PRELIMINARY ANALYSIS OF

ASPHALT PAVEMENT - CRACK INVESTIGATION

INTRODUCTION -

Essentially, all laboratory testing has been completed on samples taken from pavements exhibiting distress in the form of cracking in the wheel paths, longitudinal cracking at what is evidently the construction joints and raveling. The data available is limited, in fact, minimum for definitive answers for many of the projects. However, using all the data obtained from all of the projects, certain factors appear to be the cause of distress in these pavements. A limited number of pavements that were not distressed were included for comparison.

FACTORS CAUSING DISTRESS -

It appears that two major factors are basic to the early hardening of the asphalt, which in turn causes an extremely brittle mixture incapable of withstanding even normal deflections under heavy wheel loadings. These factors are: (1) a lack of an adequate amount of asphalt in the mixture, and (2) a lack of compaction of the surfacing. In some projects both factors are present causing an even greater rate of hardening and early cracking.

Several investigators have reported that high air voids causes early and rapid hardening of the asphalt. The most recent publication and probably most definitive work was by Goode and Tulsey in their paper, "Voids, Permeability, Film Thickness and Hardening" in the proceedings of the AAPT Vol. 34, 1965. They found that a ratio of the Voids to the Bitumen Index correlated very well with the retained penetration of asphalt in mixtures having differing void contents. (See Fig. 1). Their work resulted in recommendations that the total air voids should exceed three, and the voids bitumen index ratio not exceed four.

The Asphalt Institute recommends that air voids of 3 to 5 percent when determined by the Rice Method. The air voids in this study were determined by the Rice method, and are therefore an indication of meeting this criteria. Several states recommend that compaction meet 95 percent of laboratory standard from the Marshall Test, and others 90 percent of laboratory theoretical zero air voids density.

No. Carolina and Minnesota each use Marshall 95 percent, Ohio uses 92 percent zero voids. No. Carolina also uses 90 percent zero void on base courses. Washington in reporting the allowance of 8 - 10 percent voids is actually stipulating 90 - 92 percent of a voidless density using the "rice" method to determine the zero void density.

The limited discussion above indicates considerable variation in thinking and in procedures to control the actual mixes. It is evident from our data that if the air voids are above eight on an average, that we have cracking. Only when the total voids are below about seven has the project been free of cracking. This doesn't fully describe the problem, however, as extremely thin asphalt films are also subject to brittleness and hardening. Even though densities may be high, and air voids are moderate, if the gradation is such that the film thicknesses are less than 6 microns (a bitumen index of 0.0012 or less) that an unsatisfactory condition exists. This figure is reported as a satisfactory film thickness in Goode and Tulsey's paper.

Figures 1 and 2 illustrate the effect of air voids on rapid hardening of asphalt.

Monismith Secor and Blackmer in studies of "Asphalt Mixture Behaviour in Repeated Flexure", show that as the void content of a mixture increases the fatigue life is shortened very materially. They also report that as the asphalt content is increased the fatigue life is also increased. (See Fig. 3).

These studies show the very import effect of attaining mixtures that have minimum voids and consistent with stability to attain durability. The hardening due to excessive voids increases the brittleness of the paving mixture to the point that the permissible flexure without failure is reduced below normal flexure for otherwise adequately designed pavements. Cracking of the pavements due to flexure failures then leads to deterioration from the elements, ice water etc.

LIMITATIONS FOR SATISFACTORY PAVEMENTS -

It appears that to have a satisfactory asphalt pavement it must have:

1. A satisfactory asphalt content with film thicknesses at or above 6 microns and sufficient air voids when fully compacted to avoid flushing. The most desirable asphalt content should be as high as possible and still permit the mixture to have stability, and yet not flush. A minimum of air voids of about 3 per cent is the limiting value to prevent flushing. However air voids should not exceed about 6 percent or the voids bitumen index ratio exceed 4 percent, or excessive voids cause hardening and brittleness. These values should apply to Laboratory mix designs.

2. Field compaction should provide for attaining not less than 96 percent of the weight per cubic foot of a laboratory compacted specimen of the same mixture. If the upper void content is allowed in the Lab mix design, and a minimum compaction only attained in the field, the

total voids would exceed 8 percent slightly, but should be the maximum. Although this value is higher than desirable it appears to be a practicable limitation on either design or compaction.

3. Field control of the range of asphalt content should be such that the maximum deviation from the optimum asphalt content is held to within ± 0.5 percent. A variation of one-half percent is the equivalent of varying compaction or air voids one percent. A lowering of asphalt content one-half percent in compaction by two percent would increase air voids by three percent which is critical to satisfactory performance. (See Fig. 4, 5 and 6).

4. Field control of compaction should be such that the mixture is compacted to not less than 96 percent of the laboratory weight per cubic foot of the mixture. Variations in gradation and asphalt content will affect this laboratory standard. (See Fig. 7, 8 and 9).

5. Gradation of aggregates should be as dense as possible and yet provide adequate space for asphalt and the necessary air void.

6. Highly absorptive aggregates should not be used in asphalt pavements.

The studies in this regard are incomplete and it is not known how rapidly large quantities of asphalt will be absorbed within stone. It appears that when air voids are within limits and that stabilities are satisfactory that any amount of asphalt needed should be used even though much greater than general. An asphalt content of 7 or even 8 percent should be used if absorptions are high but satisfactory air voids yet remain and stability is not impaired. Precise limits on absorption cannot be given. Work by California indicates highly absorptive aggregates do cause cracking in pavements. Their work was reported at the H.R.B. meeting in January 1965 resulted in these conclusions.

1. Is high absorption - high expansion mix.
2. Max. expansion occurs during wet cycles.
3. Max. contraction during dry cycles.
4. Mixtures do not return on drying to original length.
5. Strains induced by expansion and contraction cause cracking.
6. Removal of clay reduces expansion.
7. Increases in asphalt reduces expansion some.
8. Mineral fillers reduce expansion, others increase it.
9. Studies show good correlation to field performance.

The California Department is using a modification of the C.K.E. test to determine the absorption of aggregate. Tests are underway at the Laboratory although specific limitations are not known although 0.5 percent may be satisfactory using the C.K.E. method.

We have tested aggregates for asphalt absorption and have records of sources absorbing in excess of 2 percent in the vicinity of Twin Falls and Malad. The highest recorded value exceeded four percent. No doubt absorption may influence performance on individual projects, but it is not reasonable to assume all projects having distress results from this cause.

RESULTS OF IDAHO TESTS -

Table I shows the results of tests on pavements investigated during the past year. It is evident that air voids are high as is the voids bitumen index ratio on field cores. The same mix recompacted in the Lab also gives high results, although is in part offset by viscosity as the asphalt is hardened. It does indicate, however, when the values are much above the value indicated under criteria that the asphalt content was low.

In general it can be said Idaho test results follow the pattern discussed above, i.e., when voids are high penetrations are low, voids being high comes from two causes, a lack of compaction or insufficient asphalt, or combination of the two.

Looking at the data it appears the projects having a 96 percent compaction or better show little distress if the asphalt content is adequate or less distress if asphalt contents are lower than desirable.

Similarly, projects having very low asphalt contents have distress even though adequately compacted.

The Blackfoot Street project does not follow the hardening trend for highway voids, but was sampled within seven months and evidently did not have time to harden in this period.

Project I-15-1(5)17 did not show any distress when examined in 1965, but after receiving the test data it was decided to visit the project as it should have shown some distress. This was done in March 1966 and tracking was evident, comparable to other projects after about two years.

It is noted that the large majority of projects show low asphalt contents or less than 5.5 and some even less than 5.0 percent. Most of these projects have recommended asphalt contents of only 5.0 to 5.3 percent, and extractions only rarely indicate this much in the field cores. Correlation with asphalt voids bitumen index on Lab compacted mixtures shows that projects having a V/BI value less than 5 if compacted to more than 96 percent that performance is satisfactory.

RECOMMENDATIONS FOR ALLEVIATION OF PAVEMENT DISTRESS ON FUTURE PAVEMENTS

No single factor can be blamed for the cause of distress in existing pavements. It appears that a lack of compaction, lack of asphalt or both in combinations is the primary cause. It appears that a very large percentage, if not all of the problem, can be eliminated if we obtain higher asphalt contents and satisfactory compaction.

THEREFORE it is recommended that the Laboratory should:

1. Determine air voids by Rice Method for all mixtures (Vacuum Gravity Method) and no longer report voids calculated from specific gravities.

2. Determine asphalt absorption of aggregates if the water absorption exceeds 1.0 percent on coarse aggregate and 1.5 percent on fine aggregate. The bulk S.S.D. Sp. Gravity can be determined on samples having minus 200 removed to aid in calculating absorption.

3. Determine curves for mix design using 4.5, 5.5, 6.5, and 7.5 percent asphalt in lieu of the present 4, 5, 6, and 7 so as to obtain more information at higher asphalt contents. Filler material is to be included, if any.

4. Determine WI/CF compacted, stability Cohesiometer values as presently tested, also test for best filler to be used with mix.

5. Compute air voids using Rice Method specific gravity of coated mixture on not less than two points of four pats tested to draw zero air voids curve.

6. Determine asphalt absorption by Rice Method using specific gravity of asphalt mixture and bulk S.S.D. specific gravity of 3/4 - and No. 4 aggregate, No. 4 - No. 200 aggregate and apparent specific

gravity for any filler and/or material passing the No. 200.

7. Select optimum asphalt content such that the following criteria is met:

Air voids	3.0% minimum
Voids-Bit. Index Ratio	4 Maximum
Stability	35 Minimum
Absorption Asphalt	1.5% Max.
Bitumen Index	0.0012 Minimum

Should Asphalt absorption exceed 1.5 percent a special series of tests should be undertaken to determine if mix is sound, i.e., cold water abrasion, immersion compression or other tests

Should air voids, voids bitumen index ratio or stability fail to meet above requirements, then gradation should be changed to obtain compliance if possible.

8. Any field samples tested for job mix formula should have a design provided that gives sufficient latitude for variations in compaction asphalt content etc. within above criteria, i.e., design should provide for a plus and minus variation and not be for decline on any item.

9. Set job mix formula to meet above criteria and not the production of a stockpile.

The Construction Division should endeavor to obtain the most careful control in the field emphasizing:

1. Adequate compaction when mixture is hot. A temperature cooling rate curve should be required frequently so that inspection and contractor personnel will know the approximate temperature of the mix based upon time only period. This permits inspectors to require rolling to be completed in not more than a specified time as a control measure. Pickup

by pneumatic tires is a problem but once the tires are heated to above 150° F., it is reported to no longer exist. (See Fig. 9).

2. Provide a means for measuring density or Wt/CF compacted in the field. Then permeability is of doubtful value as once compacted adequately, the value is about zero.

3. Control the aggregate moisture contents for uniformity to prevent troubles in rolling -- too hot -- too cold from temperature variations.

4. Endeavor to keep asphalt content as nearly on optimum as possible. If changes are deemed advisable check by telephone with District and Laboratory to confirm the effects of the change.

5. Heat temperature record of the mix on delivery to the roadway before and after breakdown, intermediate and finish rolling in addition to making of cooling rate curves. These records to become a part of the job records.

6. When hot joints are required make two pavers operating together mandatory to prevent cracking and cold joints.

7. Enforce rolling while mix is hot.

8. Pave courses less than 0.2 feet only during hot weather.

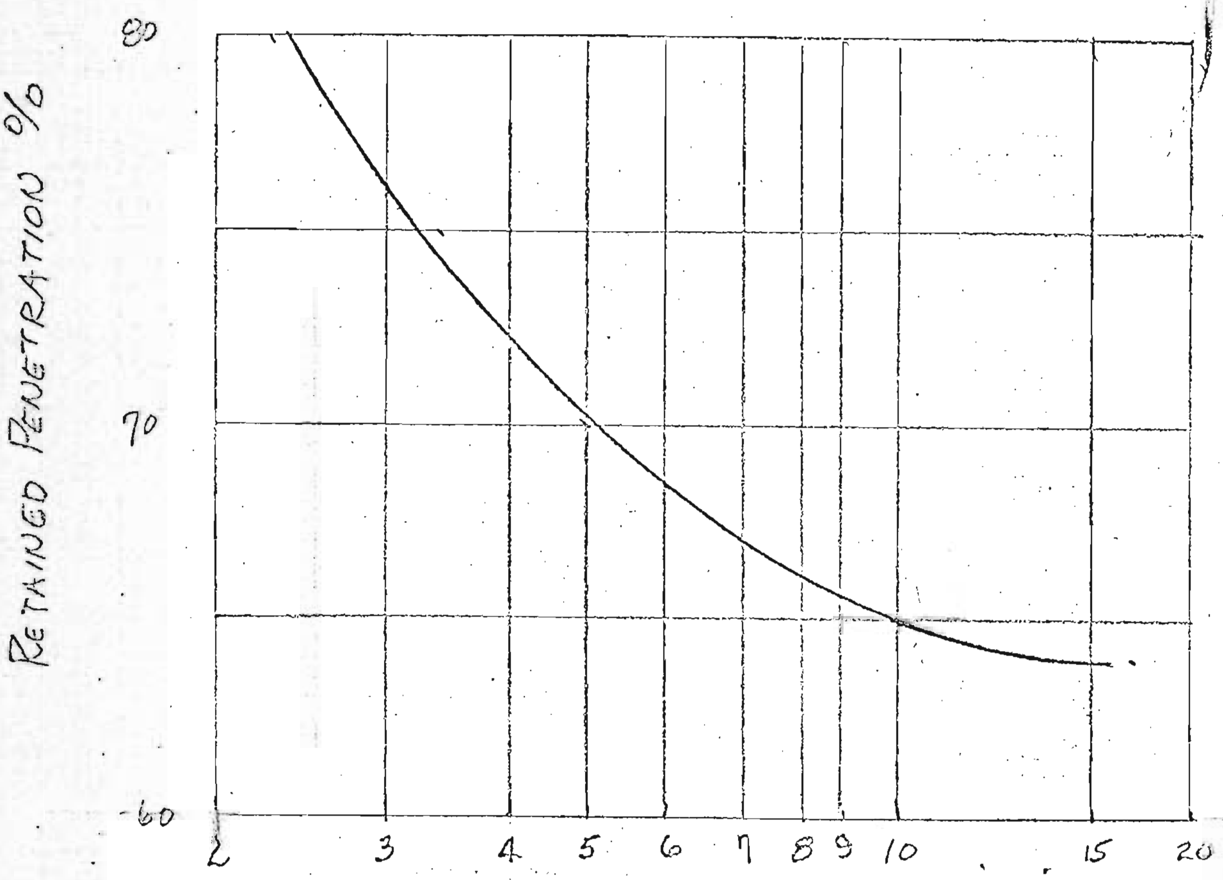
Seal coating of finished pavements must be given consideration. We have avoided seal coating projects on the supposition that a seal was not necessary. This might have been true had we obtained pavements adequately compacted and with sufficient asphalt to prevent deterioration. This has not been the case and many existing pavements would have been in hectic condition had seal coats been applied. A notable example is I-80N-2(3)206. This project was determined to be too dry and given a seal coat the year following construction, and very little distress was evident thereafter until the 0.1 foot course was placed last season.

Caution must be used, however, as any project having even a slight excess of asphalt would become apt to flush and cause slipperiness. However, it is possible to determine as soon as the mixture is given its final rolling whether a seal coat is advisable. Core samples taken and tested for air voids and the voids bitumen index ratio will indicate the need. It is suggested that as a beginning criteria voids above 8 percent and a void bitumen index ratio above 5 be the signal to fog seal immediately with an MC-70 and sand, and to program a seal coat using a 3/8" max. chips as maximum size the following season. The use of an MC-70 for a fog seal will permit some penetration of the mix and prevent ravel. An emulsion or R.C. would tend to merely paint the surface and be less effective.

TABLE I

Project	Performance: Long Crack	Performance: Wheel Path Crack	Performance: Ravel	Age	Voids: Field Cores	Voids: Lab Comp	Comp. % Lab	Voids/Bit Ind.: Field Cores	Voids/Bit Ind.: Lab Comp.	% Ext Asph	% Asph Rec	% Asph Field	Grade	Pen Rec	Source	Probable Cause
F 1361(10)	Some		Severe	1	9.5 15.4	2.9 7.7	91.5 95.4	6.2 9.0	3.4 3.8	4.83 5.27	5.46	3.8 5.3	120 150	80 100	Empire	Lack of Compac
15-1(5)17	Some	Some	None	2	7.0 11.3	5.6 6.0	94.5 98.4	4.6 16.1	3.3 5.2	5.20 E 6.03 D	5.8	5.8 B 6.4 D	120 150	51 78	Amer'n	Lack Comp in Part Lack Asph in Part
15-2(9)88A	Few	Few	Flush	3	2.2	2.9	101.1	1.1	1.4	5.65	5.6 B 5.7 D	5.8 B 6.4 D	120 150	64 66	Phillips	Too much Asphalt
15-2(11)96	V. Few	None	None	3	2.5 6.7	2.1 3.4	95 100	2.6	1.7	4.9 5.47	5.0 B 5.24 D	4.3 6.1	120 150	41 68	Amer'n	Excellent Job
15-2(8)104 (11)96B	Numerous	Serious	Slight	3	2.2 8.7	0.3 3.7	94.8 99.8	1.4 6.5	0.2 2.8	5.2 5.4	5.2	4.5 6.3	120 150	39 58	Amer'n	Compaction in Part Possibly Asphalt
15-2(7)111	Numerous	Serious	Slight	3	9.8	6.0	99.6	7.6	4.6	5.2	5.0 5.3	4.5 6.3	85 100	37 38	Amer'n	Lack Asphalt.
15-2(5)117	None	None	None	3	8.0	5.4	96.1 100.0	5.7	3.8	4.96 4.96	4.9 5.5	4.6 6.1	85 100	35	Phillips	Excellent Job
15W5(4)118 EBL.	Numerous	Serious	Slight	2	7.0 9.9	7.7 12.4	98.8 101.0	5.4 9.1	6.9 9.1	4.86 5.81	5.0 5.2	5.8 6.3	120 150	35 38	Amer'n	Lack Asphalt.
15W5(4)118 WBL	Few	None	None	4	6.0 8.7	6.8 7.4	98.7 99.2	6.3	5.6	4.8 5.0		4.8 5.3	85 100	36 50	Humble	Excellent Job
30N 3(3)206 Unused Hwy.	Few		None	4	7.6 10.4	8.1 10.3	94.8 95.8	5.1	5.0	3.6		5.0 4.5	85 100	20 21	Sinclair	Portion Under 1 No Traffic
30N 3(3)206	Few		None	4												Project Sealed - Too [illegible] Performance Good
90-1(7)11	Severe	Severe	Some	4	9.1 9.6	8.7 10.0	95.0(?) 100.6	4.9	4.9	4.2 5.5	5.0 5.4	4.4 5.5	85 100	16 23	Blackline	Lack of Asphalt.–(
90-1(6)23	Numerous	Numerous	Slight	4	9 12	7.7 7.9	96.0 98.8	8.6	6.5	4.76 4.81	[illegible]	5.0 5.4	85 100	24	Blackline (Husky)	Lack Asphalt
30N 3( ) 3	Numerous	Numerous	Slight	4	7.6 10.4	8.1 10.3	96.8 99.9	5.1	5.0	4.5 4.6	5.0	4.1 6.4	85 100	20 22	Sinclair	Lo Asphalt
Criteria					3+	3+	97+	<4	<4							

FIG 1

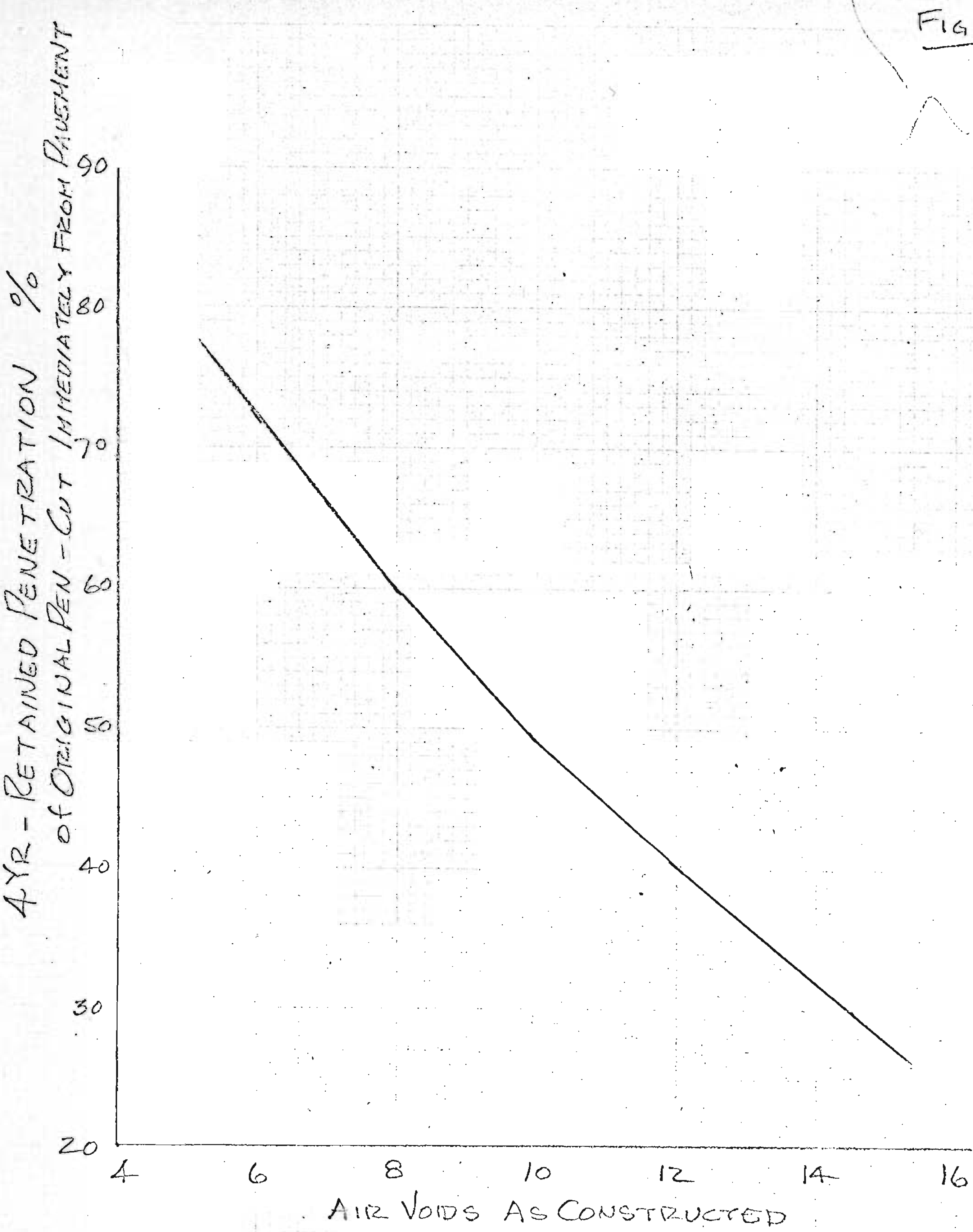


VOIDS - BITUMEN INDEX RATIO = $\frac{\% \text{ AIR VOIDS}}{\text{Bit. IND} \times 10^3}$

FROM - AAPT VOL 34

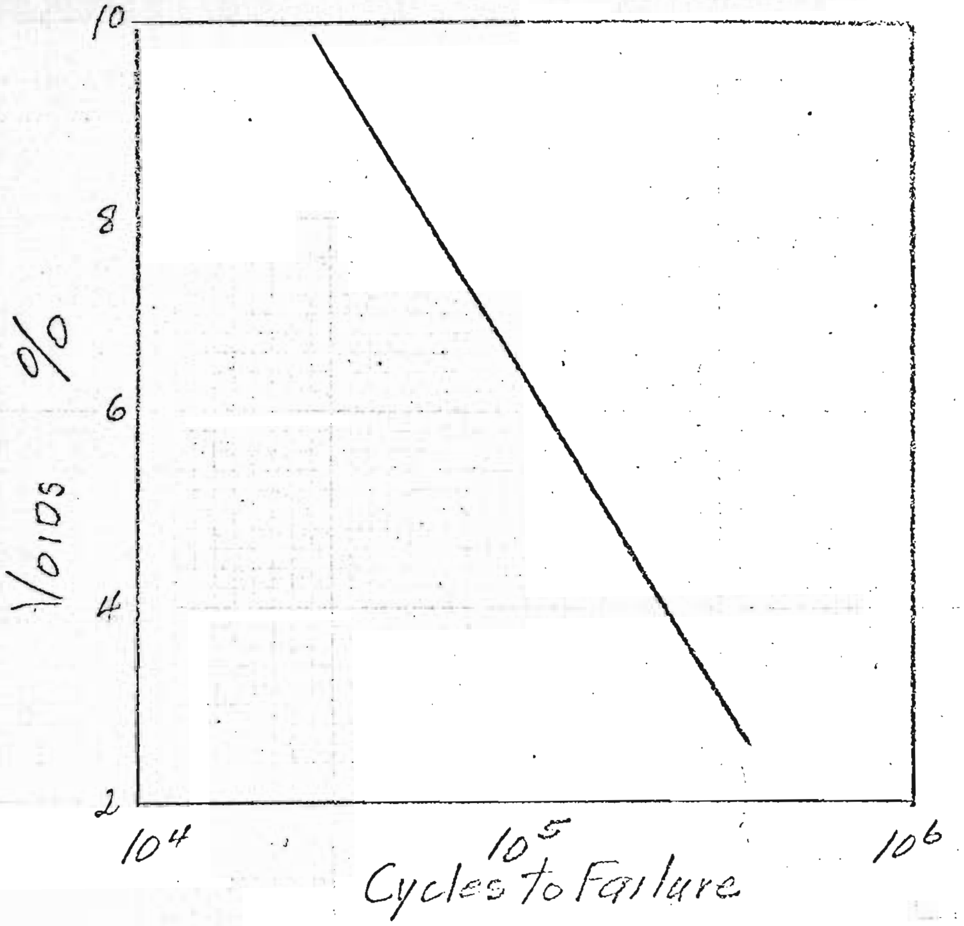
GOODE & LUFSEY VOIDS VS HARDENING

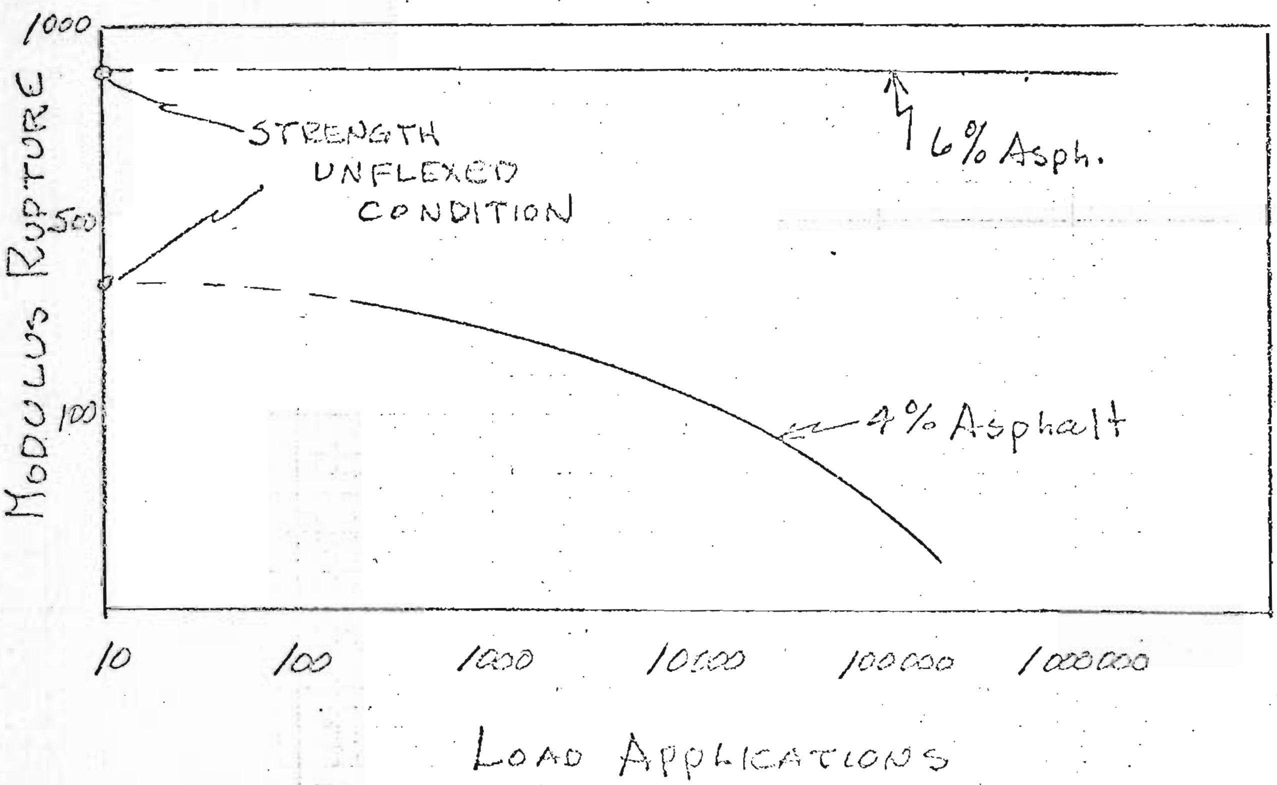
FIG 2



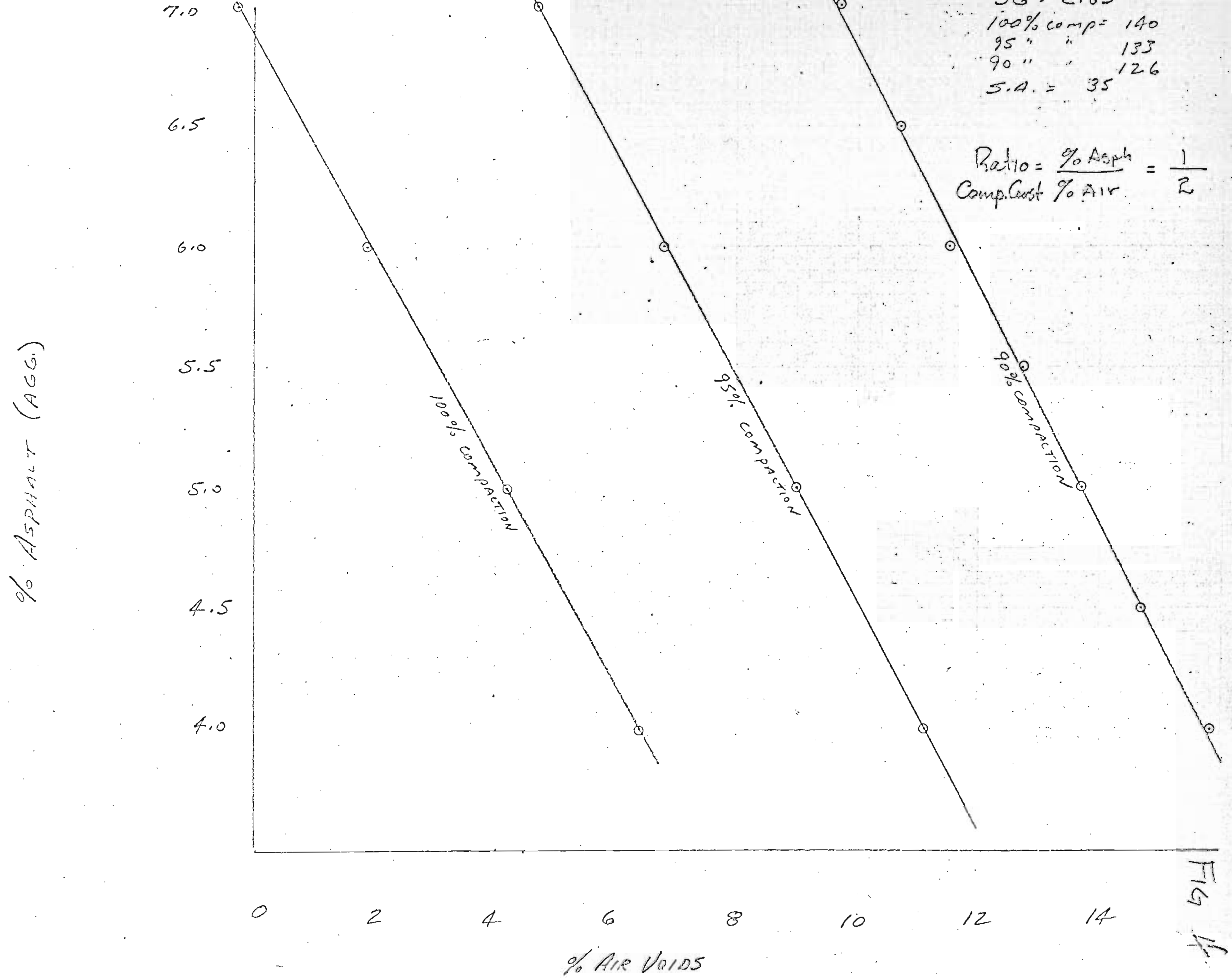
FROM - McLEOD PAPER HRB 1966
INFLUENCE VISCOSITY of ASPHALT CEMENTS
ON COMPACTION of PAVING MIXTURES IN FIELD

FIG 3





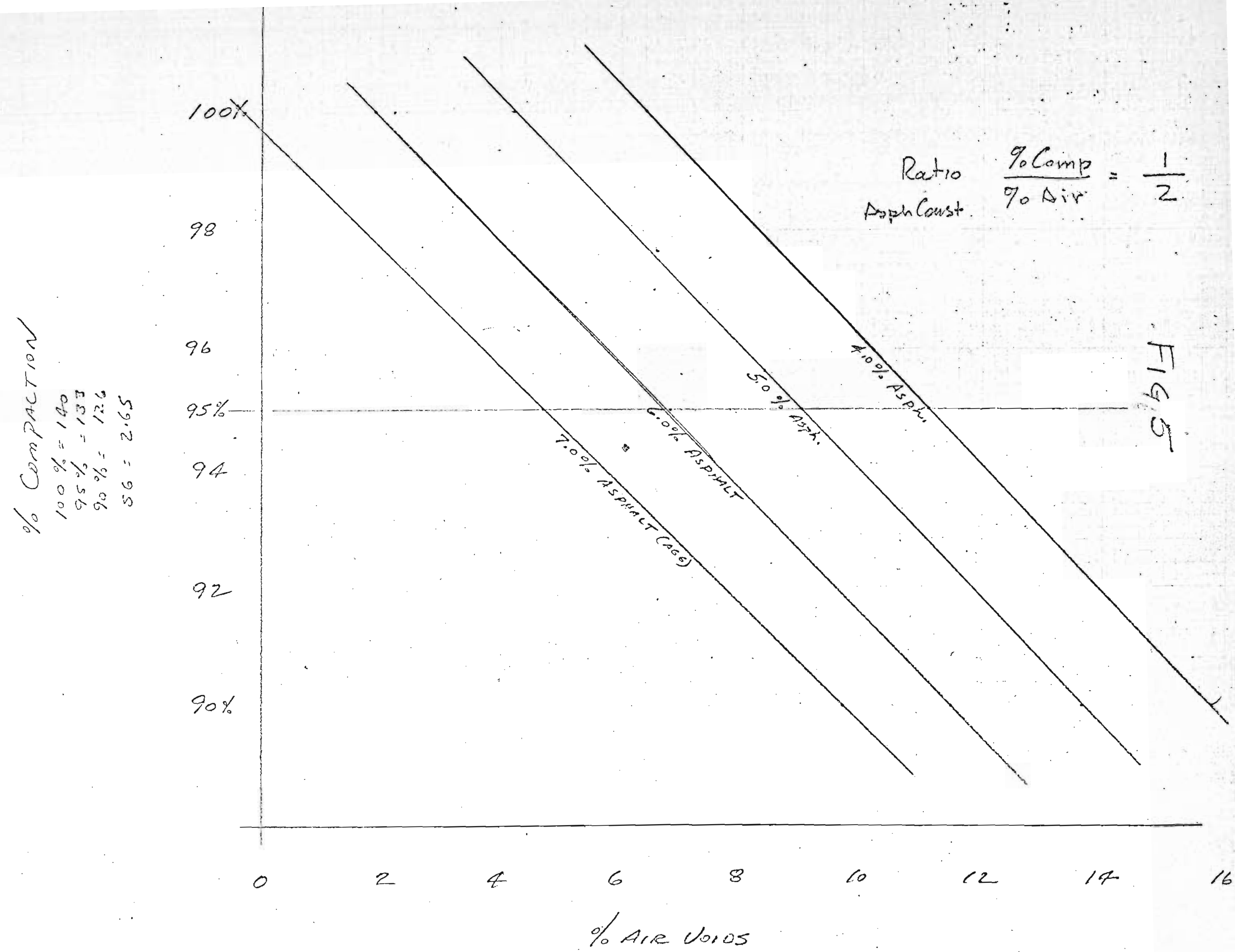
FROM - MONISMITH, SECOR & BLACKMER
ASPHALT MIXTURE BEHAVIOUR IN REPEATED FLEXURE AAPT - VOL 30 - 1961



100% comp = 140
95 " " 133
90 " " 126
S.A. = 35
Ratio = % Asph / % Air = 1/2
Comp. Cost
90% COMPACTION
95% COMPACTION
100% COMPACTION
7.0
6.5
6.0
5.5
5.0
4.5
4.0
% ASPHALT (AGG.)
0
2
4
6
8
10
12
14
% AIR VOIDS

FIG 4

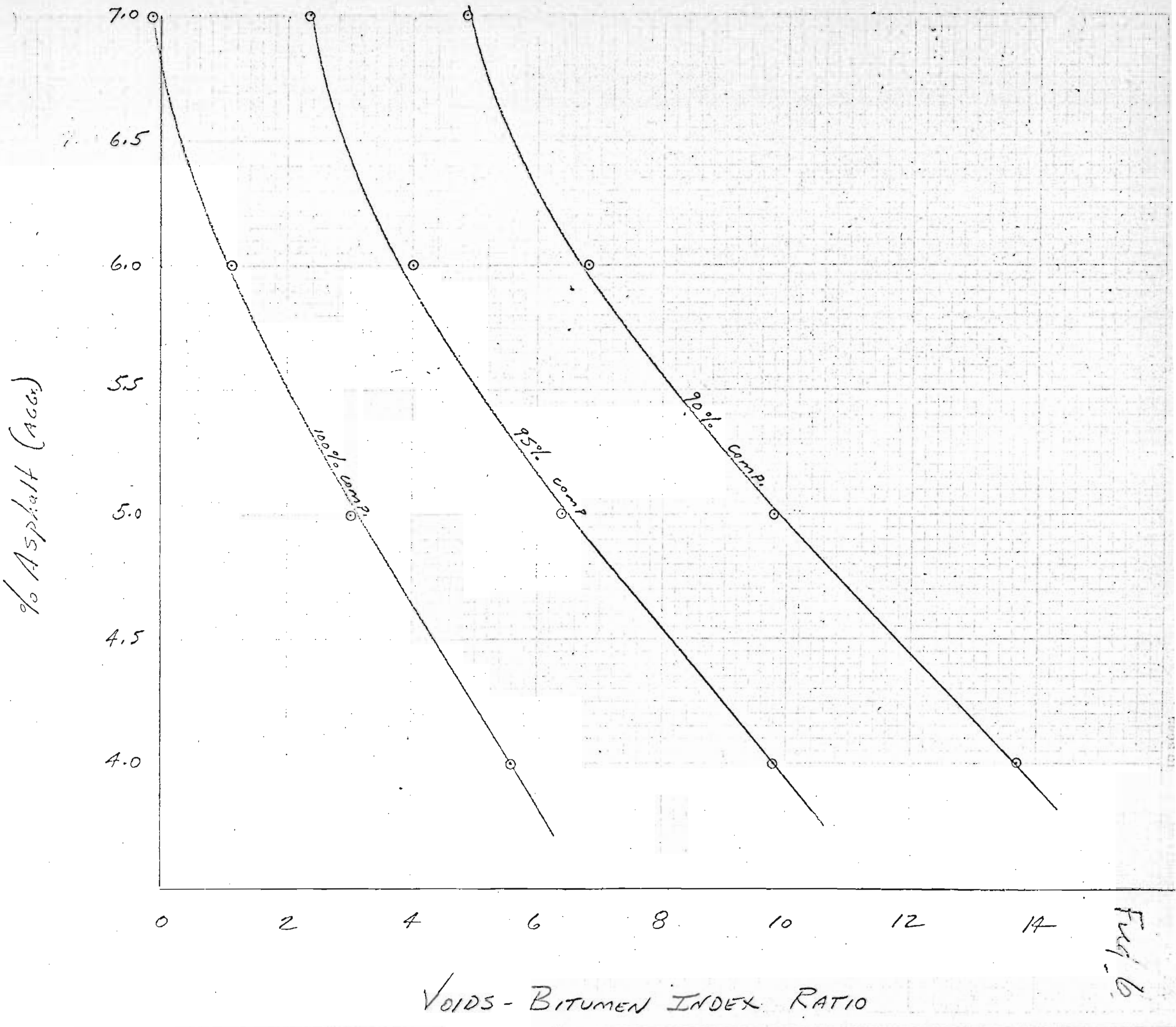
FIG 5

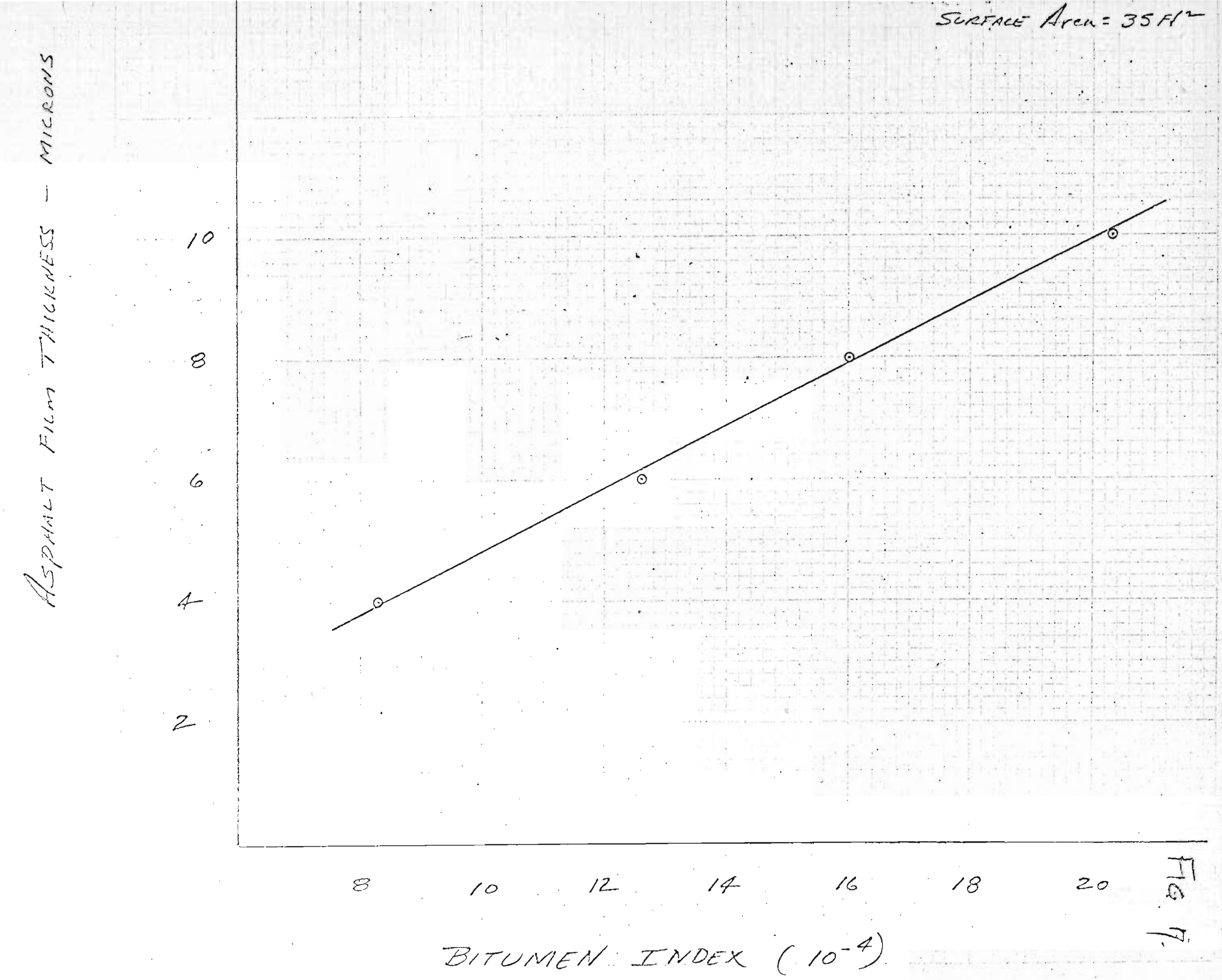


Ratio Asph Const. % Comp / % Air = 1/2
% COMPACTION
100% = 140
95% = 133
90% = 126
SG = 2.65
100%
98
96
95%
94
92
90%
4.0% Asph.
5.0% Asph.
6.0% ASPHALT
7.0% ASPHALT (AGG)
0
2
4
6
8
10
12
14
16
% AIR VOIDS

Fig. 6

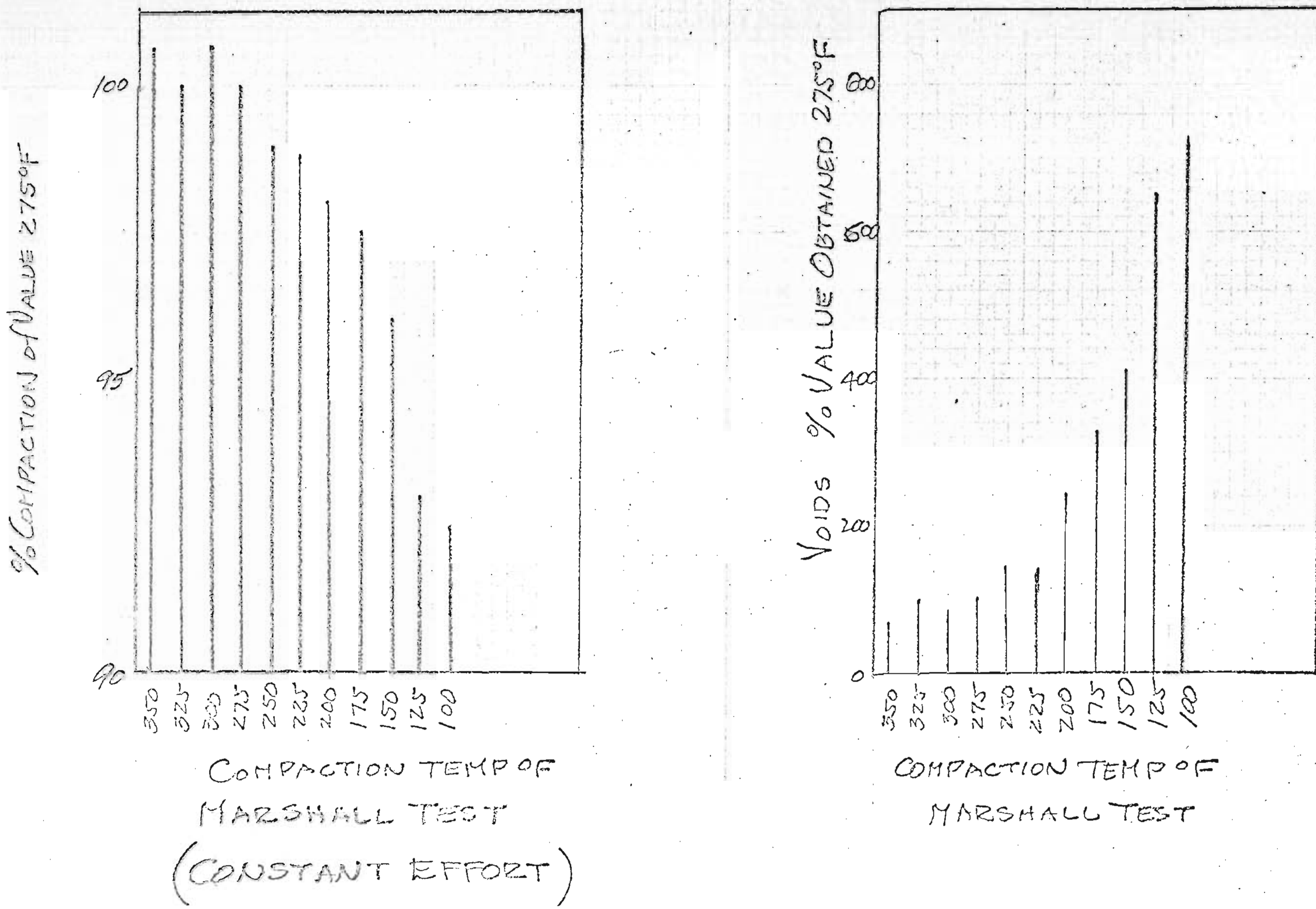
Surface Area = 35
SG = 2.65
100% comp = 140 (Agg)
95% " = 133 "
90% " 126 "





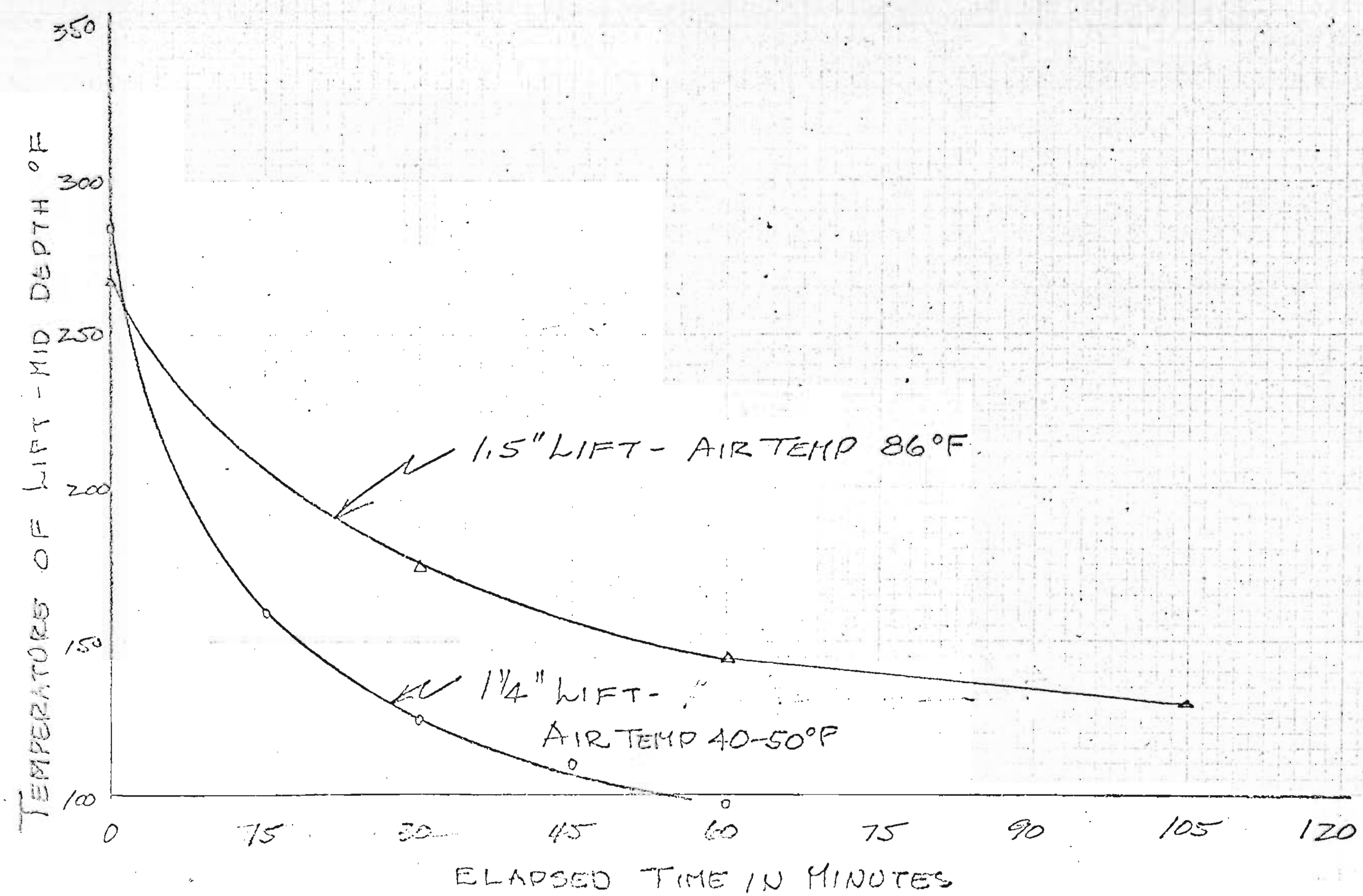
SURFACE Area = 35 Ft²
ASPHALT FILM THICKNESS – MICRONS
10
8
6
4
2
8
10
12
14
16
18
20
BITUMEN INDEX (10^{-4})

FIG. 7.



From - Chas F Parker Discussion - Paper by Fromm
Pavement Compaction - AAPT Vol 33 1963

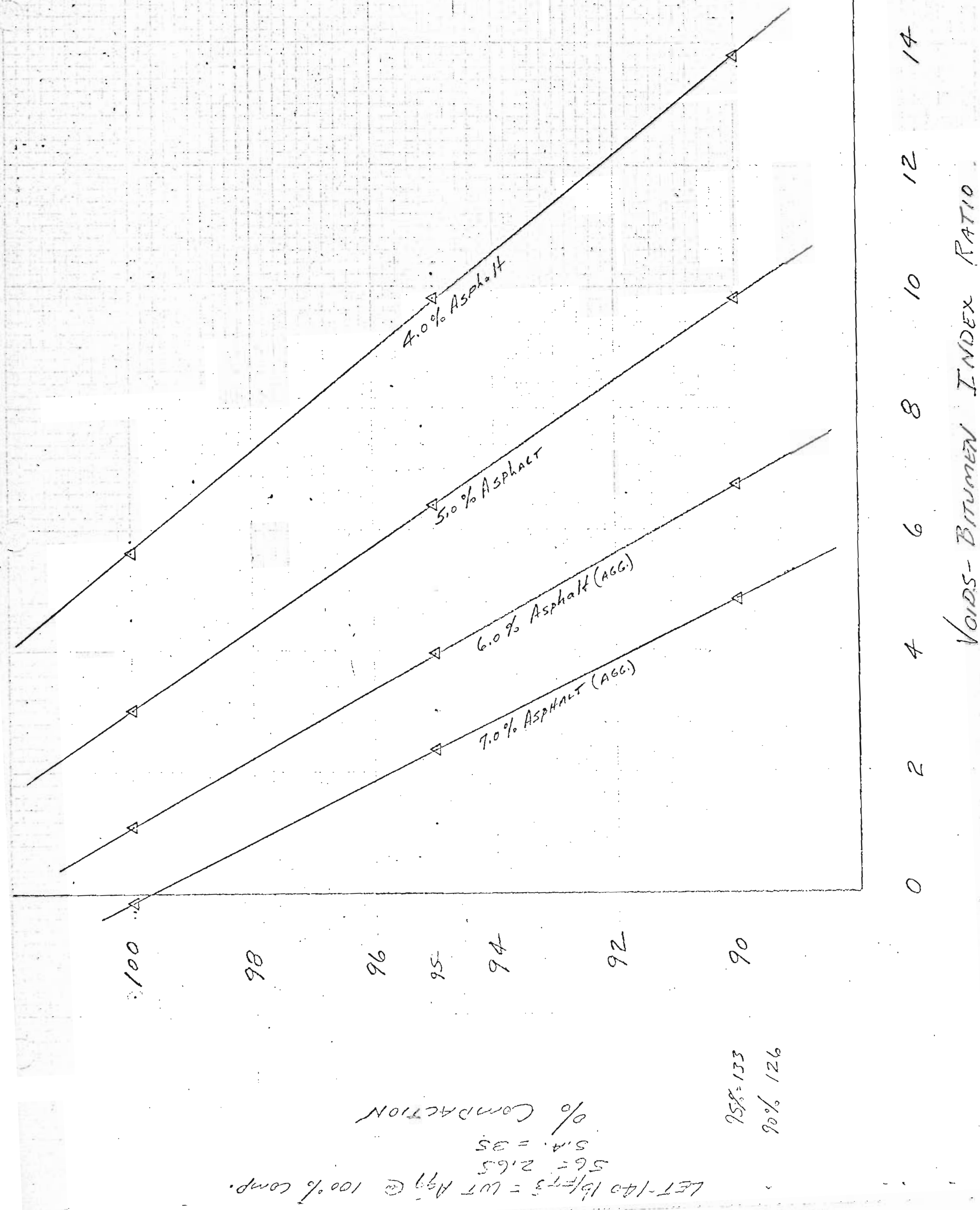
Fig 8



FROM McLEOD PAPER - INFLUENCE OF VISCOSITY OF ASPHALT CEMENTS ON COMPACTION OF PAVING MIXTURES IN THE FIELD - GIVEN HRB ANNUAL MEETING JAN 66

FIG 9

FIG. 10


4.0% Asphalt
5.0% Asphalt
6.0% Asphalt (AGG.)
7.0% Asphalt (AGG.)
Voids-Bitumen Index Ratio
0
2
4
6
8
10
12
14
100
98
96
95
94
92
90
% Compaction
95% = 133
90% 126
LET-140 lb/ft³ = WT Agg @ 100% comp.
SG = 2.65
S.A. = 35