Asphalt Cements from Canadian Light Crudes and Their Use in Pavement Construction

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INTRODUCTION

The National Oil Policy adopted by the Federal Government encourages the use of petroleum products manufactured from Canadian crude oils, throughout the region between the Ontario - Quebec boundary and the Pacific Coast, Figure 1. Additional refining capacity is being constructed in Ontario to increase the effectiveness of the National Oil Policy in this province.

The principal Canadian oil producing areas are located in Western Canada, from which crude petroleum is transported by pipeline to refineries in Ontario, the Prairie Provinces, and British Columbia. Of the current Canadian crude oil production of nearly 650,000 barrels per day, approximately 600,000 barrels per day, or about 92 per cent, consists of light (relatively high gravity) crudes. Because of this very high proportion of light crudes, a large percentage of the current demand for asphalt cements throughout the region between the Pacific Coast and the western boundary of Quebec (about 4,000,000 barrels per year), is likely to be manufactured from Canadian light crudes. The asphalt cements made from these light crudes have relatively low viscosities at 275°F.

More than a quarter of a century ago, Mexican asphalt was being so enthusiastically promoted as the apex of quality for pavement construction, that when Mexican crude supplies declined it was very difficult to persuade engineers to substitute asphalt from Venezuelan crude which was then becoming abundant. Because of the relatively new, more recently discovered major petroleum producing areas, such as Western Canada and the Middle East, another asphalt cycle is beginning. However, as with Mexican asphalt earlier, the characteristics of Venezuelan asphalts in turn have been so thoroughly impressed on engineers as the ultimate in asphalt quality, that some difficulty is again being experienced in gaining acceptance for asphalt cements manufactured from crudes from these newer oil fields. Venezuelan asphalts are of good quality when properly used, but so are asphalts made from crude oils from other petroleum producing areas.

A major dissimilarity between asphalts derived from Venezuelan and Western Canadian light crudes is the difference between their viscosity-temperature curves, as illustrated by Figure 2. **For the same penetration at 77°F,** at any specified elevated temperature the viscosity of a typical Venezuelan asphalt is appreciably higher than that of a representative asphalt cement made from a Western Canadian light crude. For example, Figure 2 shows that at a temperature of 275°F the viscosity of the Venezuelan asphalt is 262 seconds Saybolt Furol, while the viscosity of the asphalt cement from Canadian light crude is 100 seconds Saybolt Furol, when both asphalt cements have the same penetration of 78 at 77°F.

Satisfactory asphalt pavements can be made with asphalt cements manufactured anywhere in Canada, **provided always that these asphalt binders are utilized correctly for both pavement design and pavement construction.** Nevertheless, as a carryover from the period when Venezuelan asphalts were predominant around the world, there appears to be some tendency for engineers to believe that superior asphalt quality is neces-

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sarily associated with a high viscosity at 275°F. Habit and tradition exert such a powerful influence in the asphalt pavement field, that it is worthwhile to consider this whole matter very carefully, and especially to ask ourselves if asphalt binders with high viscosities at 275°F will necessarily result in better pavement performance than asphalt cements having lower viscosities at 275°F, other factors being equal. It is particularly important to ask ourselves this question here in Canada, since as previously pointed out, 92 per cent of the Canadian petroleum currently produced consists of light crudes from which asphalt cements with relatively low viscosities at 275°F are derived.

It is the principal purpose of this paper to show that paving mixtures containing "low viscosity" asphalt cements from Western Canadian light crudes have a number of important advantages over those made with "high viscosity" asphalt cements, when considered from the viewpoints of both,

(a) the construction stage (which lasts for only the first three or four hours of the lifetime of an asphalt pavement), and

(b) better long-term pavement performance (which for correctly designed and constructed asphalt pavements should be over a period of 20 to 25 years).

The advantages of these "low viscosity" asphalt cements will be considered under the above two major headings.

While the subject matter of this paper is organized under these two principal headings, it is recognized that they are very closely related. Whether construction practice is good or poor has a very marked influence on the resulting long term pavement behaviour. Conversely, when an organization concentrates its attention on achieving better long range pavement performance, this in turn will inevitably influence its attitude toward construction procedures it considers to be acceptable.

It is to be emphasized that the paving mixtures referred to in this paper are considered to be correctly designed asphaltic concrete. Limitations of space do not permit a general discussion of good paving mixture design other than to say that this includes satisfactory aggregate gradation for good workability, and the mixture should satisfy The Asphalt Institute design requirements listed in Table 1.

DEFINITION OF TERMS

First of all, it is necessary to define precisely what is meant by the terms "low viscosity" and "high viscosity" asphalt cements, as they are employed in this paper. Above all, it must be understood that these terms are always applied to asphalt cements of the **same penetration grade,** that is, they have the same range of penetration at 77°F, for example 85/100 penetration.

The term "high viscosity", as used here, means that an asphalt cement of a particular penetration grade has a high viscosity at 275°F. The term "low viscosity" means that another asphalt cement **of the same penetration grade** has a relatively low viscosity at 275°F. For 85/100 penetration asphalt, for example, the following ranges of viscosity at 275°F are representative of "high viscosity" and "low viscosity" asphalt cements,

(a) a typical Venezuelan "high viscosity" asphalt of 85/100 penetration has a viscosity above 175 seconds Saybolt Furol at 275°F, while

(b) typical "low viscosity" asphalt cements of 85/100 penetration from Western Canadian light crudes have viscosities within the range of 85 to 100 second Saybolt Furol at 275°F.

It should be stressed that the conclusions presented in this paper would not necessarily apply when pavements containing asphalt grades having different penetrations at 77°F are compared on the basis of the viscosities of the asphalt cements at 275°F, for example, a comparison between pavements containing 150/200 and 85/100 penetration asphalts from either the same or different crude sources. When the performance of paving mixtures containing asphalt cements having different penetrations at 77°F is compared, other factors than the differences in their viscosities at 275°F must usually be considered.

THE CONSTRUCTION STAGE

During the construction stage, which is usually limited to the first three or four hours of the lifetime of a hot-mix pavement, the aggregates are heated, dried, screened, recombined, and mixed with asphalt cement, and the finished hot mixture is transported to the job where it is spread and compacted. Problems that arise during the construction stage are usually associated with inadequate drying of the aggregate, and with compaction by rolling. The influence that the viscosity of the asphalt binder can have on these purely mechanical construction operations will be considered under two headings,

1. the mixing temperature at the hot-mix plant
2. spreading and compacting the paving mixture.

MIXING TEMPERATURE AT THE HOT-MIX PLANT

1. When the Hot Aggregates are Thoroughly Dry

(a) Since the aggregate usually constitutes from 94 to 95 per cent of hot-mix asphaltic concrete, the mixing temperature must be controlled by adjusting the temperature of the hot aggregate before it is dropped into the pug-mill.

(b) **When the hot aggregate is thoroughly dry,** the recommended mixing temperature is the temperature at which the asphalt cement has a viscosity within the range of 75 to 150 seconds Saybolt Furol, Figure 2.

(c) Figure 2 demonstrates that for a mixing viscosity of 100 seconds Saybolt Furol for example, the mixing temperature for this particular high viscosity Venezuelan asphalt of 78 penetration at 77°F would be about 315°F, while the mixing temperature for the low viscosity Canadian asphalt having the same penetration at 77°F, would be 275°F. This is 40°F lower.

(d) This 40°F lower mixing temperature results in two major advantages for the low viscosity Canadian asphalt,

   (1) there is a saving in fuel and drier operating costs

   (2) there is less hardening of the asphalt binder during the mixing operation itself, as demonstrated by the Thin Film Oven Test results of Table 2, and by the data illustrating the differences in the degree of hardening of asphalt cements during hot mixing shown in Table 3. The significance of the data of Tables 2 and 3 with respect to long range pavement performance will be discussed later.

2. When the Hot Aggregates are not Thoroughly Dry

(a) If the aggregate is not thoroughly dry when it is charged into the pug-mill and coated with asphalt, several problems can arise,

   (1) If the coarse aggregate contains appreciable capillary pore space into which the water has been absorbed, time is required for heat to penetrate far enough into the coarse particles to evaporate this capillary water. If the aggregate is coated with asphalt before the evaporation of this water is complete, steam

bubbles through the asphalt coating to escape. This bubbling of the coating on the coarse aggregate particles may still be noticeable even after the hot mix has gone through the spreader on the road.

(2) Steam escaping from a hot mix due to inadequate drying of the aggregate condenses to water against the cool sides and bottom of the box on the truck during transportation, and an appreciable quanity of free water may be observed when the truck is emptied into the spreader. For example, one per cent of moisture remaining in the aggregate when coated with asphalt, corresponds to approximately 20 pounds or two Imperial gallons (2.4 U.S. gallons) of water per ton of mix.

(3) The mix may slump and even flatten completely in the truck due to the volume of steam given off by bubbling through the asphalt coating on the aggregate particles. Even when the aggregate contains only 0.05 per cent of moisture, this corresponds to one pound of water per ton of mix. One pound of water can form approximately one cubic yard of steam at at atmospheric pressure. It should not be surprising, therefore, that steam bubbling through the asphalt coating on inadequately dried aggregate particles can cause a truck load of mixture to flatten like a liquid mass.

(4) The larger aggregate particles may appear poorly coated.

(5) The mixture may appear too brown or gray.

(b) Several possible solutions may be used to overcome these various problems that arise due to poorly dried aggregates.

(1) The mixing temperature may be lowered until very little of the moisture retained by the aggregate continues to be converted into steam. In this case, a film of moisture may exist between the asphalt coating and the aggregate, and stripping of the mix, particularly of the binder course in contact with a granular base, longitudinal cracking, etc., may develop in the pavement within only a few months of service. (See paper by J. T. Corkill, C.T.A.A. Proceedings, Volume IV, 1959.)

(2) Reduce the drier throughput to increase residence time for the aggregate within the drier. This can provide dry aggregate, but it will be at the expense of appreciably reduced mixing plant production.

(3) Arrange two driers in tandem with a conveyor belt between them. This increases the time during which the aggregate is exposed to high temperature before being coated with asphalt. Increasing the time of aggregate exposure at normal drier temperature, is more effective for achieving dry aggregate, than increasing the temperature of drying without changing the drying time. While the use of tandem driers increases drying cost somewhat, this is compensated for by increased plant production. Furthermore, the mixing temperature indicated by the viscosity temperature curve for each particular asphalt cement could be specified, Figure 2 (the temperature for a recommended mixing viscosity within the range of 75 to 150 seconds Saybolt Furol). This in turn would lead to less hardening of the asphalt binder during mixing, and as shown by Tables 2 and 3, least hardening of the binder would occur when the low viscosity asphalt cements from Canadian light crudes are used.

(4) Dry the aggregate more thoroughly by increasing the temperature of the aggregate as it is discharged from the drier. This solution can maintain plant production, but the higher mixing temperature causes greater hardening of the binder during

the mixing operation. This is implied by the Thin Film Oven Test data of Table 2.

(c) The quite misleading statement has sometimes been made that high mixing temperatures (substantially higher than that indicated by the viscosity temperature curve of Figure 2) cannot be used for low viscosity asphalt cements because the binder would drain off the coarse aggregate particles. This statement is refuted by practical experience which has shown that uniformly coated paving mixtures can be made at higher than normal mixing temperatures. Furthermore, this practical experience is supported by the data of Table 4, which indicate that both a limestone coarse aggregate and a trap rock coarse aggregate retain approximately the same quantity (same film thickness of coating) of either a high or low viscosity asphalt cement. After coating samples of ½-inch to No. 4 clean, coarse, thoroughly dry aggregate as indicated by Table 4, the coated aggregates, contained in wire baskets, were allowed to drain freely for one hour in an oven maintained at 325°F. It is apparent from the data of Table 4 that the quantities of high viscosity and low viscosity asphalts retained by these two aggregates are the same.

Figures 3, 4, and 5 demonstrate further that if higher than normal mixing temperatures are used for aggregates that are not thoroughly dry, the bubbles of steam generated by the capillary moisture which escape through the asphalt coating, cause a thinning of the coating of asphalt. For Figures 3, 4, and 5, ½-inch to No. 4 coarse aggregate at different moisture contents was placed in a wire basket, immersed in the hot asphalt cement at 300°F for two minutes, allowed to drain freely for one hour in an oven held at 325°F, and the amount of retained asphalt determined. For the three binders, one of low viscosity and two of high viscosity, represented in Figures 3, 4, and 5, there is a gradual decrease in the amount of asphalt coating retained as the amount of moisture in the aggregate at the time of coating is increased. The asphalt binder content decreases from about three per cent for the thoroughly dry aggregate to about two per cent when the aggregate contained one per cent moisture at the time of coating. A moisture content of one per cent in this aggregate when coated therefore, causes a loss of about one-third of the asphalt coating.

Table 3 indicates that either low viscosity or high viscosity asphalt binders can be used if it is necessary for any reason to employ higher than normal mixing temperatures. Furthermore, Figures 3, 4, and 5 demonstrate that if due to inadequate drying of the aggregate, poor coating of the coarse particles is observed, this can be expected regardless of whether a low viscosity or high viscosity asphalt cement is employed.

(d) It is an important advantage of low viscosity asphalt cements that, like high viscosity materials, they can be used at mixing temperatures higher than normal. On the other hand, a high viscosity asphalt cannot be used satisfactorily at the low mixing temperature that is normal for a low viscosity asphalt, for it would be too viscous. For example, Figure 2 shows that at 275°F, the viscosity of the 78 penetration low viscosity Canadian asphalt is 100 seconds Saybolt Furol, which is its normal mixing viscosity. On the other hand, the high viscosity Venezuelan asphalt of the same penetration has a viscosity of 260 seconds S.F. at 275°F, which is too viscous for satisfactory mixing. Consequently, low viscosity asphalt cements can be used at either their normal low mixing temperatures, or at high mixing temperatures. On the other hand, high viscosity asphalt cements of the same penetration at 77°F require high mixing temperatures, and they cannot be used satisfactorily at the low mixing temperatures that are normal for low viscosity asphalts.

SPREADING AND COMPACTING PAVING MIXTURES

1. Problems seldom arise during the spreading operation that can be related to the viscosity of the asphalt binder. When they do, they can usually be corrected by minor adjustments to the conditions under which the mix is being laid, for example, its temperature.

2. **Only when compaction is done by steel-wheeled rollers,** do high viscosity asphalts have any advantage over low viscosity asphalt cements. This advantage is usually limited to the hottest days and to mixes of relatively low stability. Under these quite special conditions, because of their somewhat higher stability, there can be less delay in rolling mixes containing high viscosity rather than low viscosity asphalt cements. Figure 2 demonstrates that at the various elevated temperatures that exist during the construction stage, a high viscosity asphalt cement has a higher viscosity throughout this temperature range, than a low viscosity asphalt cement. Therefore, at elevated temperatures, mixes containing high viscosity asphalts have somewhat more stability than those made with low viscosity asphalt cements.

3. **When using heavy self-propelled pneumatic-tired rollers** for compacting hot-mix, Figure 6, and particularly when like those of Bros, they are equipped with the "air-on-the-run" principle, which enables the tire pressure to be quickly changed to any desired value between 25 and 125 p.s.i. by flicking a switch on the control panel in front of the operator, **all the construction advantages are in favour of paving mixtures that contain low viscosity asphalt cements.**

4. These large, self-propelled, pneumatic-tired rollers can be used for breakdown, intermediate, and final rolling, and have the following advantages over conventional steel-wheeled rollers,
   (a) By adjusting to a low tire inflation pressure, the pneumatic-tired roller can do breakdown rolling immediately behind the spreader when the paving mixture is hottest and can be compacted to high density with a minimum of compactive effort. The combination of large diameter tires and low inflation pressures that can be provided by these rollers, enables breakdown rolling to proceed immediately behind the spreader even on mixes that would ordinarily be considered to have low stability, and that could result in delayed rolling by steel-wheeled rollers. The sandier type of asphaltic concrete mix, currently favoured because it tends to provide more skid-resistant surface courses, often tends to tear under steel-wheeled rollers when rolled hot, and rolling must be delayed. For these mixes, steel-wheeled rollers lose the advantage of the greater effectiveness of rolling at highest mix temperatures. With pneumatic-tired rollers, on the other hand, these mixes can be rolled immediately behind the spreader.

   (b) When they are utilized properly, these large self-propelled pneumatic-tired rollers compact paving mixtures to higher densities. This contributes to better long-range pavement performance.

   (c) Pneumatic-tired rollers provide pavements with a much tighter surface texture, Figure 7, than is usually obtained with steel-wheeled rollers. This makes it more difficult for water and air to penetrate into the pavement.

5. With respect to spreading and compaction, paving mixtures containing low viscosity asphalt cements have the following advantages over those made with high viscosity asphalts,
   (a) As shown by Figure 2, at any given temperature of interest during the construction stage, a low viscosity asphalt cement is more fluid than a high viscosity asphalt having the same penetration at 77°F. Because of this, paving mixtures containing low viscosity asphalt

cements are compacted to higher density by any given amount of rolling effort.

(b) Paving mixtures containing low viscosity asphalt cements can still be compacted effectively by rolling at lower in-place temperatures than is possible for mixes with high viscosity asphalts.

(c) The greater compactibility of mixes containing low viscosity asphalt cements, at lower in-place temperatures on the road, is a valuable feature when trying to achieve adequate compaction by rolling during cold weather construction in the early spring, and particularly in the late fall.

BETTER LONG TERM PAVEMENT PERFORMANCE

Although better long term pavement performance should be the principal aim of owner and builder alike, this objective seems very often to be almost completely disregarded when difficulties arise during the pavement construction stage. Furthermore, the solutions that are sometimes adopted to alleviate the construction difficulties may actually be the principal cause of poor long range pavement performance. It is worthwhile, therefore, to examine how construction procedures would be influenced by the need for ensuring satisfactory long term pavement performance.

In a study of causes of asphalt pavement cracking more than twenty years ago, The Asphalt Institute found that pavements were almost certain to be cracked if the asphalt recovered from them had a penetration of 20 or less. Cracking was probable if the recovered asphalt had a penetration of 30 or less. In a further study to determine when or where this hardening of the asphalt cement was occurring, The Asphalt Institute found that the asphalt cement lost about 30 points in penetration on the average, during the hot mixing operation alone. Hardening of the asphalt binder continued in the pavement in service, but at a much slower rate. To avoid pavement brittleness and cracking, therefore, pavement construction should be conducted in such manner that a mimimum of hardening of the binder will occur during hot mixing, and that the rate of hardening of the asphalt cement in the pavement will be as slow as possible.

1. Effect of Mixing Temperatures on Long Range Pavement Performance

As pointed out immediately above, a major objective of the temperature adopted for hot mixing should be minimum hardening of the asphalt cement during the hot mixing operation. How is this to be attained?

If the aggregate is thoroughly dry, and if a satisfactory mixing viscosity is assumed to be 100 seconds Saybolt Furol, Figure 2 demonstrates that for the high viscosity Venezuelan asphalt of 78 penetration at 77°F, the mixing temperature should be 315°F, while for the low viscosity Canadian asphalt cement of the same penetration at 77°F, the mixing temperature would be 40°F lower, or 275°F.

The A.S.T.M. Thin Film Oven Test is intended to provide some indication of the amount of hardening of an asphalt cement that occurs during the hot-mix operation. If this test is to be significant in this respect, it must be run at the mixing temperature required for each asphalt cement. Consequently, for the mixing viscosity considered here (100 S.S.F.), the amount of hardening of the high viscosity Venezuelan asphalt (Figure 2) would be determined by running the Thin Film Oven Test at 315°F, and it would be run at 275°F for the low viscosity Canadian asphalt (Figure 2). Table 2 shows the results obtained from such a comparison. The residue from the Thin Film Oven Test when run on high viscosity Venezuelan asphalt A (same as Figure 2) shows very serious hardening to 47.5 per cent of this asphalt's original penetration at 77°F, while the Thin Film Oven Test residue is 74.3 per cent of the original penetration of low viscosity Canadian asphalt C (also same as Figure 2). Obviously, therefore, at the same mixing viscosity, high viscosity Venezuelan asphalt A would be expected to harden a great deal more during the hot mixing operation than low viscosity Canadian asphalt C.

The Thin Film Oven Test (at 325°F) residue from high viscosity Venezuelan asphalt A is slightly harder than some specifications that include the Thin Film Oven Test would permit. This high viscosity asphalt was included in Table 2, to demonstrate that high viscosity at 275°F does not in itself endow an asphalt cement with any special virtue. It may even fail to meet a normal specification in some other respect. On the other hand, high viscosity Venezuelan asphalt B would satisfy specifications that include the Thin Film Oven Test. However, for a mixing viscosity of 100 seconds S.F., the mixing temperature for this asphalt would be 300°F. Table 2 shows that the Thin Film Oven Test run at 300°F on this asphalt would result in a residue that was 59.5 per cent of its original penetration.

Table 3 compares the amount of hardening that occurred when identical laboratory paving mixtures were made with two different asphalt cements, at mixing temperaures corresponding to a mixing viscosity of 85 seconds S.F. After mixing, the asphalt binders were recovered, and their penetrations at 77°F were measured and recorded. Table 3 shows that high viscosity Venezuelan asphalt B had hardened to 57 per cent of its original penetration, while the low viscosity Canadian asphalt D had hardened to only 85 per cent of its original penetration.

The data of Tables 2 and 3 demonstrate that **for equal mixing viscosities,** considerably less hardening during the mixing operation would be expected for the low viscosity Canadian asphalt cements than for the high viscosity Venezuelan asphalts.

The data of Table 2 demonstrate also, that if due to a need for obtaining drier aggregate for example, the mixing temperature was arbitrarily raised to say 325°F, the amount of hardening of low viscosity Canadian asphalts C and D, and of high viscosity Venezuelan asphalt B, during the mixing operation, would be about the same. In addition, Table 4, and Figures 3, 4, and 5 indicate that low viscosity Canadian asphalt cements can be expected to provide just as uniformly coated paving mixtures at these higher mixing temperatures as high viscosity Venezuelan asphalts.

Very briefly, therefore, **at equal elevated mixing temperatures,** low viscosity Canadian asphalt cements and high viscosity Venezuelan asphalts can in general be expected to harden by approximately similar amounts during the mixing operation. **At equal mixing viscosities,** on the other hand, low viscosity Canadian asphalts harden very much less during the mixing operation than high viscosity Venezuelan asphalt cements.

2. Effect of Compaction on Long Range Pavement Performance

Easy entrance of air and water into an asphalt pavement causes the asphalt cement to harden more rapidly, and the pavement to become brittle, after which pavement deterioration usually occurs. For dense graded asphalt pavements, therefore, a major objective of good rolling during their construction is compaction to high density and to relatively low air voids to keep out air and moisture.

It will be shown below, that for the same rolling or compactive effort, the use of low viscosity Canadian asphalt cements in paving mixtures contributes to better long term pavement performance, because they provide higher pavement densities and lower air voids than when paving mixtures otherwise the same contain high viscosity asphalts. Some of the ways in which better rolling practice and more adequate compaction promote better long range pavement performance are also indicated.

1. Figure 8 presents the results of an investigation by Kiefer at Cornell University. It demonstrates very clearly, that for a given compactive effort, a very much higher pavement density can be attained by compacting a paving mixture at a high rather than at a low mixing

temperature. Figure 8 also shows that for the same compactive effort and at the same temperature, a paving mixture containing a low viscosity asphalt cement is compacted to very noticeably higher density than when an identical mix is made with a high viscosity asphalt cement. For Figure 8, the low viscosity asphalt cement has a penetration of 94 at 77°F and a viscosity of 120 seconds Saybolt Furol at 275°F, while the high viscosity asphalt had a penetration of 92 at 77°F and a viscosity at 275°F of 230 seconds S.F.

2. It has already been pointed out that for the sandier type of surface course mix currently preferred, rolling at high temperature with a steel-wheeled roller can cause tearing or serious cracking of the mix. On the other hand, pneumatic-tired rollers can be used at these high temperatures.

3. Figure 8 indicates further that to achieve a given pavement density with a given compactive effort, for example 146.5 pounds per cubic foot, the mix containing the high viscosity binder must be compacted at a temperature of 205°F, while the same mix made with the low viscosity binder can be compacted to the same density at a temperature of only 160°F.

   This indicates a marked advantage for low viscosity asphalt cements for cool weather pavement construction in early spring and particularly in late fall.

   Each year, a number of paving jobs constructed during cold weather in the late fall ravel and wear away seriously during the first winter. Sometimes the entire surface course wears through. Tests on samples cut from these pavements invariably show that the pavements were very poorly compacted during construction, probably because the mixture chilled too quickly. Air voids as high as 15 per cent have been measured, and the degree of compaction has been less than 90 per cent of laboratory compacted density.

   It is highly significant, that on a Canada-wide basis, of the considerable number of these pavements laid in the late fall that have been brought to our attention because they deteriorated seriously during the following winter, nearly all of them have contained high viscosity asphalt cements. This is to be expected, because as Figure 8 very clearly demonstrates, at an in-place pavement temperature that is too low for compaction when the binder is a high viscosity asphalt, compaction could still occur if the binder was a low viscosity asphalt cement.

4. Figure 9 illustrates the results of an investigation of in-service asphalt pavements that has been conducted over a period of years by the U.S. Bureau of Public Roads. Figure 9 shows very clearly that the rate at which asphalt binders have hardened in these asphalt pavements over a period of four years is directly proportional to the per cent of air voids that existed in each pavement at the time when rolling was considered complete during construction. At the end of four years, the asphalt binder was still soft in pavements that had been thoroughly rolled to high density and low air voids. On the other hand, Figure 9 shows that the asphalt cement had become hard and was approaching brittleness in pavements that contained high air voids and were of low density immediately after rolling. The Bureau of Public Roads concluded from this investigation that asphalt pavement construction specifications should require rolling during construction until the air voids are less than 7 per cent.

   For most well designed, dense graded asphalt paving mixtures (see Table 1), rolling until air voids are less than 7 per cent is equivalent to specifying compaction to about 97 per cent of laboratory compacted density during construction. This degree of compaction is very difficult to achieve with steel rollers, but can be attained with the new large self-propelled pneumatic-tired rollers. As Figure 8 demonstrates, rolling to this compaction requirement is assisted by the use of low viscosity asphalt cements.

5. In Canada, compaction requirements for rolling are usually specified in terms of the density provided by the Marshall test. For heavy, medium, and light traffic, 75-blow, 50-blow, and 35-blow Marshall compaction, respectively, is employed (Table 1). The laboratory compaction specified should equal that which the paving mixture will ultimately attain under traffic. Minimum rolling requirements during construction are normally stipulated as per cent of Marshall laboratory compacted density, for example, 95 per cent of 75-blow Marshall density.

   Figure 10 illustrates the relationship between the number of blows per face of a briquette versus per cent of laboratory compacted density based on 75-blow compaction as 100 per cent of laboratory compacted density.

   Figure 11 shows the relationship between number of blows per face of a briquette versus Marshall stability.

6. Figure 12 is of particular interest because it illustrates the serious effect that lack of compaction can have on Marshall stability. For example, at 100 per cent of laboratory compacted density, this paving mixture has a Marshall stability value of 1400 pounds. On the other hand, when compacted to only 94 per cent of laboratory compacted density, its Marshall stability is only 200 pounds.

   It is well known that paving mixtures laid on driveways and parking lots seldom receive more than superficial compaction. They are often rolled to less than 90 per cent of laboratory compacted density. Figure 12 explains why driveways and parking areas are frequently quite unstable immediately after construction. Figure 12 also emphasizes that more adequate rolling would greatly improve the stability of these pavements.

   Figure 12 shows that a marked increase in the stability of a paving mixture will result if specifications are written to require rolling to a minimum of 97 per cent instead of the common current minimum of 95 per cent of laboratory compacted density.

7. Figure 13 indicates that poor compaction also results in a higher value for the Marshall flow index. Figure 14 is taken from an earlier discussion by the writer in which he showed that some laboratory data obtained by Goetz of Purdue University could be plotted to indicate a relationship between Marshall flow index and the angle of internal friction of asphalt paving mixtures. It is known that stability increases with angle of internal friction. Furthermore, stability increases very rapidly as the angle of internal friction increases above 40°. Consequently, Figures 13 and 14 demonstrate that low pavement density results in a high value for flow index, which in turn indicates lower pavement stability or strength.

8. Most specifications require that a pavement be rolled during construction to 95 per cent or to some similar percentage of the specified laboratory compacted density (75-blow Marshall for example). Consequently, if a mixture is designed to have four per cent air voids after receiving ultimate compaction under traffic, it will contain 9 per cent air voids if it is rolled during construction to only 95 per cent of laboratory compacted density. At 9 per cent air voids a paving mixture is relatively open, and is subject to damage by air and water. It is desirable that it close up under traffic compaction to 4 per cent air voids as quickly as possible. In addition to practical experience, there are laboratory data to show that the rate at which compaction under

traffic occurs increases when the pavement contains a lower viscosity asphalt cement.

When surfacing a four-lane highway near Flint, Michigan, seven years ago, several asphalt cements having different viscosities at 275°F were used. At the time of construction all paving mixtures were compacted to 95.5 per cent of laboratory compacted density represented by 50-blow Marshall.

On one section containing a very high viscosity asphalt, a rather open surface texture has persisted since construction. The surface of adjacent mixtures that are identical except that they contain asphalt of lower viscosity, have closed up under traffic.

Although these pavement sections were rolled to practically the same density and air voids content during construction, after seven years of heavy traffic, the air voids in the pavements containing the higher viscosity binders are higher than those in adjacent pavement sections that were made with lower viscosity asphalt binders.

9. As has been pointed out several times, the adoption of self-propelled pneumatic-tired rollers would elminate the occasional delayed rolling that has been a basis for criticism of the use of low viscosity asphalt cements. For mixes that are otherwise properly designed and constructed, it becomes possible by combining the use of pneumatic-tired rollers and low viscosity asphalt cements to construct asphalt pavements of exceptional service performance.

RESISTANCE TO STRIPPING FROM THE AGGREGATE

1. Table 5 shows that low viscosity Canadian asphalts have as good resistance to stripping from aggregates as typical Venezuelan high viscosity asphalts. The test employed for the data of Table 5 is A.S.T.M. D 1664. Because of the difficulty of determining by visual examination the precise amount of uncoating of the aggregate that has occurred, A.S.T.M. D 1664 states that the results are to be reported only as "above 95 per cent coated", and "below 95 per cent coated". Trap rock usually shows good adhesion for asphalt binders, but Massachusetts' rhyolite is widely recognized as an aggregate from which some asphalts tend to strip rather easily. Table 5 indicates that all five asphalts pass this stripping test with both aggregates.

GENERAL

1. The single advantage that paving mixtures made with high viscosity asphalt cements have over similar mixtures containing low viscosity asphalts, is their higher Marshall stability at the elevated temperatures required during construction. This is due chiefly to the higher viscosities of these asphalt cements at high temperatures. Figure 15 provides Marshall stability values for paving mixtures that are identical except that one is made with high viscosity Venezuelan asphalt B from Table 2, while the other contains low viscosity Canadian asphalt D from the same table. These paving mixtures were compacted by 75-blow Marshall.

Figure 15 shows that for temperatures above about 100°F, the paving mixture containing the high viscosity asphalt cement has the higher Marshall stability. Below a temperature of about 100°F, the paving mixture made with the low viscosity asphalt has the greater Marshall stability.

Until the advent of the pneumatic-tired roller, the higher stability of paving mixtures containing high viscosity asphalt cements was a distinct advantage because it eliminated delays when rolling with steel-wheeled rollers. The introduction of the new large self-propelled pneumatic-tired rollers has largely eliminated this former advantage.

2. As has been indicated a number of times, the greater stability at elevated temperatures of paving mixtures containing asphalt cements of high viscosity, Figure 15, has its own special demerit. This greater stability at elevated temperatures makes the pavement more resistant to rapid compaction to ultimate density under traffic. Because the pavement remains more open for a longer period of time, the asphalt cement may become seriously hardened.

3. While the advantages of self-propelled pneumatic-tired rollers for compacting asphalt paving mixtures have been pointed out frequently during this paper, they require further development to make them more generally useful and acceptable. There is serious need for some mechanism that will keep the pneumatic tires hot, or for some special treatment of the rubber, so that the paving mixture does not stick to them.

4. It might be asked if there is any region where low viscosity asphalt cements have been in continuous use for many years, and how the pavements containing them are performing.

   For more than thirty years nearly all of the asphalt cement used along the Pacific Coast and the adjacent interior of British Columbia has been of the low viscosity type. In general, the asphalt pavements in this area, including those on the streets of Vancouver, are among the best in Canada. If any construction difficulties with these low viscosity asphalt cements ever occurred, they seem to have been solved satisfactorily long ago.

   California is another region where large quantities of low viscosity asphalt cements have been used in pavement construction for several decades. Here, too, the quality of the asphalt pavements would be given a high rating in comparison with those in adjacent areas.

SUMMARY

1. The advantages of low viscosity asphalt cements for use in asphalt pavements have been reviewed.

2. Any difficulties that occur when laying paving mixtures containing low viscosity asphalt cements can be overcome by the use of self-propelled pneumatic-tired rollers.

3. It is shown that properly designed and constructed pavements containing low viscosity asphalt cements can be expected to show superior service performance.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Mr. J. A. A. Lefebvre of our Research Department for obtaining the data that appears in most of the Tables and Figures, and to Mr. C. L. Perkins for his skill and patience in drafting the various diagrams.

TABLE 1

MARSHALL DESIGN CRITERIA

Traffic Category	Heavy and Very Heavy		Medium		Light	
No. of Compaction Blows Each End of Specimen	75		50		35	
Test Property	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Stability, all mixtures	750	—	500	—	500	—
Flow, all mixtures	8	16	8	18	8	20
% Air Voids						
Surfacing or Leveling	3	5	3	5	3	5
Sand or Stone Sheet	3	5	3	5	3	5
Sand Asphalt	5	8	5	8	5	8
Binder or Base	3	8	3	8	3	8
% Voids in Mineral Aggregate						
	See Fig.		See Fig.		See Fig.	
Surfacing or Leveling	A	—	A	—	A	—
Sand or Stone Sheet	"	—	"	—	"	—
Sand Asphalt	"	—	"	—	"	—
Binder or Base	"	—	"	—	"	—

TABLE 2

COMPARISON OF RESIDUES WHEN THIN FILM OVEN TEST RUN AT VARIOUS TEMPERATURES

ORIGINAL ASPHALT	High Viscosity Venezuelan		Low Viscosity Canadian	
Identification	**A**	**B**	**C**	**D**
Penetration at 77°F.	78	81	78	80
Viscosity at 275°F. S.S.F.	262	199	100	111
Temp. °F. for Visc. at 100 S.S.F.	315	300	275	280
RESIDUES FROM THIN FILM OVEN TEST				
% of original penetration when thin film oven test made				
at 275°F.	62.8	72.4	74.3	70.2
at 300°F.	53.8	59.5	65.5	63.1
at 325°F.	42.3	57.1	59.0	57.5

TABLE 3

HARDENING OF ASPHALT CEMENTS DURING HOT MIXING

ORIGINAL ASPHALT	High Viscosity Venezuelan	Low Viscosity Canadian
Identification	**B**	**D**
Penetration at 77°F.	81	80
Viscosity at 275°F. S.F.	199	111
ASPHALT RECOVERED AFTER HOT-MIXING		
Mixing temperature °F. (85 sec. S.F.)	315	285
Ductility at 77°F.	150+	150+
Penetration at 77°F.	57	68
Per cent of Original Penetration	70.4	85

TABLE 4

RETENTION OF ASPHALT ON CLEAN COARSE AGGREGATE AT 325°F.

ASPHALT CEMENT	High Viscosity Venezuelan	Low Viscosity Canadian
Identification	**A**	**C**
Penetration at 77° F.	78	78
Viscosity at 275° S.S.F.	262	100
Temp. °F. for Visc. of 100 S.S.F.	315	275
AGGREGATE IMMERSED IN ASPHALT FOR 2 MIN. AT 300°F. DRAINED 1 HOUR AT 325°F.		
Limestone. % Asphalt Retained	3.5	3.4
Trap Rock. % Asphalt Retained	2.9	2.9
AGGREGATE MIXED WITH 4% ASPHALT FOR 2 MIN. AT 300°F. DRAINED 1 Hour at 325°F.		
Limestone. % Asphalt Retained	3.3	3.1
Trap Rock. % Asphalt Retained	2.6	2.7

TABLE 5

STRIPPING RESISTANCE OF ASPHALT CEMENTS

		% Surface Remaining Coated	
Asphalt	**Source**	**Rhyolite**	**Trap Rock**
Lagunillas	Venezuela	95+	95+
Tia Juana	Venezuela	95+	95+
Redwater	Western Canada	95+	95+
Leduc	Western Canada	95+	95+
S.E. Sask.	Western Canada	95+	95+

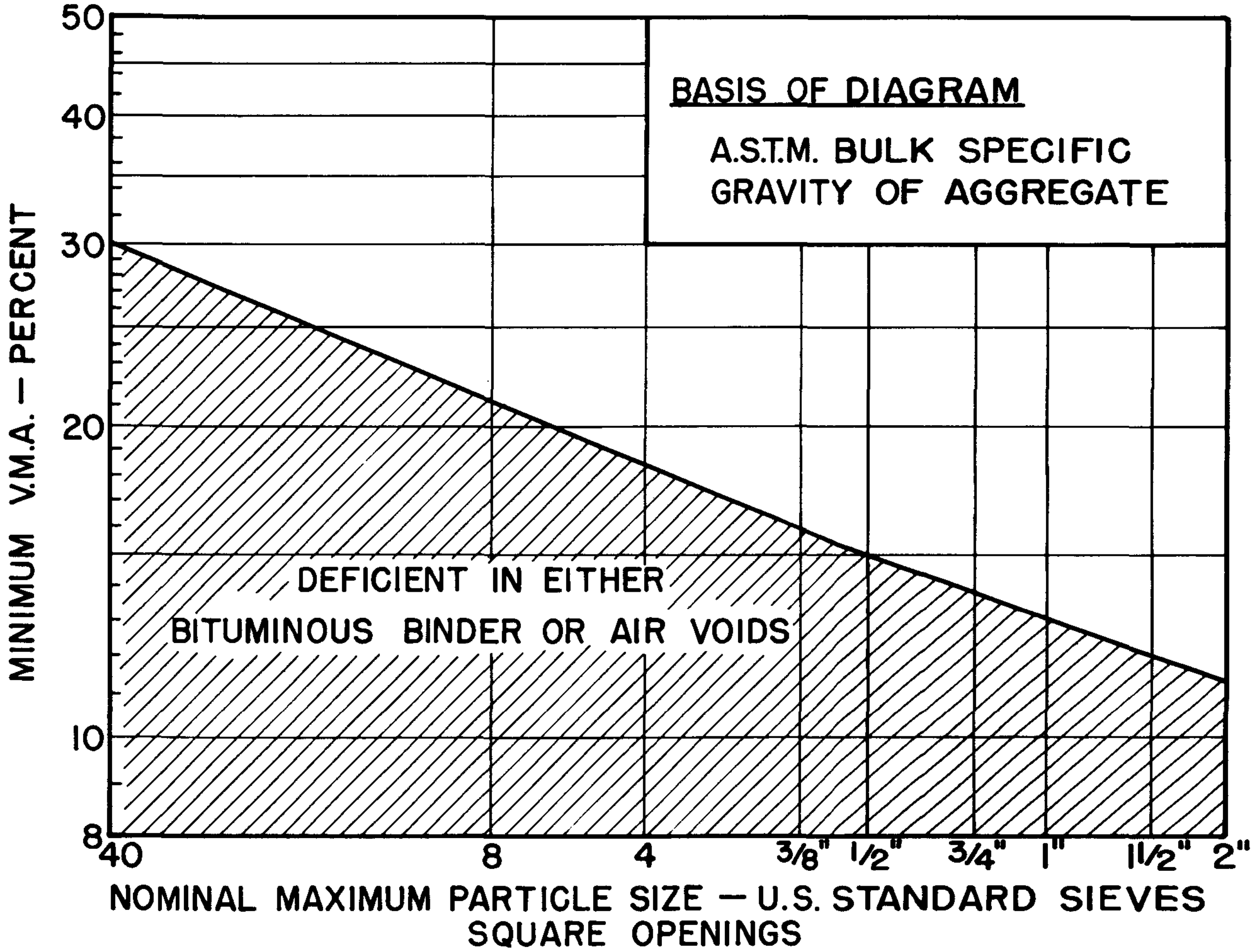

FIGURE A RELATIONSHIP BETWEEN MINIMUM V.M.A. AND NOMINAL MAXIMUM PARTICLE SIZE OF THE AGGREGATE FOR COMPACTED DENSE GRADED PAVING MIXTURES.

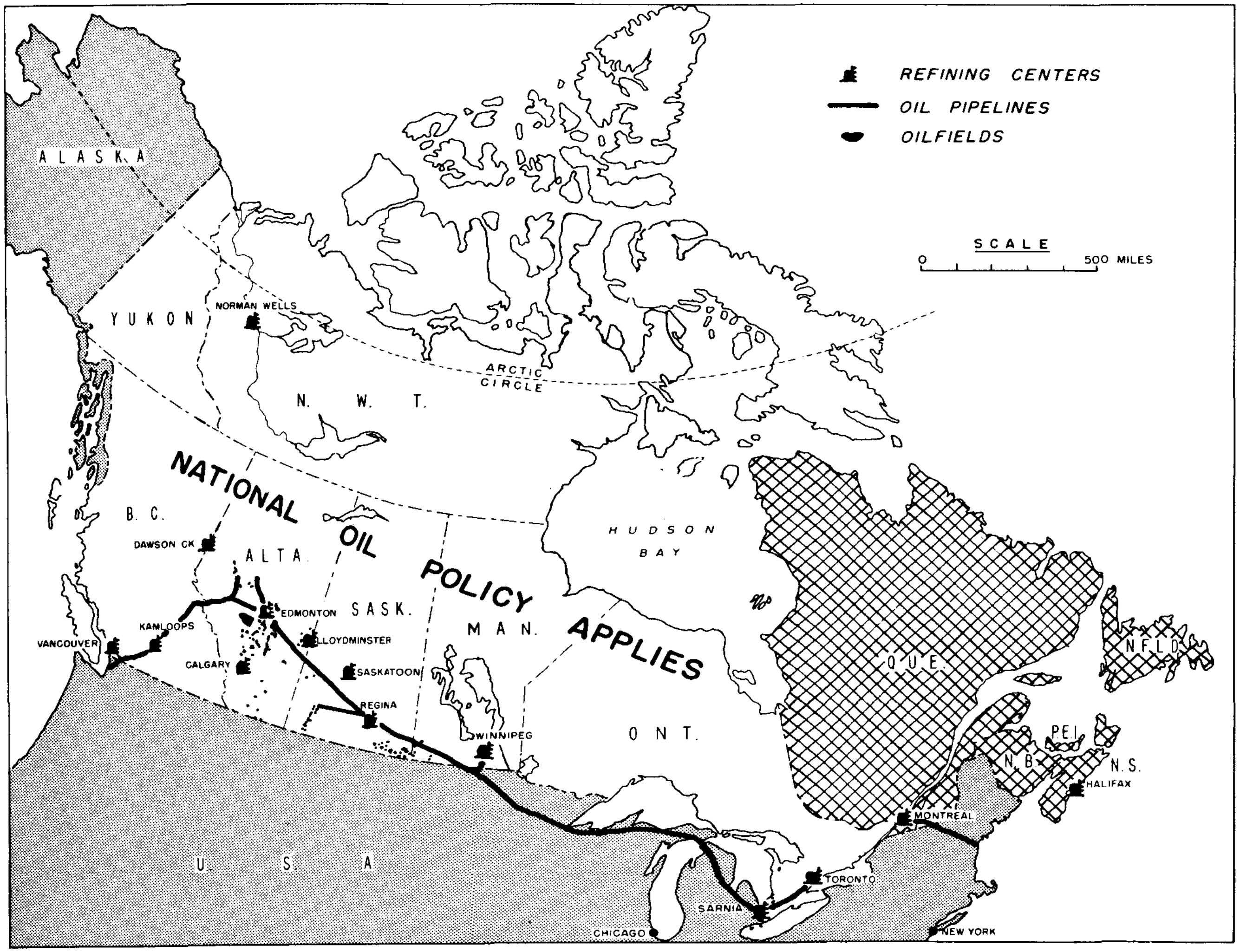

FIG. I REGION OF CANADA COVERED BY THE NATIONAL OIL POLICY (1960)

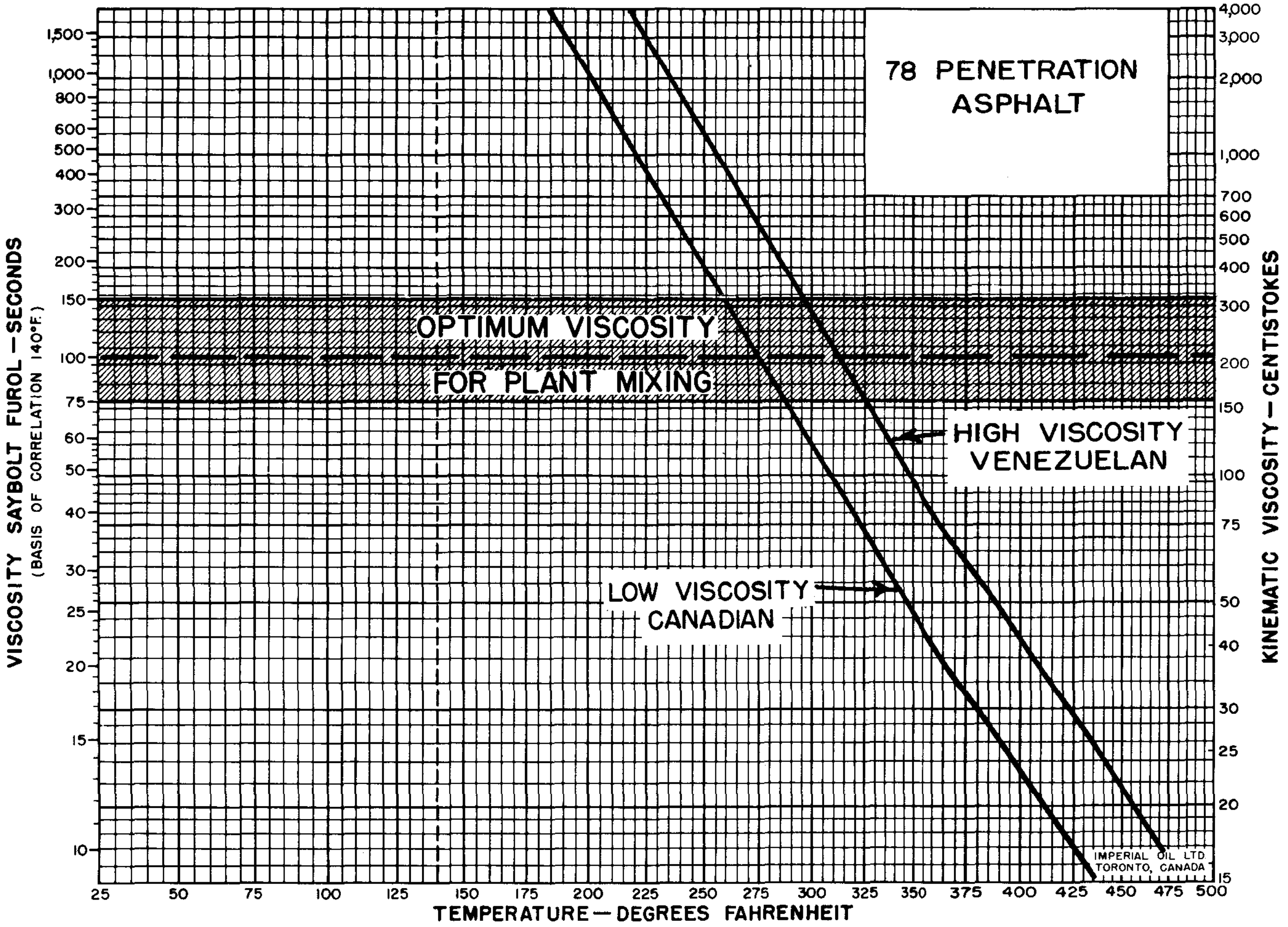

FIG. 2 A COMPARISON OF VISCOSITY TEMPERATURE CURVES FOR LOW VISCOSITY CANADIAN AND HIGH VISCOSITY VENEZUELAN ASPHALT CEMENTS.

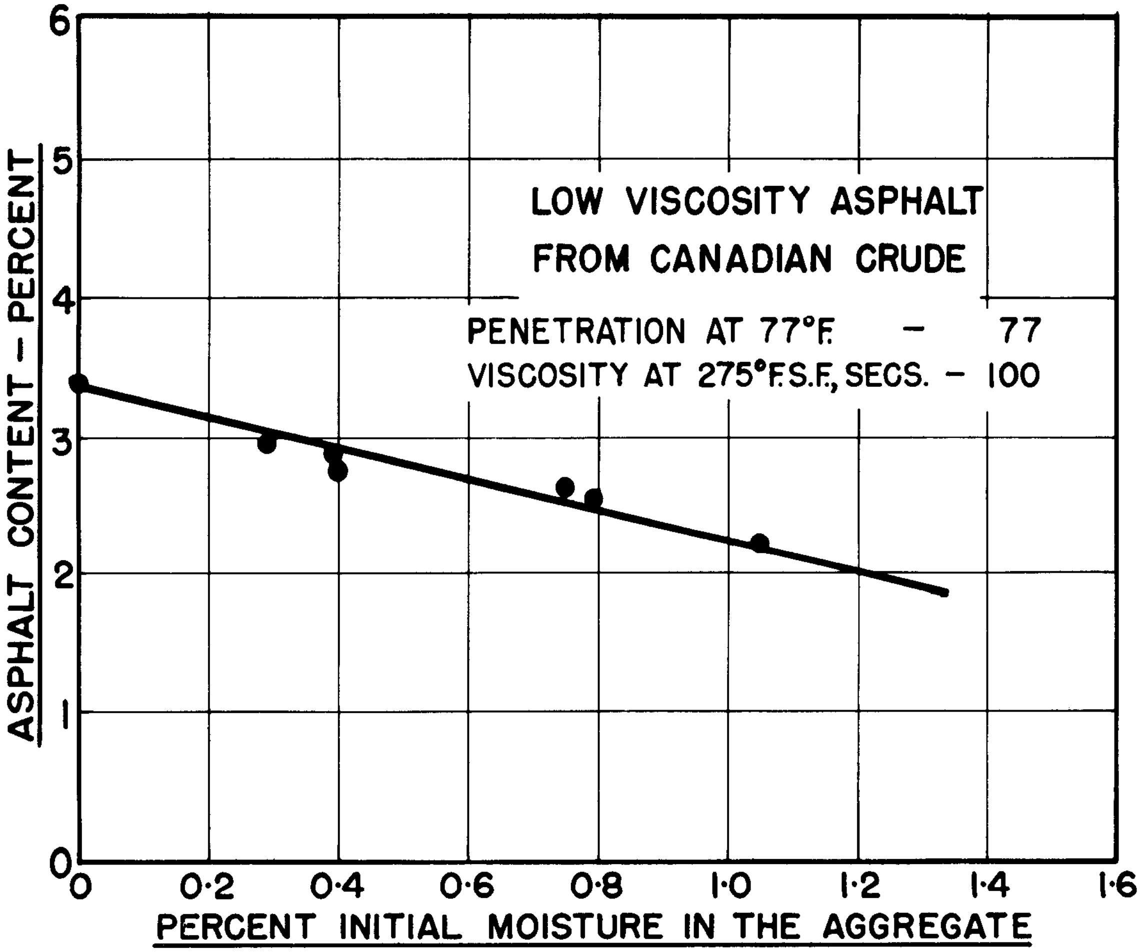

FIG.3 INFLUENCE OF MOISTURE CONTENT OF AGGREGATE WHEN COATED ON RETENTION OF ASPHALT BINDER (LOW VISCOSITY CANADIAN ASPHALT).

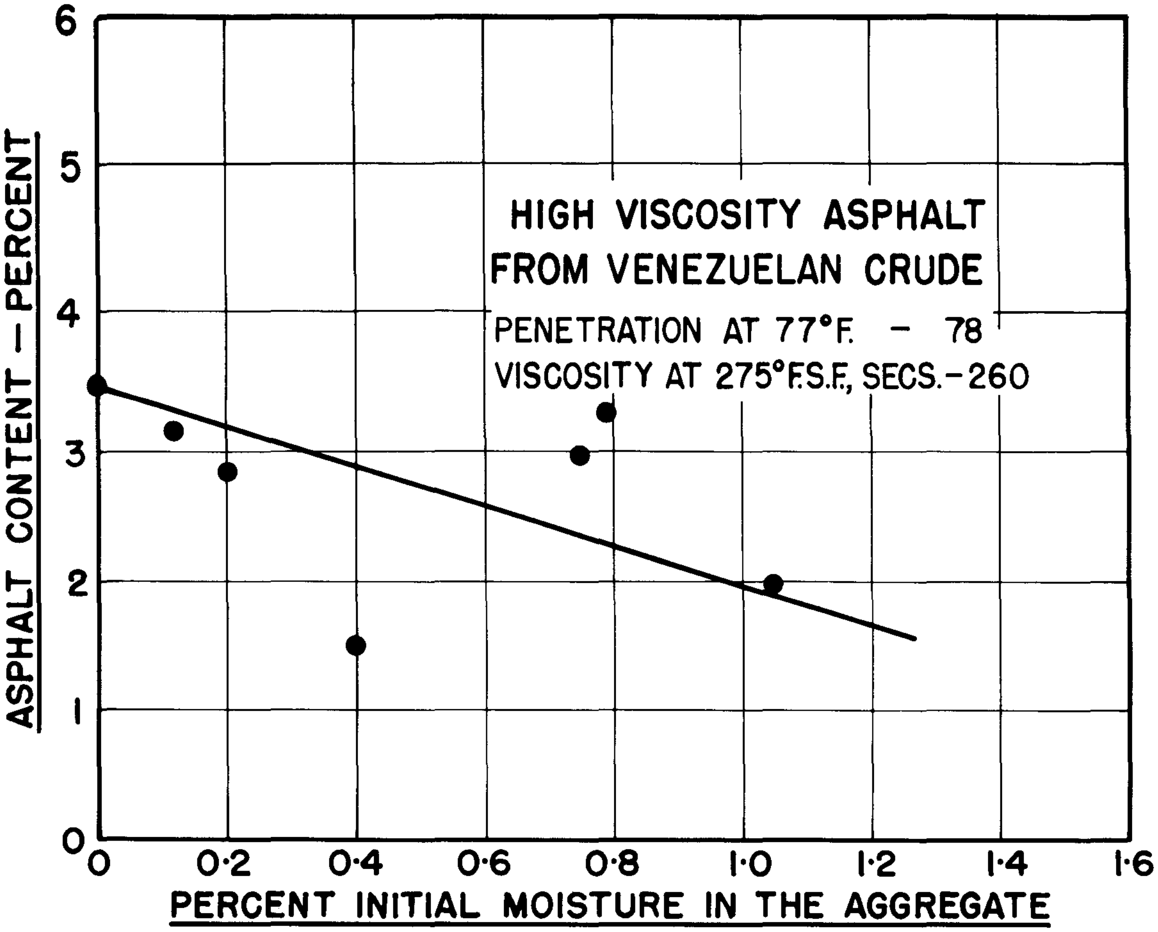

FIG.4 INFLUENCE OF MOISTURE CONTENT OF AGGREGATE WHEN COATED ON RETENTION OF ASPHALT BINDER (HIGH VISCOSITY VENEZUELAN ASPHALT).

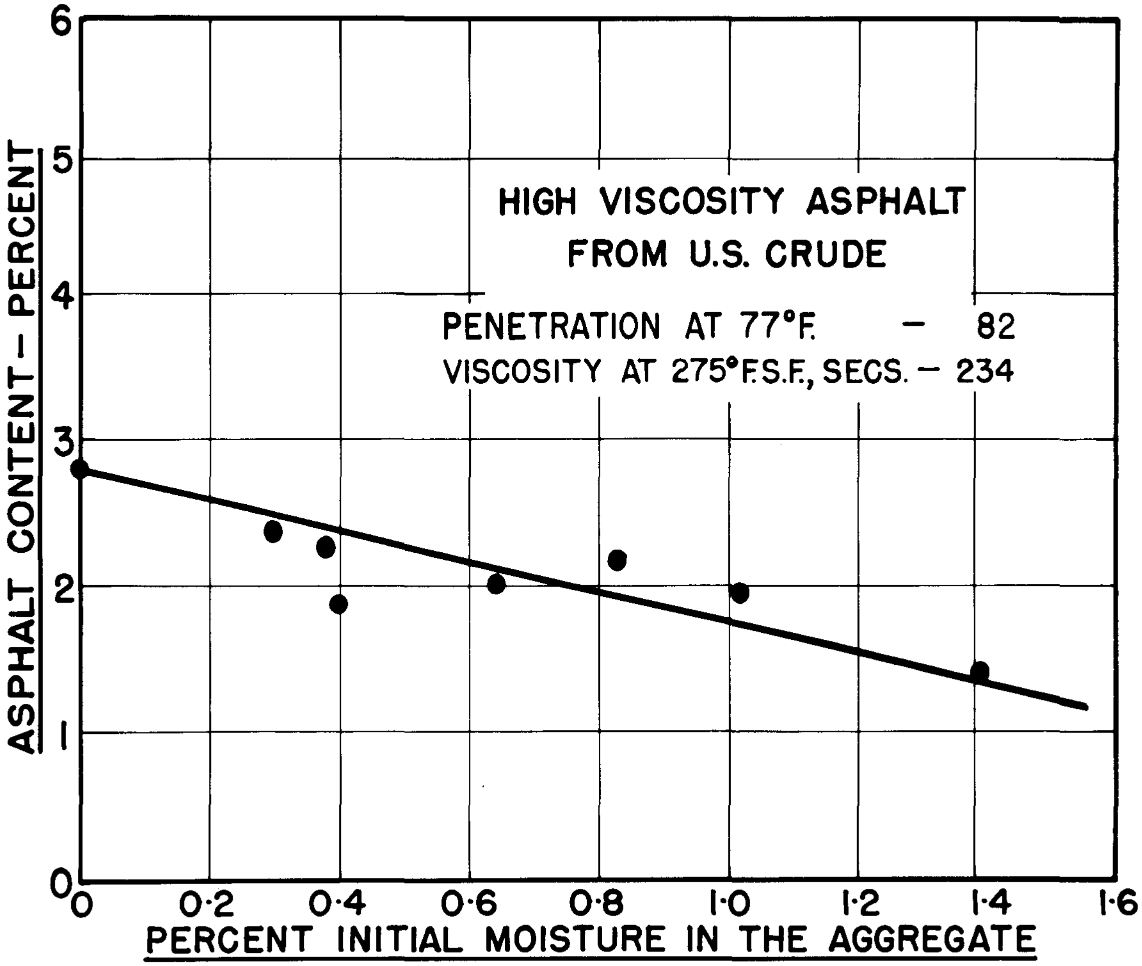

FIG.5 INFLUENCE OF MOISTURE CONTENT OF AGGREGATE WHEN COATED ON RETENTION OF ASPHALT BINDER (HIGH VISCOSITY U.S. ASPHALT).

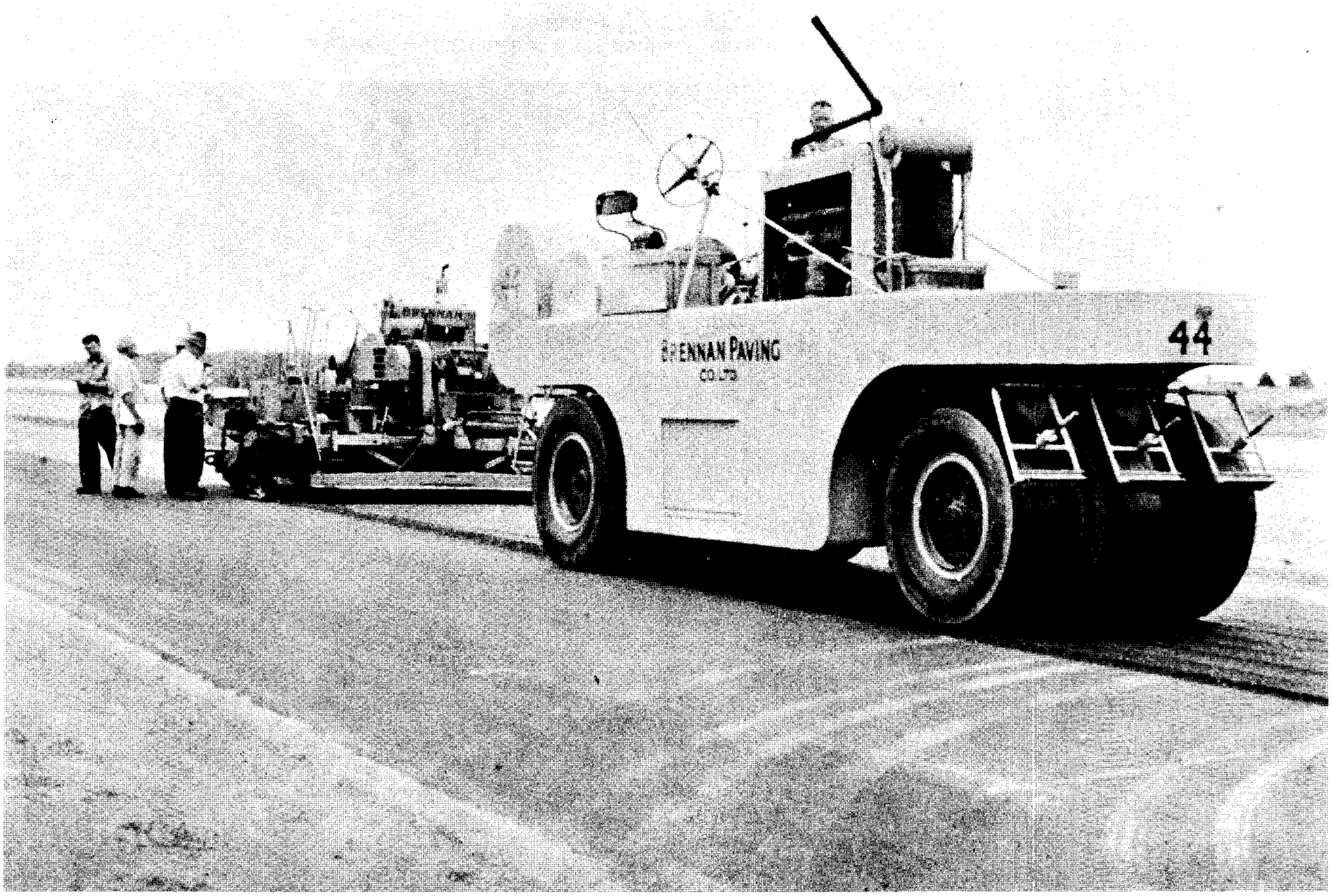

Figure 6—Self-propelled Pneumatic-tired Roller.

Figure 7—Illustrating tight surface texture provided by a pneumatic-tired roller.

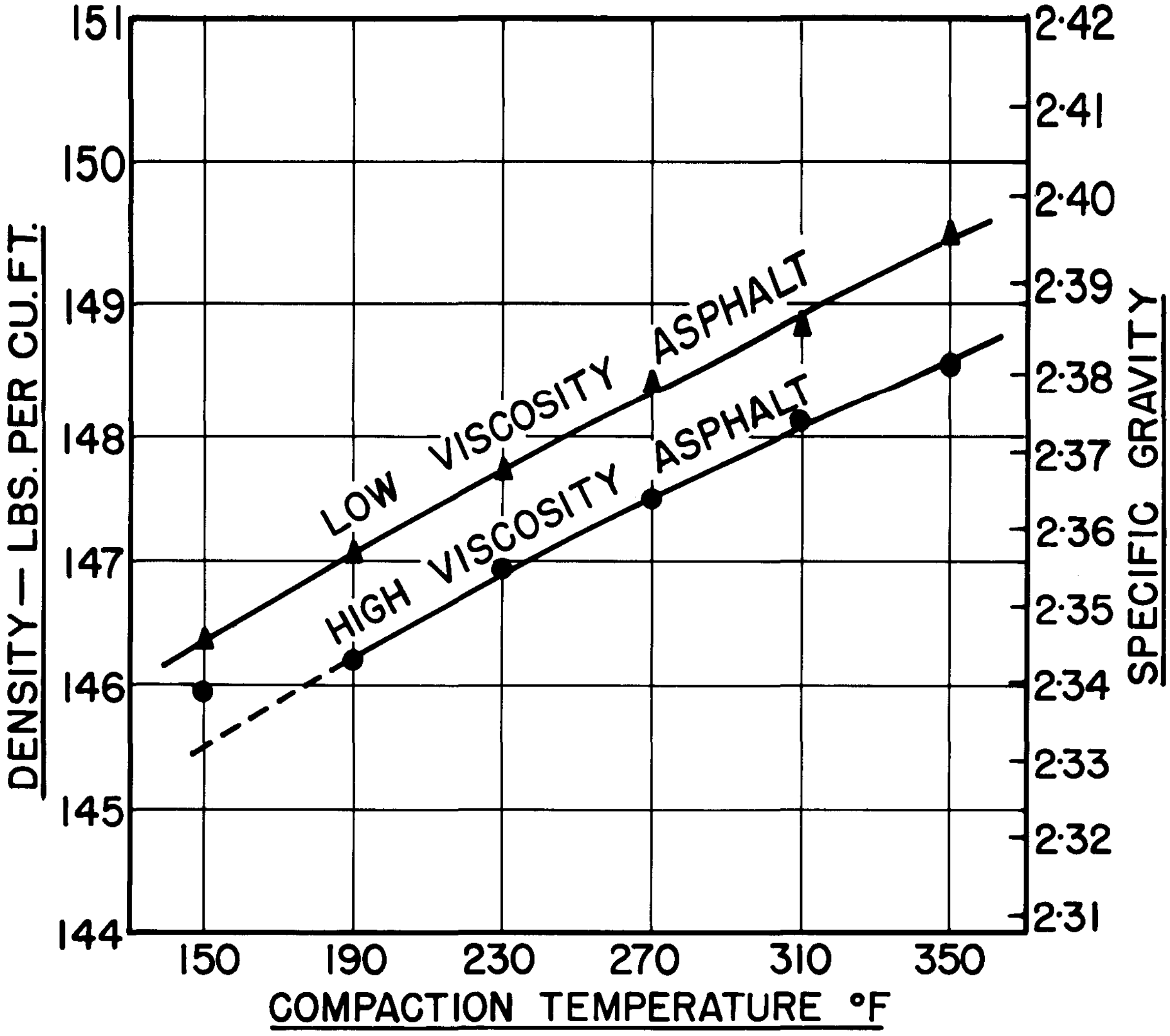

FIG.8 INFLUENCE OF ASPHALT VISCOSITY ON EASE OF COMPACTION OF PAVING MIXTURES.

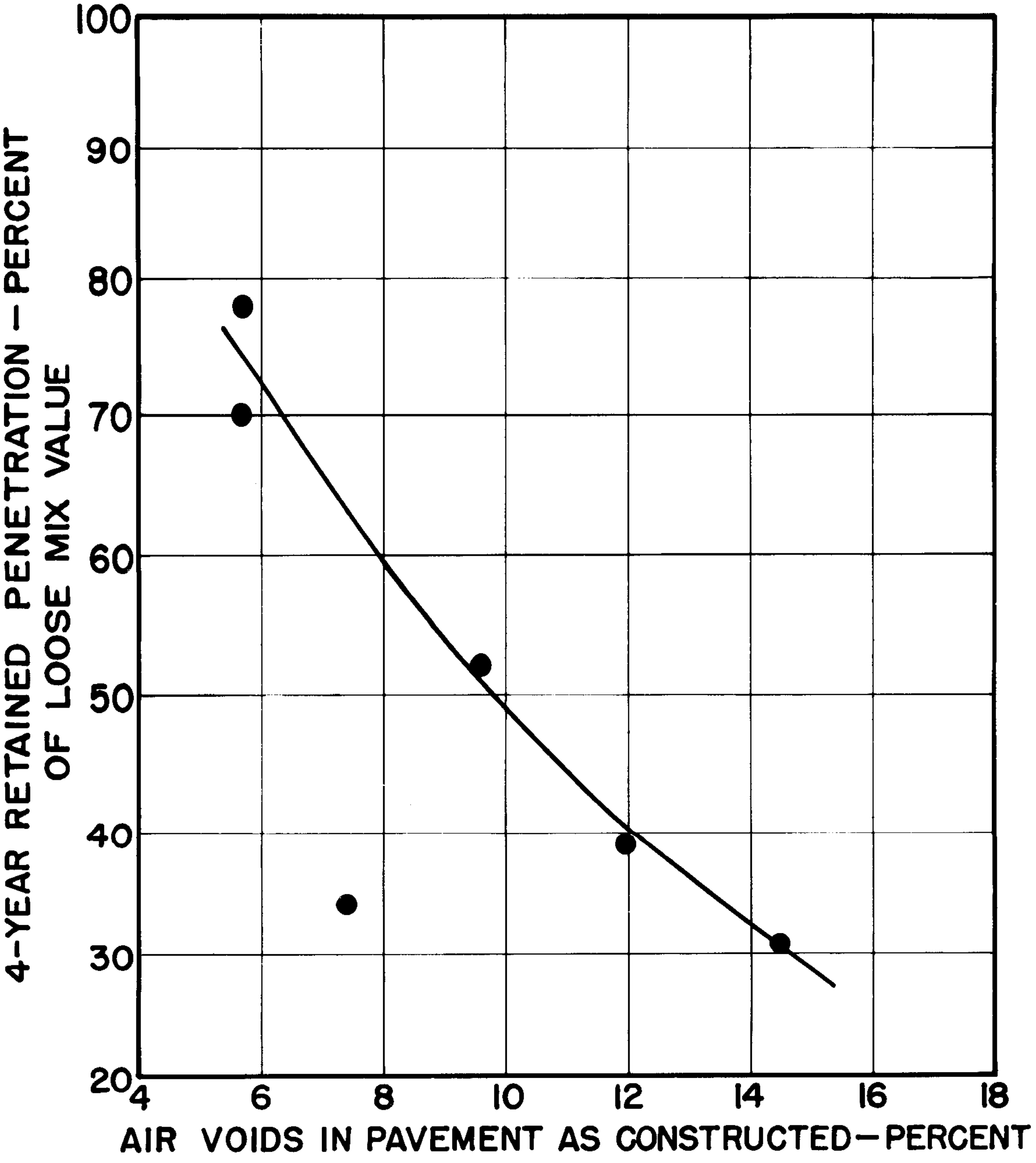

FIG.9 EFFECT OF INITIAL AIR VOIDS IN PAVEMENT ON CHANGE IN PENETRATION OF ASPHALT AFTER FOUR YEARS OF SERVICE.

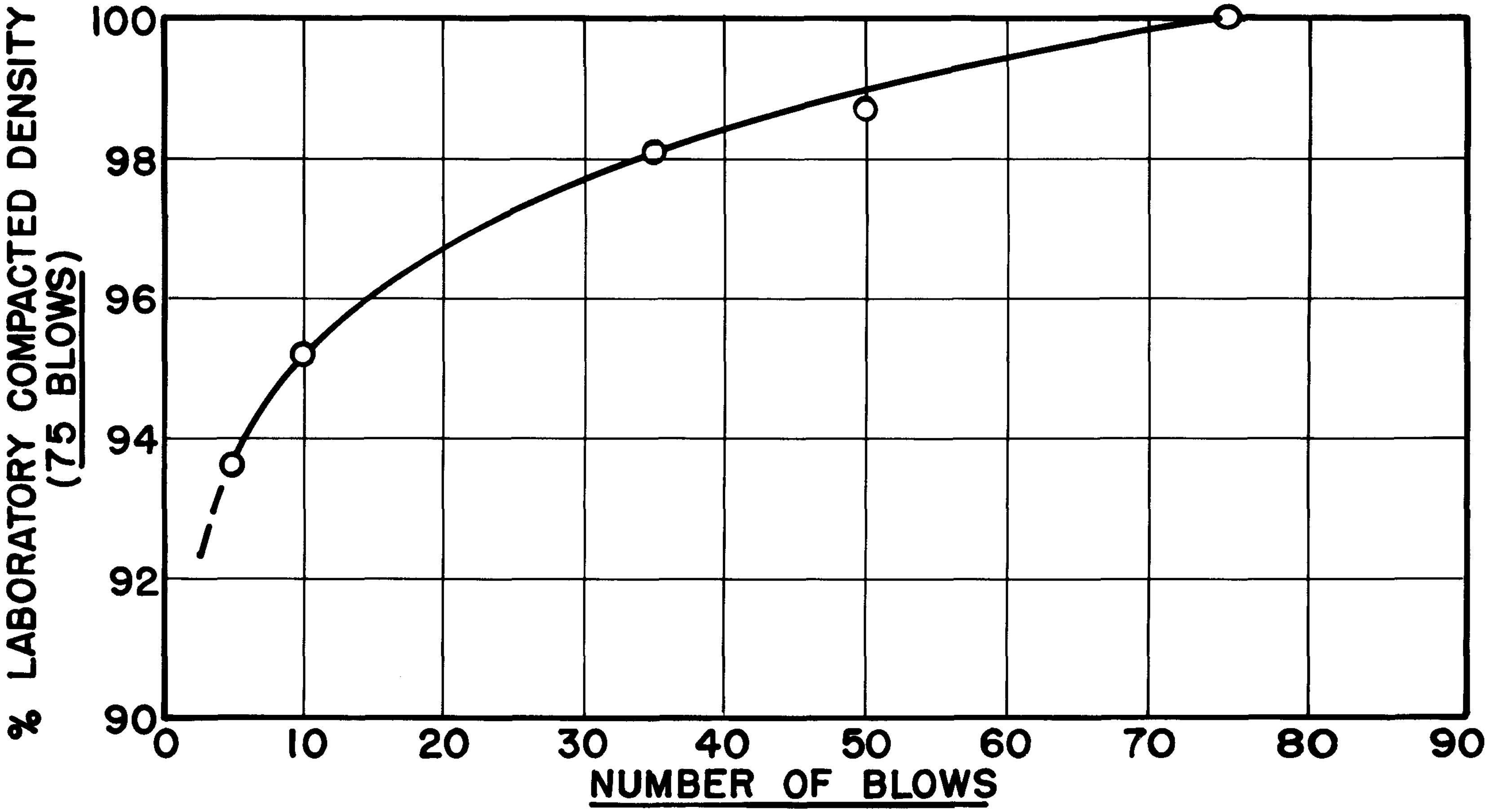

FIG.10 INFLUENCE OF MARSHALL COMPACTION ON PAVEMENT DENSITY.

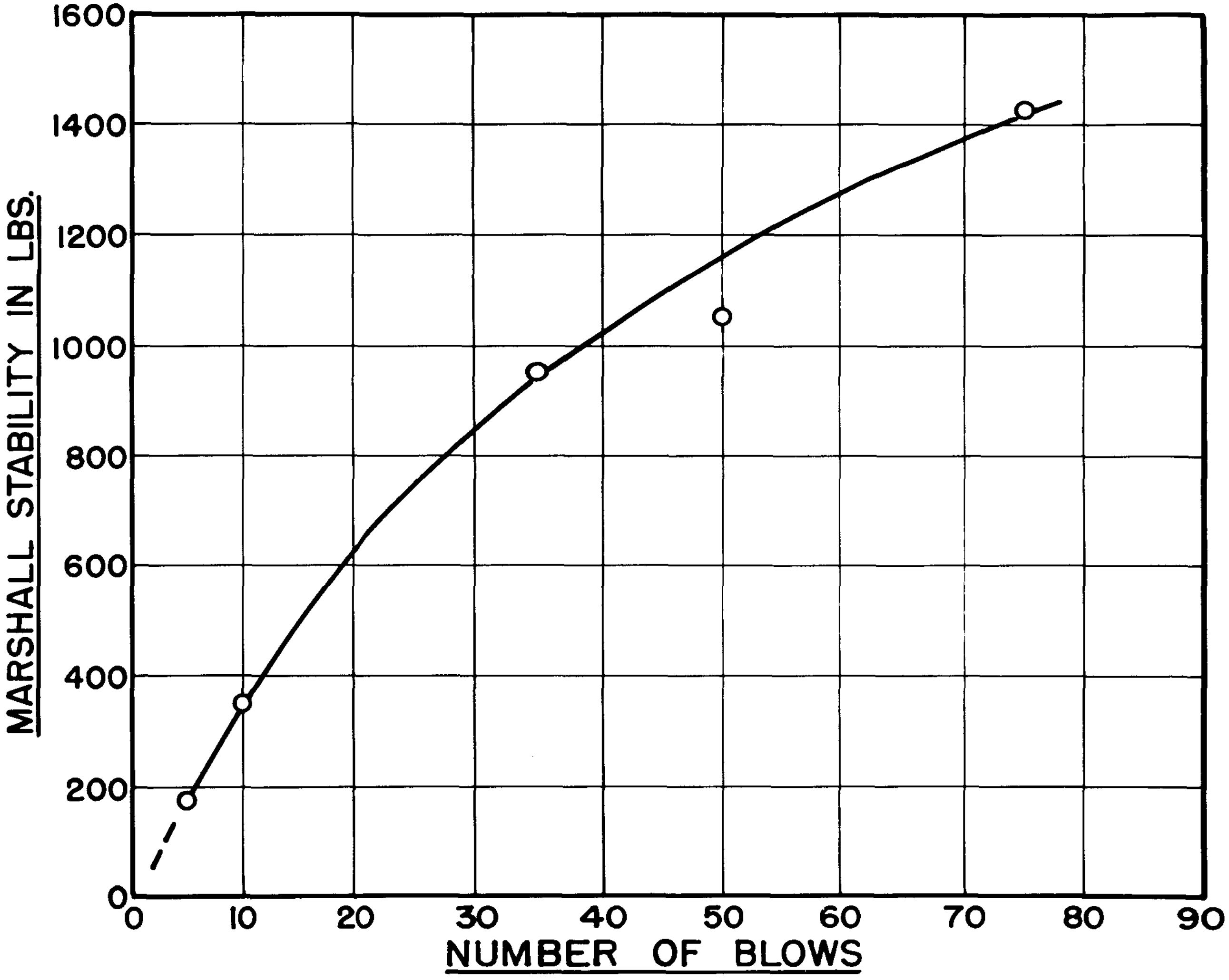

FIG.11 INFLUENCE OF MARSHALL COMPACTION ON MARSHALL STABILITY.

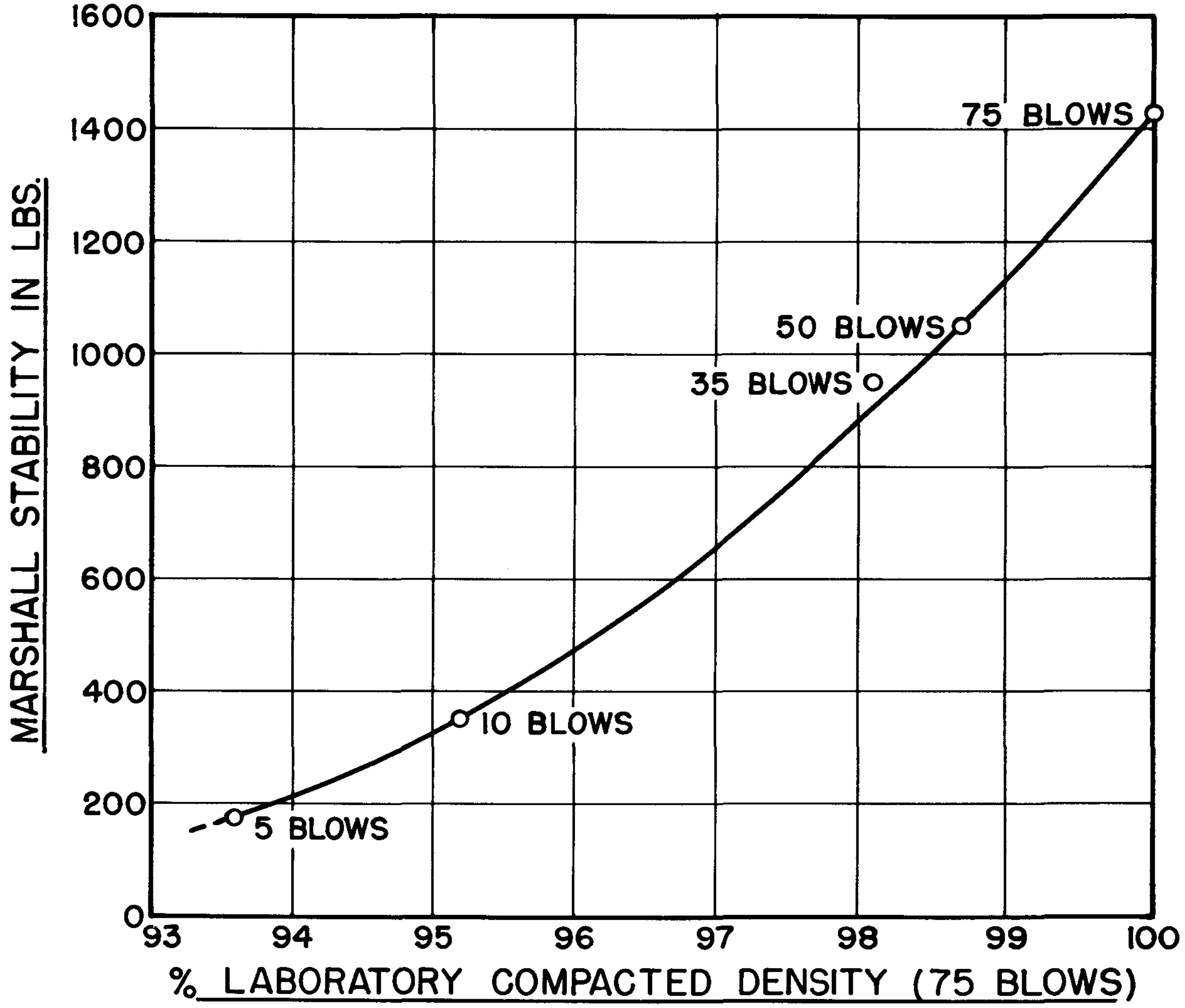

FIG.12 INFLUENCE OF PAVEMENT DENSITY ON MARSHALL STABILITY.

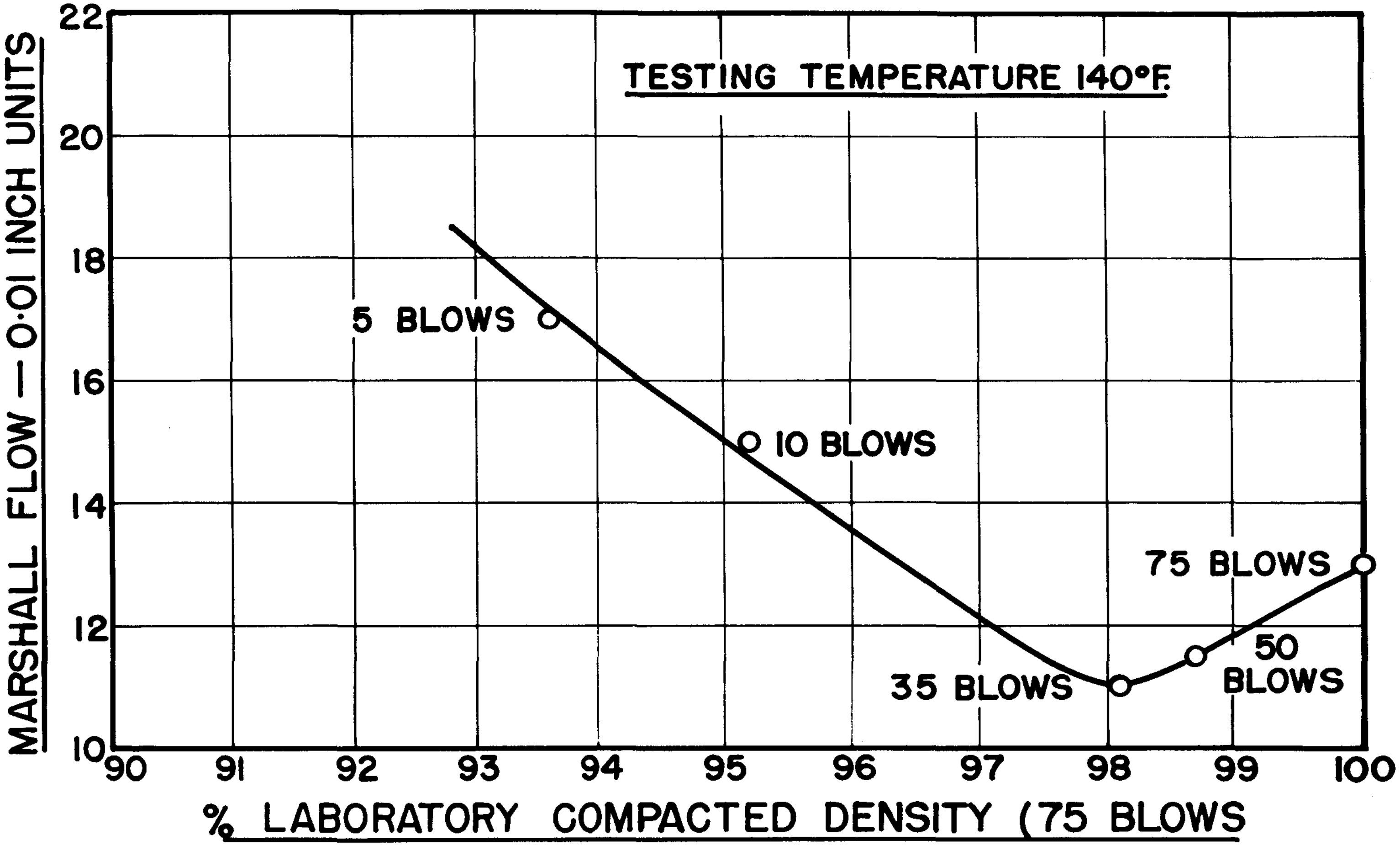

FIG.13 INFLUENCE OF DEGREE OF COMPACTION OF A PAVING MIXTURE ON THE VALUE OF ITS MARSHALL FLOW INDEX.

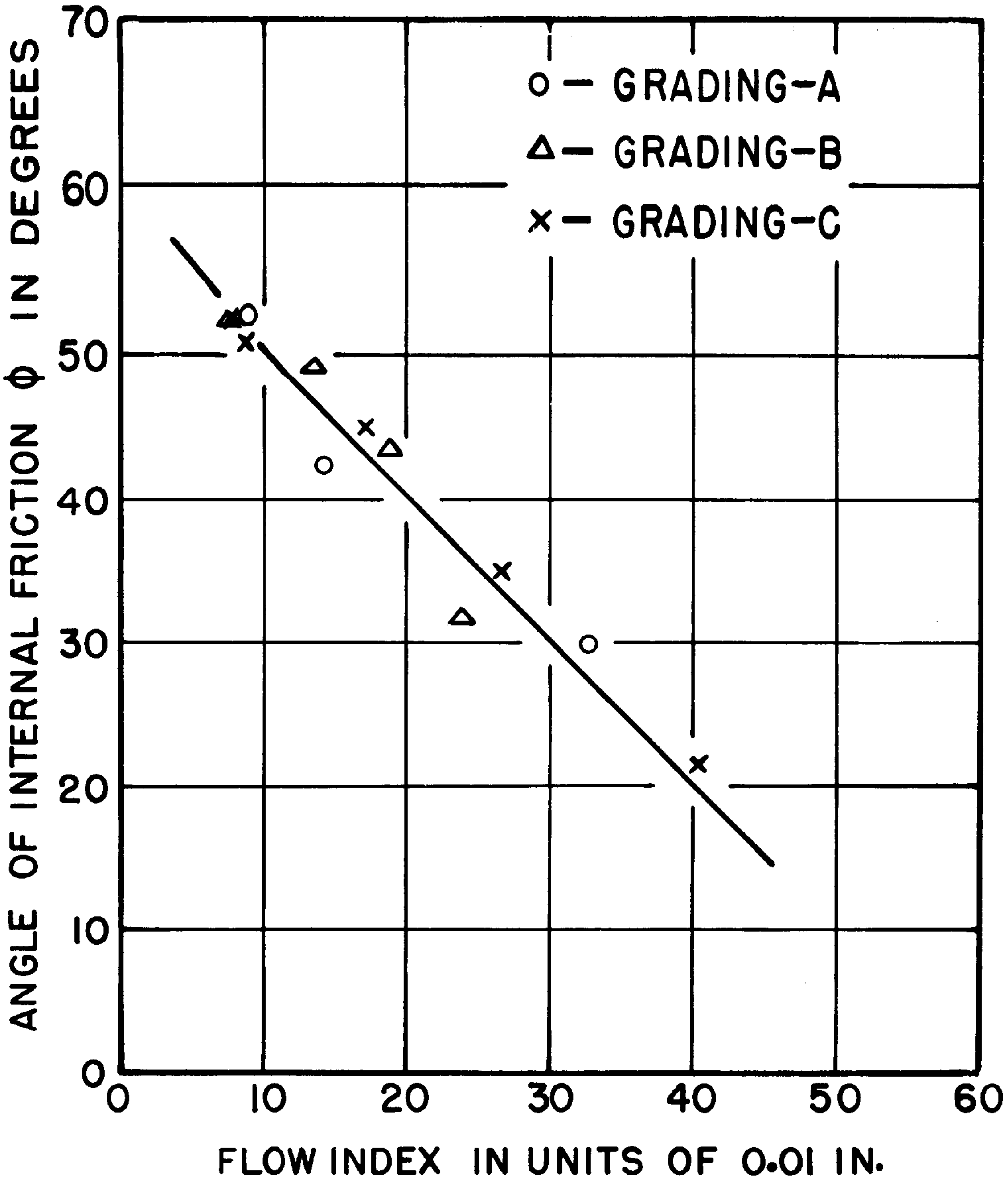

FIG. 14 RELATIONSHIP BETWEEN ANGLE OF INTERNAL FRICTION ϕ AND FLOW INDEX

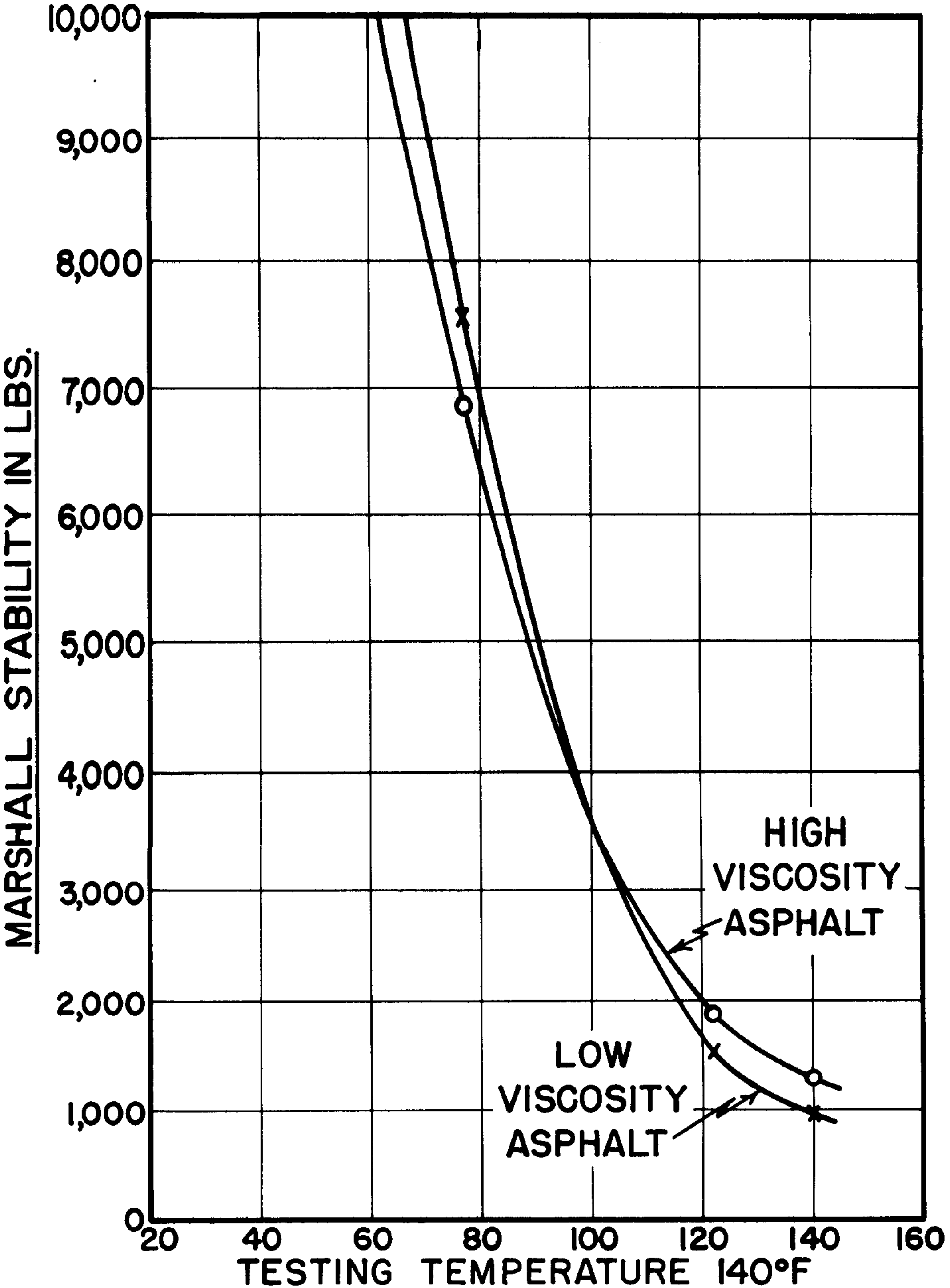

FIG.15 INFLUENCE OF TESTING TEMPERATURE ON MARSHALL STABILITY VALUES OF A PAVING MIXTURE CONTAINING LOW VISCOSITY AND HIGH VISCOSITY ASPHALT CEMENTS.