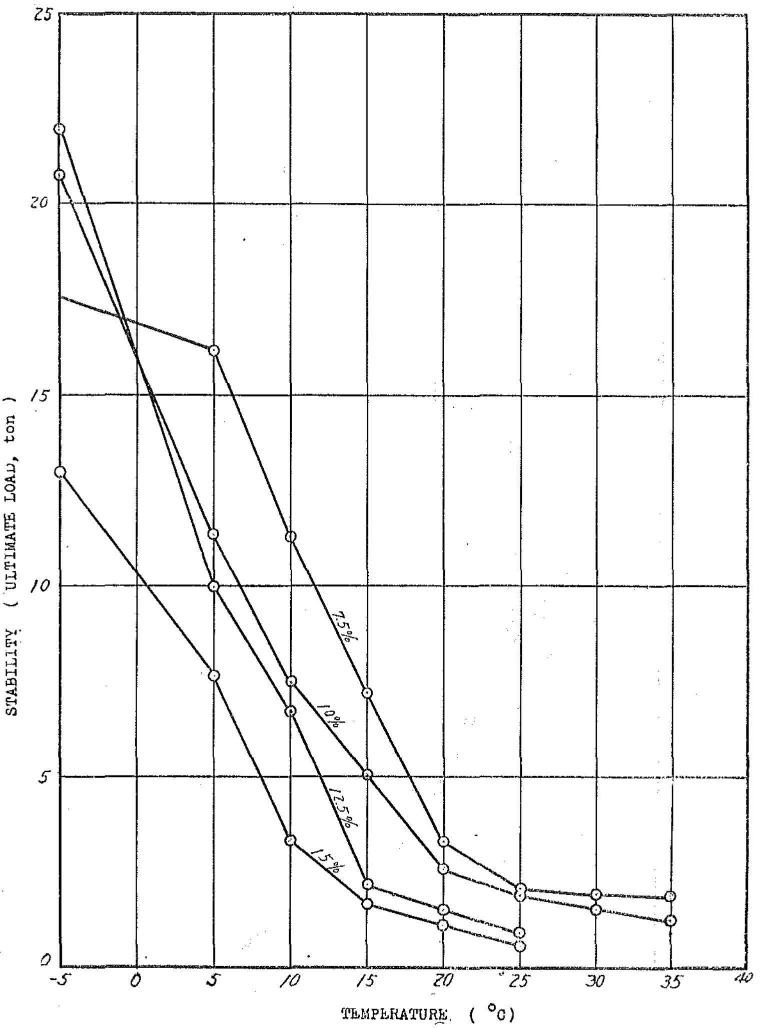


Fig. 48 Relation between stability by Hubbard test and test temperature on asphalt concrete.

1) The sensitivity of bituminous mixtures measured by a Hubbard stability test apparatus was remarkably affected by temperature variation, but there were no considerable differences among the various specimens constituted of different qualities of bituminous cement. These facts might be taken to show that the sensitivity of bituminous mixtures was influenced by the sensitiveness of the bituminous cement used in mixtures.

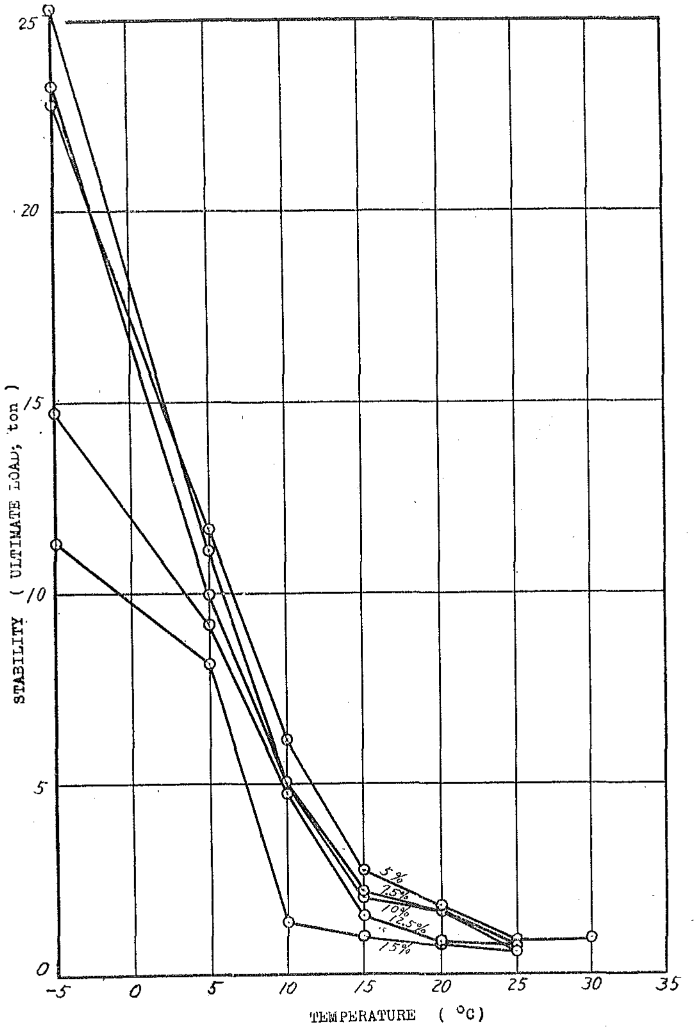


Fig. 49 Relation between stability by Hubbard test and test temperature on asphalt mortar.

2) The stability of bituminous concrete was affected remarkably by bituminous content. The stability of mixture of comparatively lower bituminous content showed high stability at normal atmospheric temperature, while the mixture of either high or low bituminous content showed lower stability at low temperatures. The optimum bituminous content as determined by this test was 10 to 12.5%.

TABLE 10 Percent stability of asphalt concrete of various compositions at various temperatures.

(Stability of asphalt concrete of 10% content at test tempreature 15°C being taken as 100%)

Test temperature (°C)	Percent stability			
	7.5 %	10.0 %	12.5 %	15.0 %
−5	—	416	440	260
5	324	228	220	152
10	226	150	134	66
15	144	100	44	34
20	66	52	28	22
25	42	36	18	12
30	38	30	—	—
35	38	24	—	—

TABLE 11 Percent stability of asphalt mortar of various compositions at various temperature.

(Stability of asphalt mortar of 10% asphalt content at test temperature 15°C being taken as 100%)

Test temperature (°C)	Percent stability				
	5.0 %	7.5 %	10.0 %	12.5 %	15.0 %
−5	1135	1260	1165	735	565
5	585	560	500	460	410
10	310	250	250	235	70
15	135	110	100	75	50
20	90	85	85	45	40
25	45	25	35	35	25
30	45	—	—	—	—

3) The stability of bituminous mortar was affected by low temperatures, but there were no considerable differences at normal temperatures.

4) The stability of bituminous concrete was higher than that of bituminous mortar at same bituminous content and at the same test temperature.

Chapter 7 Summary and conclusions.

Results of the above investigations are summerized as follows:

I. Test procedures.

1. At the normal temperatures between 10°C to 30°C, various test procedures showed variation of characteristics in asphaltic mixtures, except in the case of tests employing the present Charpy impact testing machine. Among the apparatus used, that which gave satisfactory results was the Page impact testing machine, while the best results were obtained with the soniscope.

2. At temperatures higher than about 35°C, as is generally known, the mixture was transformed to fluid state and began to flow, so that there could not be found any suitable procedure to test its stability as solid.

3. At temperatures lower than 10°C, especially below 5°C, neither Hubbard stability testing apparatus nor the present Charpy testing machine could show dependable results. On the other hand, the Izod impact testing machine gave sufficient results; next came the Page impact, while the best one was the soniscope.

4. Although various test procedures other than using the soniscope, even those considered as sufficient, served for identification of characteristics in nominal stability of asphalt mixtures, they showed simply the differences or comparisons and did not yield any meaning from the view-point of statics or of dynamics.

5. The soniscope could give dynamic elastic moduli and it is considered at present to be best apparatus for such tests as those described in this paper. It is the intention to develop the soniscope for determination of various characteristics of asphalt mixtures in all temperature ranges, except in fluid state, especially at low temperatures, aided sometimes by the Page and the Izod impact testing machines.

II. Test results.

1. Wide differences were found in impact resistance, according to the kinds of asphalt used. Asphalt content showing the highest value in impact resistance was 20 to 25% in every case with the Page impact testing machine (Figs. 3 to 22), 20% with the Charpy and the Izod (Tables-3 and 4). The optimum asphalt content for actual use was considered as 10 to 15%, under high to low temperatures so far as the present qualities of asphalt cement are concerned.

2. In any composition and at temperatures 5°C to 20°C, the relation between toughness and temperature was quite close to a straight line on a semi-log. paper (Figs. 23 to 36.).

3. Although there was no remarkable difference in toughness or dynamic stability at temperatures below 5°C, the absolute values were considerably smaller than those at normal temperature (Figs. 3 to 36).

4. For the mixtures which have asphalt content of 20% or less, dynamic stability was directly proportional to asphalt content, the slope of the proportion being different according to the mixture compositions (Figs. 3 to 22).

5. Mixtures in which aggregate of coarser particles were prominent, had high dynamic stability (Figs. 48 and 49).

6. It is expected that the dynamic stability of mixtures subjected to freezing and thawing action is rather high (Figs. 38 to 41).

7. To get durable asphalt surface course, the improvement of quality of asphalt cement as well as proper selection of aggregates is essential.

III. Application of the test results.

In field practice, asphalt mixtures constituted of richer than 15% asphalt might not be used; accordingly mixtures of 10 to 15% asphalt content may be used satisfactorily in actual projects.

As the application of these results, on the test road section of the National Highway No. 36 between Sapporo City and Chitose Air Port, asphalt mixtures using 12, 13 and 14% of asphalt were paved, and the service records will be gained through next summer (1955).

IV. Future development of research.

Tests on the stability of bituminous mixtures against dynamic loading in cold climate should be performed from the view-point of dynamics rather than from that of statics. The soniscope can be satisfactorily used for that purpose.

On the other hand, the stability of asphalt mixtures against loading depends mainly upon the characteristics of the asphalt cement. The main object in order to get high stability of asphalt cement at low temperature is to improve the characteristics of asphalt cement.

Looking toward the production of such a stable asphalt ement, investigations of asphalt mixtures with rubber powder and various kinds of cut back asphalt of low viscosity are now being carried on by the authors in the laboratory low temperature room and also as a project of National Highway No. 36 in cooperation with the Hokkaido Development Bureau.

Regarding the manner of testing the stability of test procedures on stability of asphalt surface course and coating, especially against scaling and ravelling due to beating effect of tire chaines of high speed traffic, the use of sand blasting and special ravelling testing machine in low temperature room is being considered. The latter has been designed already and is now under trial construction. The test results in laboratory will be ready for publication in the autumn this year.

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