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R 318

Technical Report

EVALUATION OF ASBESTOS ASPHALT PAVING MIXES

29 June 1964

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

EVALUATION OF ASBESTOS ASPHALT PAVING MIXES

Y-F015-15-01-122

Type C   Final Report

by

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ABSTRACT

An experiment was conducted to determine the effect on strength properties of adding asbestos fibers to asphalt paving mixtures. Beams, cylinders, and tensile briquets were molded with various percentages of asbestos (up to 2 percent) in combination with other fillers and a constant percentage of asphalt. Specimens were tested at the age of 0 months and at 6 and 18 months (accelerated). Marshall specimens were made of the same mixes and tested as soon as molded.

On the basis of a statistical analysis of the test results, strength properties did not improve enough to warrant further study.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

INTRODUCTION

The term "filler," as used by asphalt technologists, normally includes, in a paving mixture, that fraction of the mineral aggregate which passes a number 200 sieve. Generally speaking, the purpose of filler in a bituminous mixture is to fill the voids in the mineral aggregates and thus create a denser mixture than would be the case if the minus 200 material were omitted. It is usually assumed that each particle of filler is coated with a thin film of the asphalt binder, and thus, in addition to filling the voids, the filler assists in binding the entire mass together.

During the past several years, there has been a substantial amount of study on the effect of the chemical composition, origin, shape, and properties of fillers on the physical properties of the bituminous paving mixtures in which the fillers are incorporated. Results have been inconclusive. Studies have been made also on optimum quantities of filler in mixtures, and it has generally been concluded that the selection of a proper filler content depends on the specific mixture, that is, on the gradation and shape of the aggregate particles making up the mixture.

The study described in this report is the result of a suggestion that asbestos fibers used as a filler in a bituminous paving mixture might improve its resistance to the effects of jet aircraft exhausts. Field tests would be expensive, so it was decided to conduct laboratory studies on the effect of the asbestos fibers on the strength and durability characteristics of the paving mixtures. If the addition of asbestos fibers substantially improved the strength and durability properties of the paving mixture, the next logical step would be to install test sections in the field for exposure to jet exhaust.

The laboratory study was not to include investigation of the effect of the addition of the asbestos fibers on the asphalt binder itself. The objective of the study was to determine if the addition of asbestos fibers to flexible pavement mixes improves strength and durability properties.

Specimens were made then for flexure tests, tension tests, and cylindrical compression tests. Various percentages of asbestos were used in combination with or as a substitute for other fillers. Tests on specimens were made immediately after the specimens were formed (0 age) and, as a measure of durability, at accelerated weathering ages of 6 and 18 months. Stability specimens were also made but were not subjected to accelerated weathering tests. The test program was statistically designed, and the test results were analyzed from a statistical point of view.

MATERIALS

The basic aggregate from which the asphaltic concrete specimens were made was a river-run gravel indigenous to Southern California. It conformed to the following gradation:

Sieve Size	Percent Passing
1/2 in.	100.0
3/8 in.	88.0
No. 4	70.0
No. 10	51.0
No. 40	26.0
No. 80	16.0
No. 200	6.0

A substantial quantity of the aggregate was separated, into fractions retained on each of the sieves indicated above, for recombining when the various percentages of filler were used for the various specimens.

The asphalt cement used in this study was a paving grade asphalt with an 85/100 penetration grade. For the Marshall stability specimens, two penetration grades of asphalt were used, 85/100 and 40/50.

Short-fiber asbestos (Johns-Manville Corporation 7M06) was used in this study. Because of the elongated shape of the fibers, this material does not meet the definition of a filler expressed above (material passing a No. 200 sieve). But it functions as a filler in that it fills the voids between the particles of aggregate, and the individual fibers do receive a coating with a thin film of asphalt in the mixing process.

As indicated, the asbestos was used in combination with or as a substitute for other fillers in the paving mixes examined. These other fillers included a natural filler, so-called because it was a part of the river run aggregate mentioned above, and limestone dust; these passed a No. 200 sieve.

SPECIMENS AND FABRICATION

At the outset of the study, limits were placed on the percentages of the various ingredients which were to be included in the specimens formed for study. The maximum filler (total mineral aggregate and asbestos passing No. 200 sieve) content in any specimen was to be 10 percent by weight of the entire specimen. A single asphalt content, 6 percent, was to be used throughout the study. The percentages of asbestos fibers to be included in the mixes were 0, 0.5, 1, and 2 percent by weight.

The cylindrical specimens fabricated for compressive strength determinations were 2 inches in diameter and 3 inches high. They were formed in steel molds and compacted under a testing machine load of 25,000 pounds applied for 2 minutes.

The briquets of asphaltic concrete made for determination of the tensile strength were formed in a standard briquet mold used in the tensile strength test of hydraulic cement mortars (ASTM Designation C-190-59). A gang mold was not used; instead, specimens were made one at a time. The briquets were compacted in the mold under a load of 25,000 pounds for 2 minutes in a compression testing machine.

The beams of asphaltic concrete fabricated for determination of the tensile strength properties were 1-1/2 by 1-1/2 by 8 inches long. These were fabricated in steel molds and were compacted under a load of 50,000 pounds (applied to a 1-1/2- by 8-inch side) for 2 minutes.

Marshall stability specimens were compacted in the conventional manner, that is, 75 blows with a Marshall hammer on each end of the specimen.

It will be noted that compaction was different for the various specimens. Beams were compacted at a different load than were the cylinders, etc. This was an effort to obtain reasonably uniform apparent specific gravities or densities among the various specimens.

Except for the Marshall specimens, a sufficient number of specimens was made for testing in both weathered and unweathered conditions.

DESIGN OF EXPERIMENT

As suggested by the CEIR Corporation, the design of the investigation of the effect of asbestos fibers on the strength and durability properties of asphaltic concrete was as shown in Table I.

The following illustrates how the Table I experimental design was used. Consider Mix No. 5 which is seen to contain 2 percent asbestos, 2 percent limestone and 0 percent natural filler. Six cylindrical specimens were made using Mix No. 5; two were tested at 0 age (24 hours after fabrication), two were tested after 6 months accelerated age, and two were tested after 18 months accelerated age. Three beams were made from the same mix; one was tested at 0 age, one at 6 months, and one at 18 months, and three briquets were made, one to be tested at each of the ages. Duplicate specimens were made for the compressive strength tests, but only single specimens were made for the tensile and flexural strength tests. This procedure was followed because it was believed that the effect of asbestos on strength would be better indicated in a compressive strength test than in the other two, and that a conclusion based on the statistical analysis of the test results would therefore be more accurate.

Marshall stability specimens were fabricated for testing at 0 age only. Since the Marshall test is normally used for design and construction control only, tests of weathered specimens would probably have little significance.

TEST PROCEDURES

Immediately after fabrication all test specimens were stored for 24 hours at 70 F before being tested or subjected to a weathering cycle; tests at 0 age were made at this temperature.

Cylindrical specimens were broken in a Riehle 20,000-pound testing machine; the load was applied so that the rate of deformation was 0.05 inch per minute (ASTM D1074-60).

Briquets were broken in a standard briquet-testing machine usually used for the testing of hydraulic cement; the load was applied continuously until the briquet failed.

Beam specimens were also tested in a Riehle testing machine; the load was applied so that deflection rate was 0.05 inch per minute. The beams were tested as simple beams with center-point loading.

Table I. Summary of Test Results for Asbestos-Asphalt Paving Mixes

Mix No.	Filler 1/ (% by weight)			Cylindrical Compression 2/ (psi)			Flexural Strength (psi)			Tensile Strength (psi)			Marshall Stability 2/ (0 months only)			
	Asbestos	Natural	Limestone	0 Months	6 Months	18 Months	0 Months	6 Months	18 Months	0 Months	6 Months	18 Months	85/100 Pen Stability	Flow	40/50 Pen Stability	Flow
1	1.0	0.0	0.0	628	628	603	303	332	374	168	160	198	3/	3/	3080	11
2	0.0	6.0	0.0	601	501	548	206	206	275	47	137	169	1680	7	2330	10
3	0.0	0.0	4.0	477	504	482	139	105	92	110	37	36	1890	10	2160	13
4	0.5	4.0	0.0	505	501	581	140	153	188	104	108	71	1270	17	2380	5
5	2.0	0.0	2.0	489	424	408	189	166	230	140	113	84	2190	16	3080	5
6	2.0	4.0	0.0	509	428	497	136	156	243	116	94	89	1970	8	3070	7
7	0.0	0.0	8.0	392	368	390	135	168	283	82	113	88	2260	10	3150	7
8	1.0	2.0	0.0	415	386	470	96	91	216	85	62	66	930	13	2520	12
9	0.0	2.0	0.0	290	344	430	90	136	187	89	107	60	1320	7	2280	8
10	1.0	0.0	2.0	450	417	497	280	178	168	133	143	87	1570	7	2840	9
11	2.0	8.0	0.0	507	442	470	127	131	193	53	104	66	1780	10	3510	7
12	0.5	0.0	2.0	343	331	396	117	138	224	88	113	70	1460	8	2620	6
13	2.0	2.0	0.0	523	400	490	131	101	238	71	81	89	1670	5	3050	6
14	2.0	0.0	8.0	594	475	591	149	197	262	108	142	116	2780	10	3030	10
15	0.5	6.0	0.0	363	331	406	97	117	319	53	124	84	1980	6	3260	6
16	0.5	0.0	6.0	423	414	429	172	202	267	122	141	96	2020	8	2790	12
17	0.5	8.0	0.0	367	377	462	131	162	190	75	84	72	1260	10	2940	6
18	0.0	4.0	0.0	247	280	368	88	112	131	53	40	57	1650	8	2320	11
19	2.0	0.0	6.0	536	424	522	175	156	242	71	61	88	2600	8	2880	8
20	1.0	0.0	4.0	393	404	490	121	168	217	89	60	51	2320	7	2790	10
21	1.0	6.0	0.0	398	295	395	91	107	202	71	44	68	2100	7	2930	7
22	0.0	8.0	0.0	329	366	414	84	114	143	85	54	70	1590	12	2540	6
23	0.0	0.0	2.0	300	340	363 4/	84	125	5/	71	48	56	1360	8	2580	7
24	2.0	6.0	0.0	440	347	458	109	174	214	75	60	62	2470	8	3520	6
25	1.0	8.0	0.0	395	446	382	88	155	165	102	82	36	2350	8	3360	6
26	0.5	0.0	4.0	362	399	355	140	247	75	89	73	51	2330	9	3140	9
27	2.0	0.0	4.0	496	479	414	79	175	79	44	58	46	2610	8	3370	7
28	1.0	0.0	8.0	454	446	453	120	178	80	48	68	74	2670	11	2590	9
29	0.5	2.0	0.0	321	320	339 4/	93	165	65	57	66	38	1130	9	2190	12
30	0.0	0.0	6.0	323	398	375	97	157	81	33	63	41	1530	7	2230	12
31	1.0	4.0	0.0	319	313	353	85	121	65	34	73	36	1380	7	2570	5
32	0.5	0.0	8.0	400	419	378	154	172	83	44	57	37	2630	9	2550	
Range of Apparent Specific Gravity of Specimens				2.17 - 2.32			2.14 - 2.27			2.13 - 2.28			2.20 - 2.32		2.19 - 2.33	

1/ Experiment design by CEIR
2/ Average of two specimens
3/ Void
4/ One specimen only
5/ Specimen destroyed before test

Marshall specimens were tested in the conventional manner.

The weathering cycle to which the specimens were subjected was that indicated as Daily Cycle B of the Recommended Practice for Accelerated Weathering Test of Bituminous Materials (ASTM D529-62). This cycle consists of:

Water spray only (70 ±5 F spray water)		1 hour
Light exposure only (140 ±5 F black panel)		1-1/2 hours
Water spray only (70 ±5 F spray water)		2 hours
Light exposure only (140 ±5 F black panel)		16-1/2 hours
Cold exposure (0 ±10 F)		1-3/4 hours
	Total	22-3/4 hours

The apparatus used in the accelerated weathering test was an Atlas single carbon arc lamp weatherometer in which 14 days of exposure to Cycle B, as described above, was the equivalent of 6 months of exposure to natural weather. Thus samples indicated as having been tested at age 6 months (accelerated) were subjected to Cycle B in the weatherometer for 14 days. Those tested at age 18 months (accelerated) were in the weatherometer for 42 days.

TEST RESULTS

The results of tests on cylinders, beams, briquets, and Marshall stability specimens are given in Table I. Table I also indicates the ranges of apparent specific gravities obtained in the compaction of specimens described in the section on Specimens and Fabrication. For analysis purposes, the strength data of Table I (except for the Marshall tests of specimens with 40/50 penetration grade asphalt) were organized as shown in Table II. These data were subjected to a statistical analysis and plotted as Figures 1 through 19 of the Appendix.

Flow values, which are indicators of the brittleness of an asphaltic concrete measured during the Marshall stability tests, are also shown in Table I.

In all but two mixes (numbers 28 and 32) the Marshall stability values were higher with the 40/50 penetration asphalt than with the 85/100 asphalt (Table I).

Table II. Strength Data

Natural (%)	Asbestos (%)	0 Months	6 Months	18 Months	Limestone (%)	Asbestos (%)	0 Months	6 Months	18 Months
Beams									
2.0	0.0	90	136	187	2.0	0.0	84	125	
2.0	0.5	93	164	65	2.0	0.5	117	138	224
2.0	1.0	96	91	216	2.0	1.0	280	178	168
2.0	2.0	131	101	238	2.0	2.0	189	166	230
4.0	0.0	68	112	131	4.0	0.0	139	105	92
4.0	0.5	140	154	188	4.0	0.5	140	246	74
4.0	1.0	84	121	64	4.0	1.0	121	168	216
4.0	2.0	136	156	243	4.0	2.0	78	175	78
6.0	0.0	206	206	274	6.0	0.0	97	157	81
6.0	0.5	97	117	319	6.0	0.5	172	202	266
6.0	1.0	91	107	202	6.0	1.0	303	332	374
6.0	2.0	109	174	214	6.0	2.0	175	156	242
8.0	0.0	84	114	143	8.0	0.0	134	168	282
8.0	0.5	131	162	190	8.0	0.5	154	172	82
8.0	1.0	88	155	164	8.0	1.0	120	178	80
8.0	2.0	126	131	192	8.0	2.0	148	196	262
Briquets									
2.0	0.0	89	106	80	2.0	0.0	71	48	56
2.0	0.5	57	66	38	2.0	0.5	88	113	70
2.0	1.0	84	62	66	2.0	1.0	133	143	87
2.0	2.0	70	80	89	2.0	2.5	140	113	84

Table II. Strength Data (Cont'd)

Natural (%)	Asbestos (%)	0 Months	6 Months	18 Months	Limestone (%)	Asbestos (%)	0 Months	6 Months	18 Months
4.0	0.0	53	40	57	4.0	0.0	110	37	36
4.0	0.5	104	108	70	4.0	0.5	89	73	50
4.0	1.0	34	73	36	4.0	1.0	89	60	51
4.0	2.0	116	94	89	4.0	2.0	41	58	46
6.0	0.0	47	136	169	6.0	0.0	97	157	81
6.0	0.5	53	124	84	6.0	0.5	122	141	96
6.0	1.0	71	44	68	6.0	1.0	168	160	198
6.0	2.0	75	60	62	6.0	2.0	71	61	88
8.0	0.0	84	54	70	8.0	0.0	82	113	88
8.0	0.5	75	84	72	8.0	0.5	44	57	37
8.0	1.0	102	82	36	8.0	1.0	48	68	74
8.0	2.0	53	104	66	8.0	2.0	108	142	116

Cylinders

Natural (%)	Asbestos (%)	0 Months	6 Months	18 Months	Limestone (%)	Asbestos (%)	0 Months	6 Months	18 Months
2.0	0.0	298	326	429	2.0	0.0	298	345	363
		282	362	430			302	335	
2.0	0.5	340	332	339	2.0	0.5	368	321	392
		302	307				318	340	401
2.0	1.0	429	380	464	2.0	1.0	442	425	491
		398	392	476			458	409	503
2.0	2.0	508	392	454	2.0	2.0	496	425	426
		538	408	528			481	424	392

Table II. Strength Data (Cont'd)

Natural (%)	Asbestos (%)	0 Months	6 Months	18 Months	Limestone (%)	Asbestos (%)	0 Months	6 Months	18 Months
4.0	0.0	236	269	368	4.0	0.0	476	504	503
		258	291	369			477	503	460
4.0	0.5	478	524	594	4.0	0.5	366	393	356
		533	478	567			358	405	354
4.0	1.0	312	316	356	4.0	1.0	395	403	494
		326	310	348			392	404	487
4.0	2.0	522	453	470	4.0	2.0	483	486	449
		496	403	524			508	473	379
6.0	0.0	592	506	568	6.0	0.0	312	412	379
		612	496	528			334	385	371
6.0	0.5	336	364	401	6.0	0.5	401	417	430
		490	298	410			444	410	428
6.0	1.0	348	283	380	6.0	1.0	612	623	602
		449	306	408			645	632	603
6.0	2.0	438	364	484	6.0	2.0	534	422	540
		442	330	432			538	425	503
8.0	0.0	317	310	400	8.0	0.0	385	364	398
		340	322	428			398	372	384
8.0	0.5	314	370	474	8.0	0.5	392	402	410
		420	384	449			408	436	346
8.0	1.0	366	450	398	8.0	1.0	455	442	455
		424	442	366			452	449	450
8.0	2.0	500	471	460	8.0	2.0	573	469	610
		514	414	480			614	480	572

Table II. Strength Data (Cont'd)

Marshall Stability Test

Natural (%)	Asbestos (%)	0 Months Duplicate Specimens		Limestone (%)	Asbestos (%)	0 Months Duplicate Specimens	
2.0	0.0	1320	1320	2.0	0.0	1344	1382
2.0	0.5	1051	1200	2.0	0.5	1478	1450
2.0	1.0	960	902	2.0	1.0	1520	1612
2.0	2.0	1735	1600	2.0	2.0	2227	2160
4.0	0.0	1627	1680	4.0	0.0	1987	1790
4.0	0.5	1276	1163	4.0	0.5	2300	2362
4.0	1.0	1420	1334	4.0	1.0	2380	2260
4.0	2.0	1934	2006	4.0	2.0	2730	2480
6.0	0.0	1598	1758	6.0	0.0	1510	1550
6.0	0.5	2112	1852	6.0	0.5	1890	2140
6.0	1.0	2150	2040	6.0	1.0	1300	1385
6.0	2.0	2615	2320	6.0	2.0	2480	2720
8.0	0.0	1598	1584	8.0	0.0	2080	2440
8.0	0.5	1290	1235	8.0	0.5	2704	2558
8.0	1.0	2290	2420	8.0	1.0	2740	2600
8.0	2.0	1660	1906	8.0	2.0	2798	2756

DISCUSSION OF TEST RESULTS

It is seen in Table I that there was little difference in the apparent specific gravities of specimens compacted according to the various procedures mentioned in the section on Specimens and Fabrication. Thus all specimens had approximately the same density.

Table II reveals no clear-cut or substantial increase in the compressive strength of cylindrical specimens when asbestos content is increased (up to 2 percent). The statistical analysis of the data, however, indicates an increase of between 20 and 67 psi per percent increase in asbestos, when averaged over all three ages and all percentages of limestone and natural filler. Considering that the average compressive strength of all cylindrical specimens tested at all ages is 424 psi, the calculated increase in compressive strength is not substantial.

As indicated by the confidence intervals shown on the curves of the Appendix, the test data do not conclusively show the effect of the addition of asbestos on flexural strength or on tensile strength. For some mixes, the addition of asbestos increases the flexural strength and a still larger addition decreases it; sometimes this is true also with regard to tensile strength, but with the same mixes the converse is sometimes true. No reason for this anomalous situation is apparent from a review of the test conditions and the control exercised.

There appears to be an increase in Marshall stability values (specimens were tested only at age 0) with an increase in the amount of asbestos in the mix. The data analysis indicates this increase is between 86 and 516 pounds per percent of asbestos. Again, the average stability value of all specimens containing 85/100 penetration asphalt is 1900 pounds, and so the effect of asbestos on the Marshall stability of specimens may or may not be substantial. That is, an 86-pound increase in stability is not large, but a 516-pound increase is. Although the results of the Marshall stability tests on specimens containing the 40/50 penetration asphalt were not analyzed statistically, it is suggested that the effect of the addition of asbestos would be independent of the penetration grade of the asphalt in the mix. The average stability value obtained on specimens made with this asphalt was 2800 pounds, and so on a percentage basis, asbestos would not increase stability as much when the harder asphalt is used.

CONCLUSIONS

Based on the test results and their statistical analysis, it is concluded that the addition of asbestos to asphalt paving mixes is not substantially effective in increasing their overall strength properties. There were some increases in compressive strength when the amount of asbestos was increased from 0 to 2 percent in combination with other fillers. There was an apparent increase in Marshall stability values with increasing amounts of asbestos. It is not known, however, whether the addition of asbestos fibers will increase or decrease the tensile or flexural strength of asphalt paving mixes. In any event, the increase (or decrease in the case of tensile or flexural strengths) is not large.

RECOMMENDATIONS

It is recommended that no further work be undertaken on the effect of adding asbestos fillers to asphalt paving mixtures.

Appendix

ANALYSIS OF TEST RESULTS

by

I. W. Anders

and

M. L. Eaton

The main conclusions drawn from analyses of the results in Table I are:

1. Under the test conditions (described in the report) averaged over all three ages, all four percentages of limestone, and all four percentages of natural filler employed, the effect of asbestos on compressive strength of cylinders is unknown exactly, but lies someplace between 20 and 67 psi increase per percent asbestos in the blends. Restated, an estimate of the relationship is:

$$Y = 386.4 + 43.6X$$

where Y = compressive strength of cylinders averaged over the 48 combinations of percents limestone, percents natural filler, and ages.

X = percent asbestos in the cylinders within the range 0 to 2 percent. This equation should not be used for extrapolation beyond 2 percent.

The figure 43.6 is far from an exact estimate. A 95 percent confidence interval for its true value extends from 20.2 to 67.1.

2. Under the test conditions, averaged over all four percentages of limestone, and all four percentages of natural filler employed; the effect of asbestos on the output of the Marshall stability test is unknown exactly, but lies someplace between 86 and 516 units per percent asbestos in the blends. An estimate of the relationship is:

$$Y = 1612.8 + 301.0X$$

where X = percent asbestos in the mix within the range 0 to 2 percent

Y = stability test results averaged over the eight percents limestone and percents natural filler used

This equation should not be used for extrapolation beyond 2 percent asbestos. A 95 percent confidence interval for the true value of the mean rate of increase (estimated as 301) extends from 86.3 to 515.7.

Similar conclusions relative to beams and briquets are not drawn. The reason is that the data do not show clearly whether asbestos causes an increase (+) or decrease (-) in strength. For beams the corresponding 95 percent confidence interval on the mean effect rate extends from -10.3 to 35.5, and for briquets from -4.24 to 8.02.

The balance of this appendix will be an attempt to explain the foregoing in somewhat more detail. The slopes of the graphs in the charts to follow should be interpreted merely as an indication of the rate of increase or decrease of strength per percent caused by addition of asbestos. In those many cases where the confidence interval for the slope brackets zero, the correct interpretation is that the effect is still unknown. The 95 percent confidence interval for each slope will be found on its graph.

In an effort to estimate the mean collective effect of filler, age and asbestos on compressive strength of cylinders, all the cylinder data was analysed. The estimated relationship is:

$$Y = 320.5 + 8.50X_1 + 57.6X_2 + 4.73X_3 - 0.35X_1X_3 - 1.71X_2X_3$$

where Y = compressive strength in psi

X_1 = percent filler in the blend (the coefficients represent the mean effect of lime and natural fillers) in the range 2 to 8

X_2 = percent asbestos in the blend, in the range 0 to 2

X_3 = months of aging, in the range 0 to 18

This equation should not be used for extrapolation beyond foregoing ranges. For $X_1 = 2$, $X_2 = 0$ and $X_3 = 0$, from this regression equation $Y = 337.5$. This is a rough estimate of the mean. A 0.95 confidence interval for this mean strength $Y(2, 0, 0)$ extends from 319.5 to 355.5. Similarly $Y(8, 2, 18) = 476.9$ with confidence interval 436.0 to 517.8. The estimated gain then is $476.9 - 337.5 = 139.4$ caused by jointly increasing filler from 2 to 8 percent, asbestos from 0 to 2 percent and aging from 0 to 18 months. This is a rough estimate of the mean effect. A 0.95 confidence interval for this mean strength increase $[Y(8, 2, 18) - Y(2, 0, 0)]$ extends from 89.9 to 188.9.

The mean collective effect of filler and asbestos on output of the Marshall test was estimated to be:

$$Y = 1038.725 + 114.8105X_1 + 334.2205X_2 - 6.6456X_1X_2$$

where Y = Marshall test output

X_1 = percent filler in the blend (the coefficients represent the mean effect of lime and natural filler) in the range 2 to 8

X_2 = percent asbestos in the blend, in the range 0 to 2

This equation should not be used for extrapolation beyond the foregoing ranges. For $X_1 = 2$ and $X_2 = 0$, from this regression equation $Y = 1268.35$. This is a rough estimate of the mean. A 95 percent confidence interval for this extends from 1001.97 to 1534.73. For $X_1 = 8$ and $X_2 = 2$, from this equation a rough estimate of mean Y is 2519.32. A 95 percent confidence interval for this extends from 2206.29 to 2832.35. The estimated gain then is $2519.32 - 1268.35 = 1250.97$, caused by jointly increasing filler from 2 to 8 percent and asbestos from 0 to 2 percent. A 95 percent confidence interval for this mean Marshall test output increase $[Y(8, 2) - Y(2, 0)]$ extends from 856.72 to 1645.22.

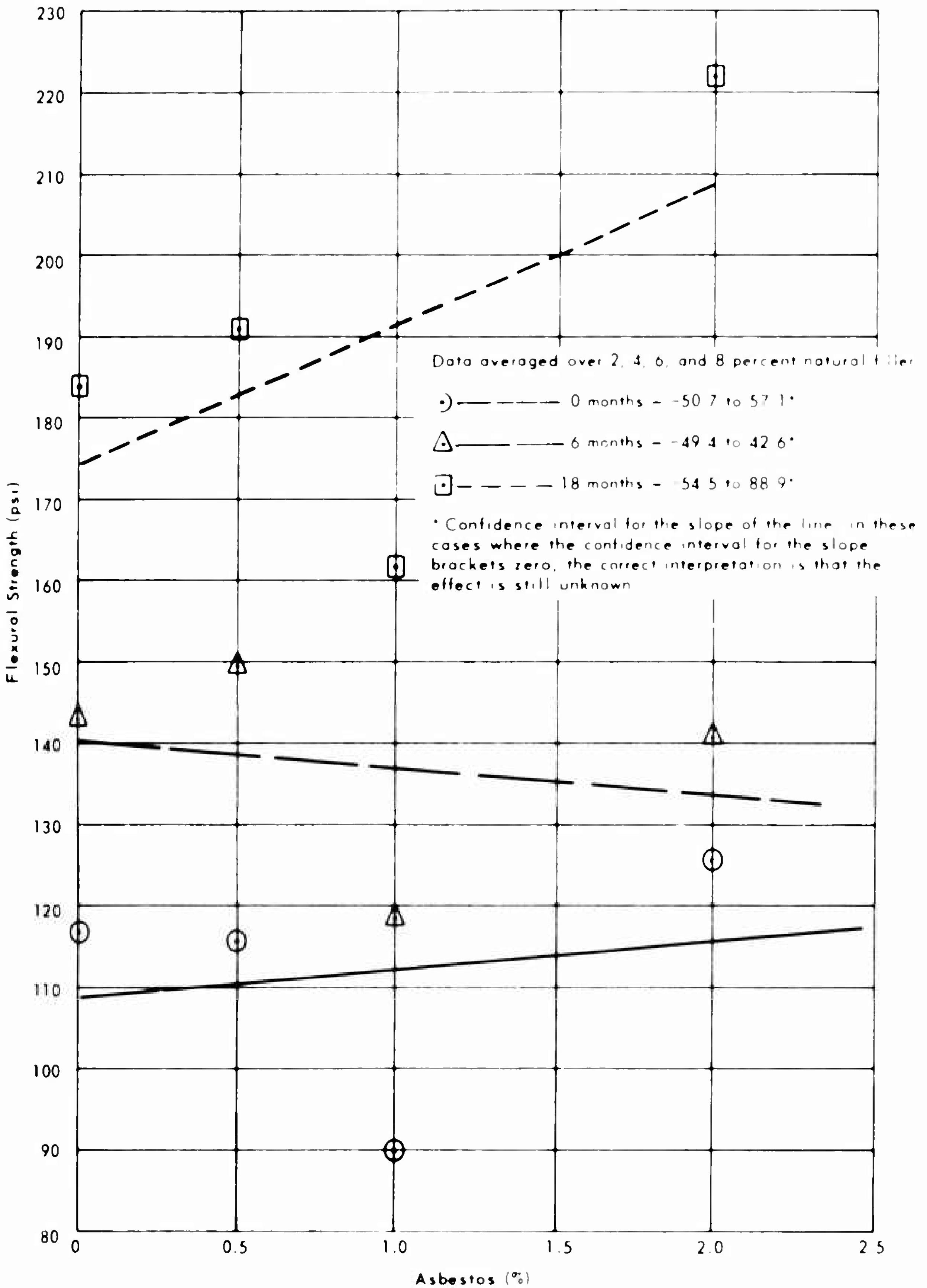

Figure 1. Flexural strength of asphaltic concrete versus percent asbestos.

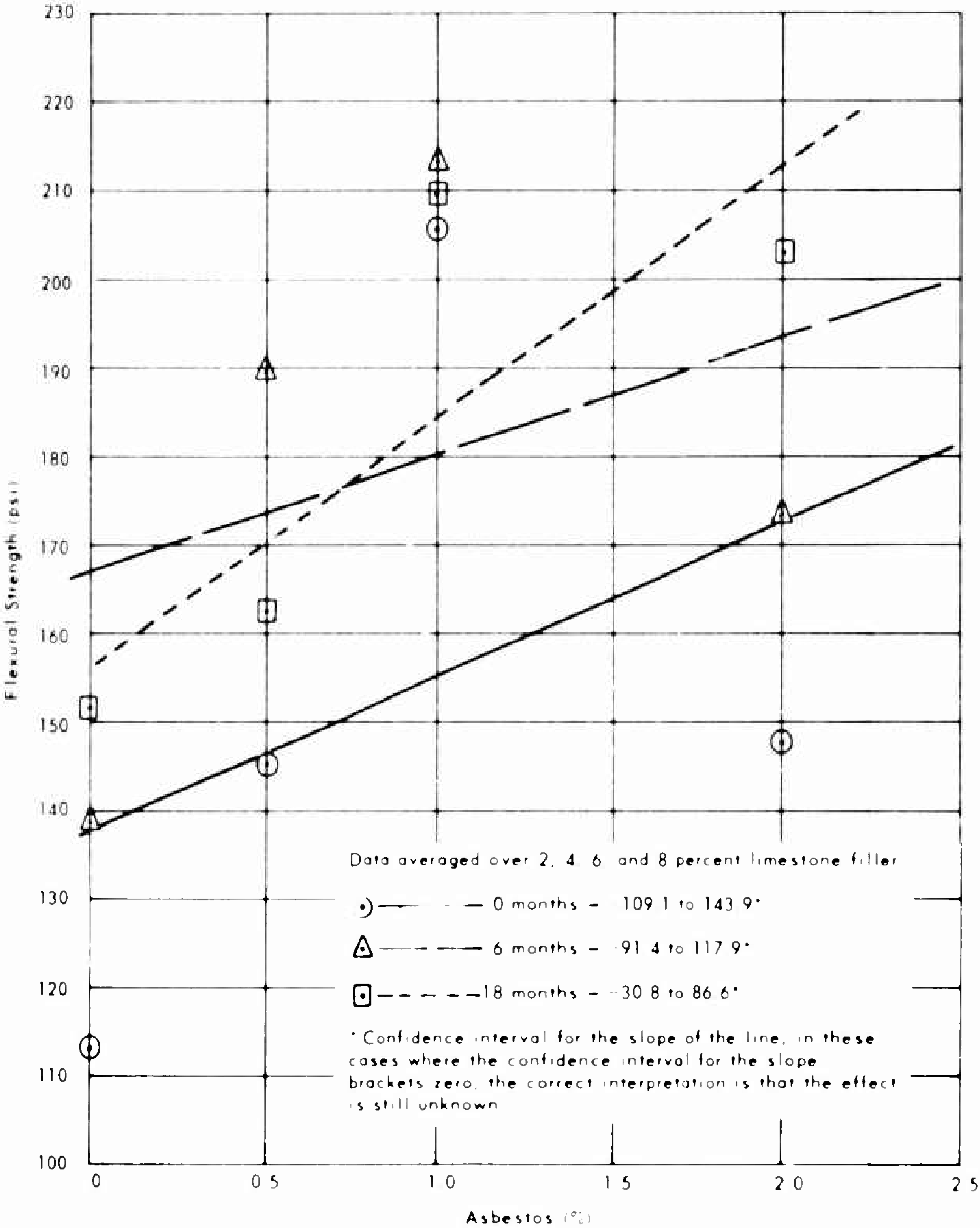

Figure 2. Flexural strength of asphaltic concrete versus percent asbestos.

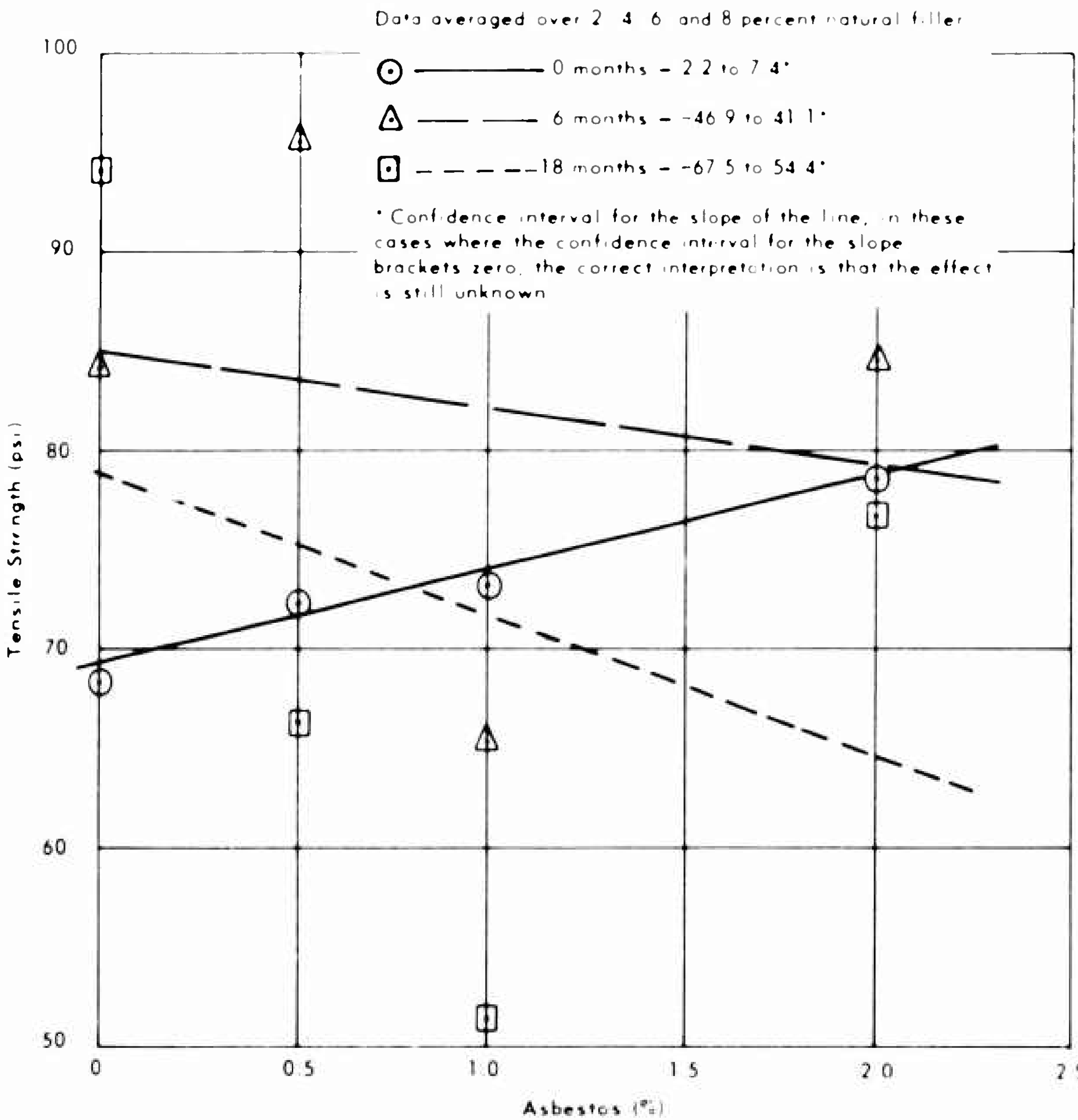

Figure 3. Tensile strength of asphaltic concrete versus percent asbestos.

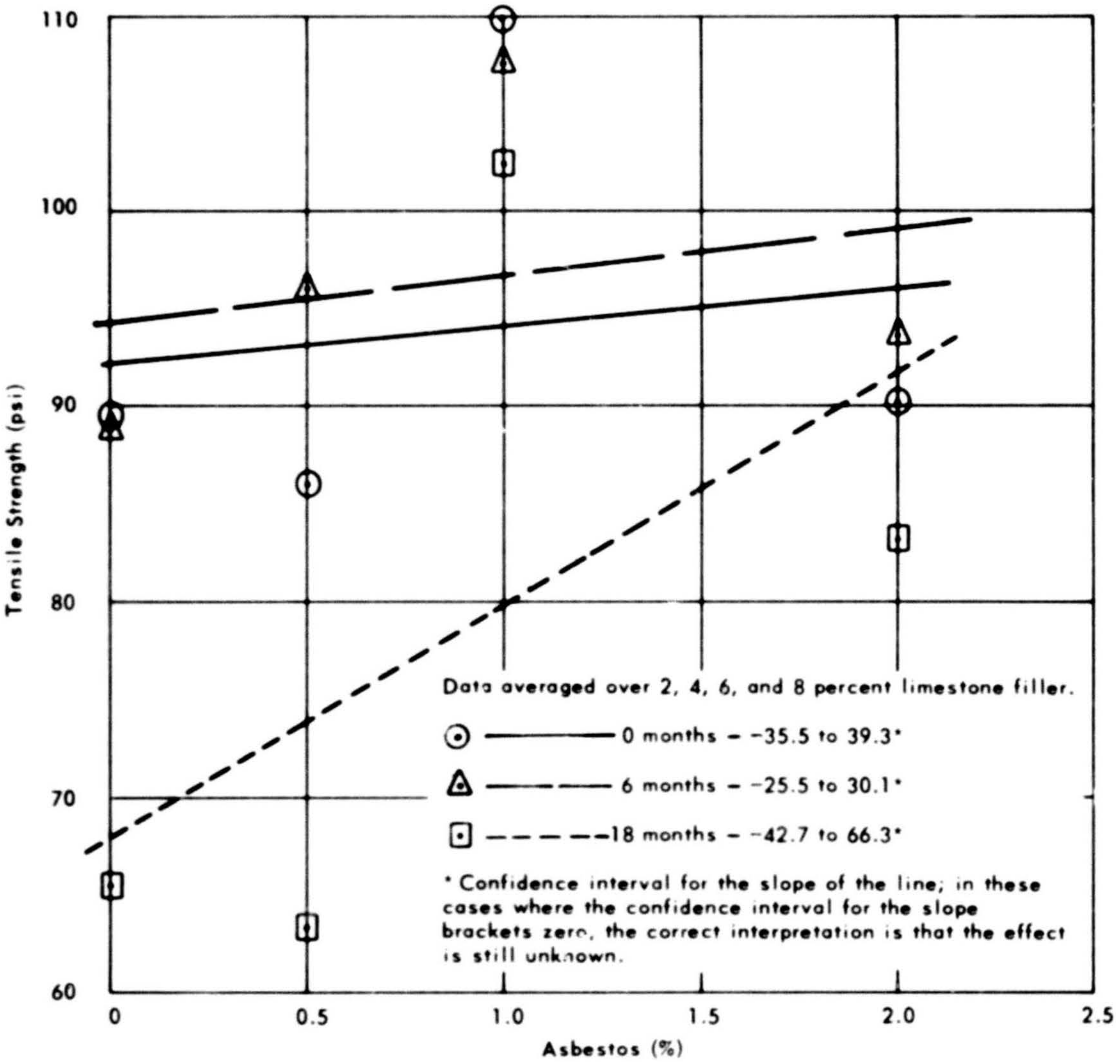

Figure 4. Tensile strength of asphaltic concrete versus percent asbestos.

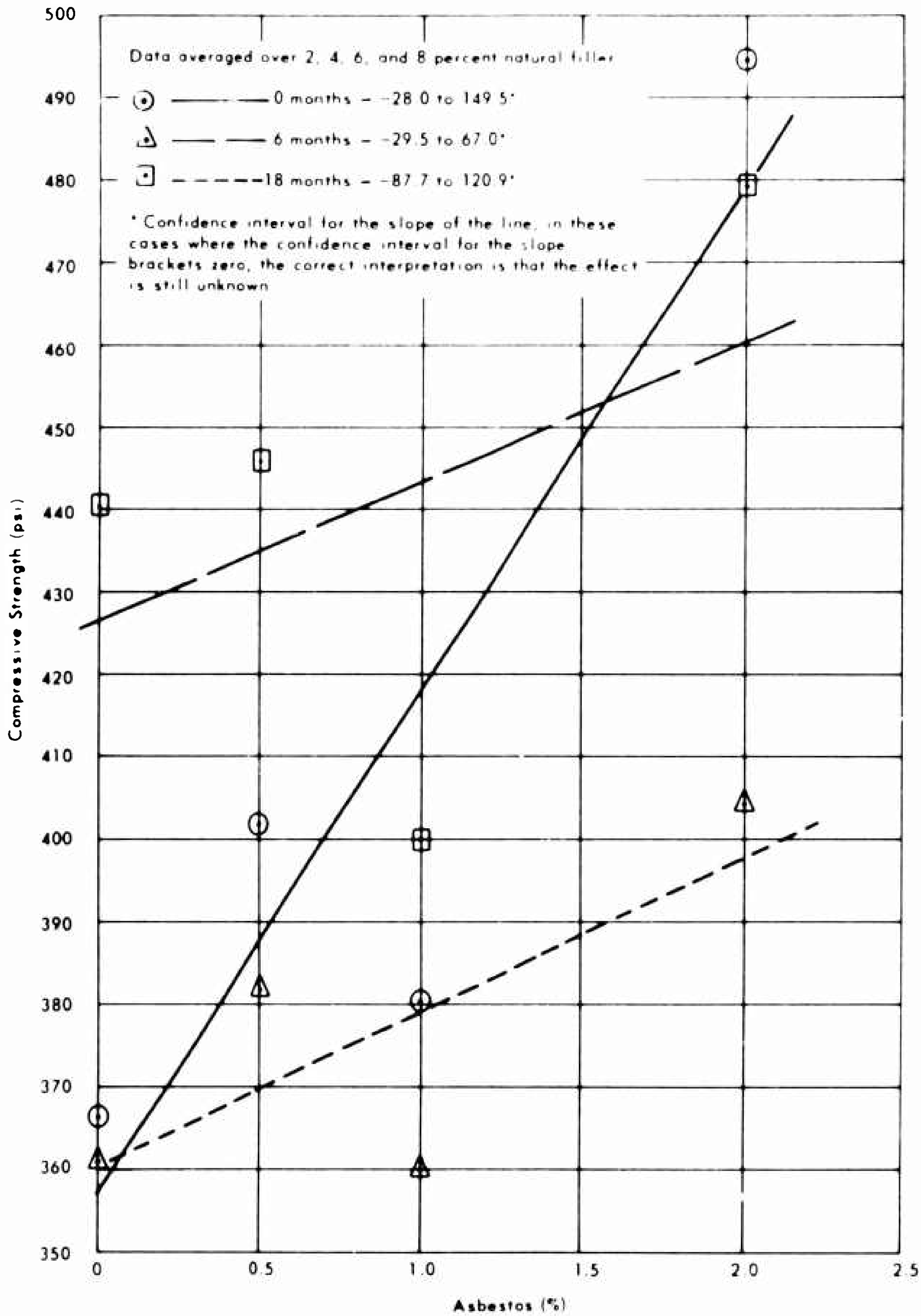

Figure 5. Compressive strength of asphaltic concrete versus percent asbestos.

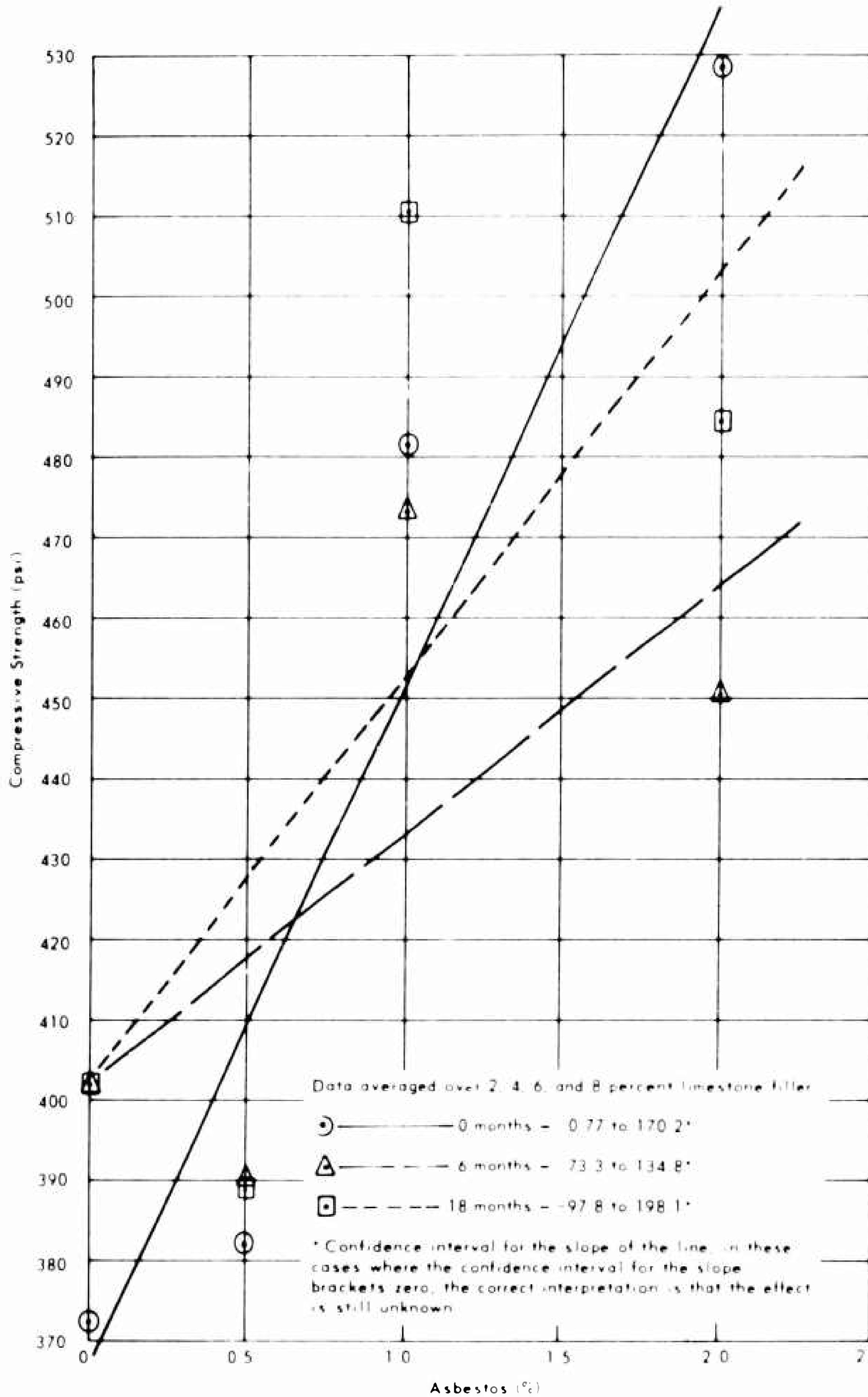

Figure 6. Compressive strength of asphaltic concrete versus percent asbestos.

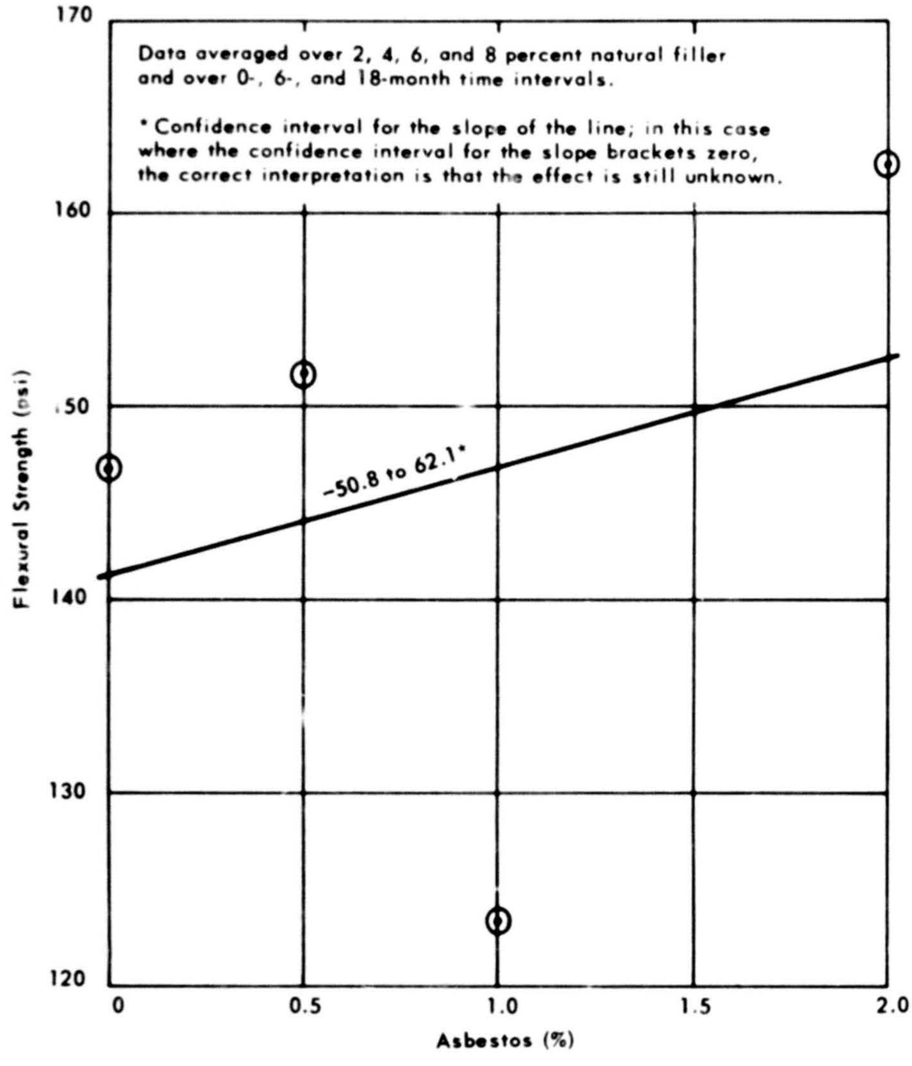

Figure 7. Flexural strength of asphaltic concrete versus percent asbestos.

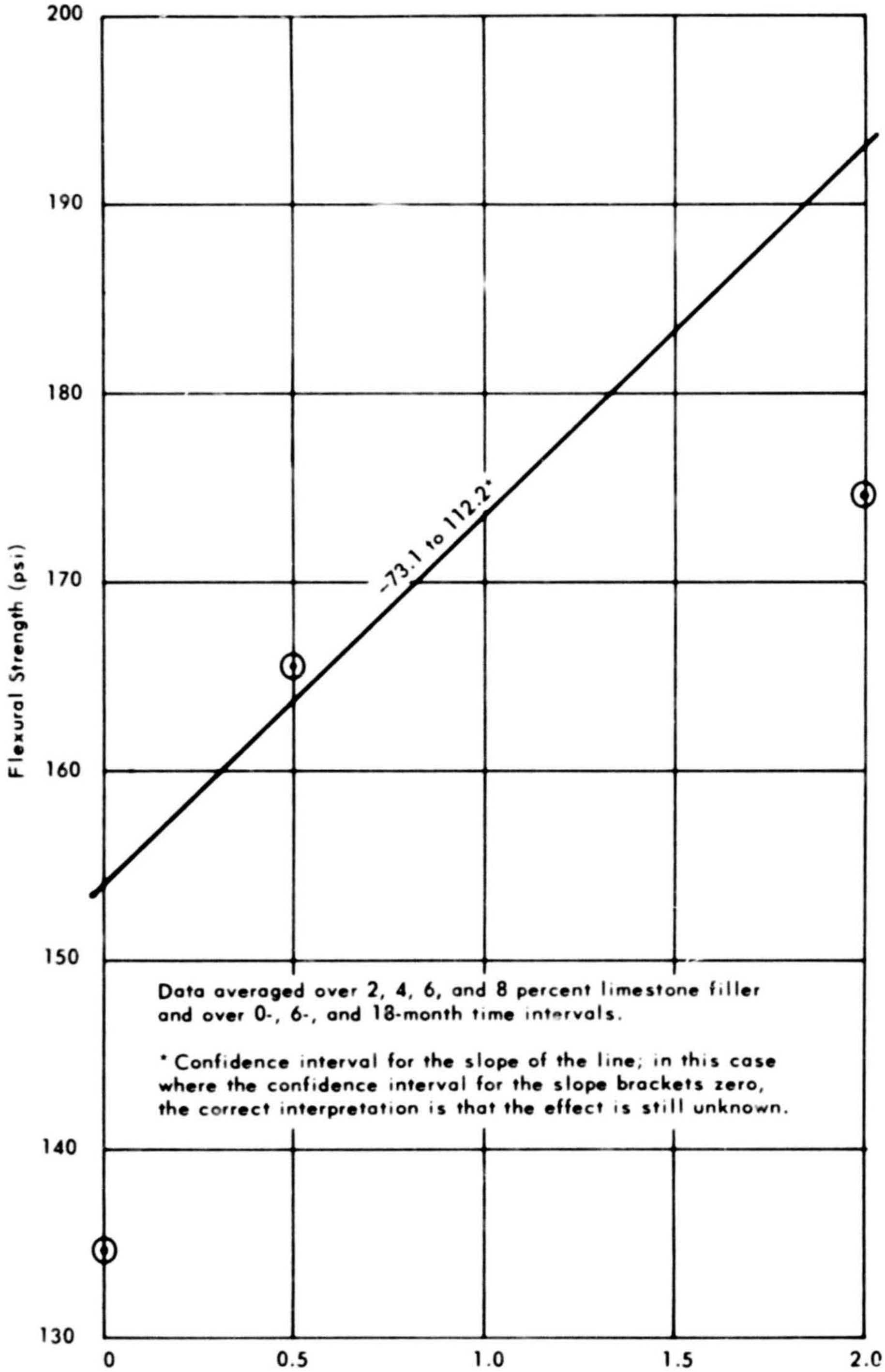

Figure 8. Flexural strength of asphaltic concrete versus percent asbestos.

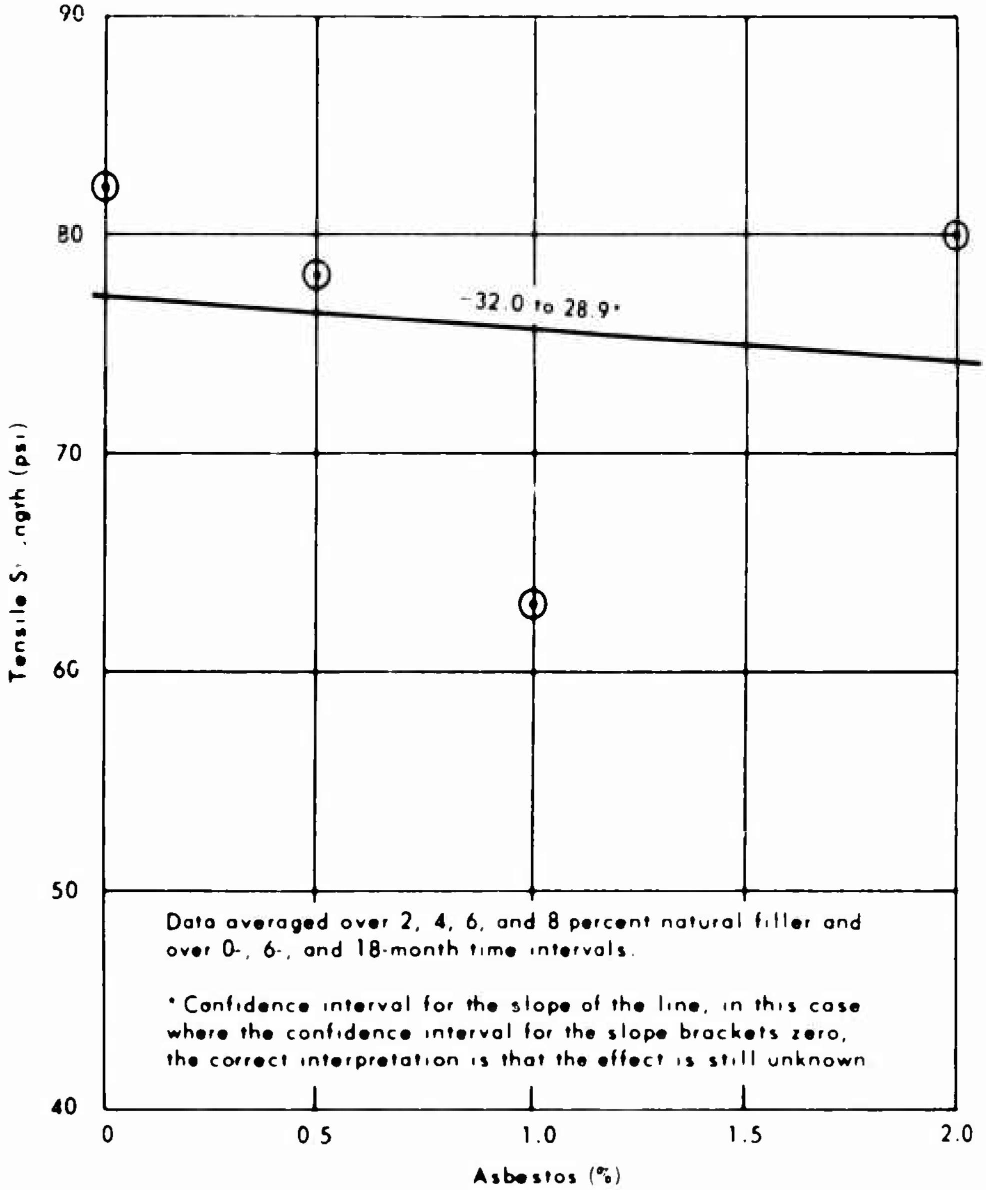

Figure 9. Tensile streng.ı of asphaltic concrete versus percent asbestos.

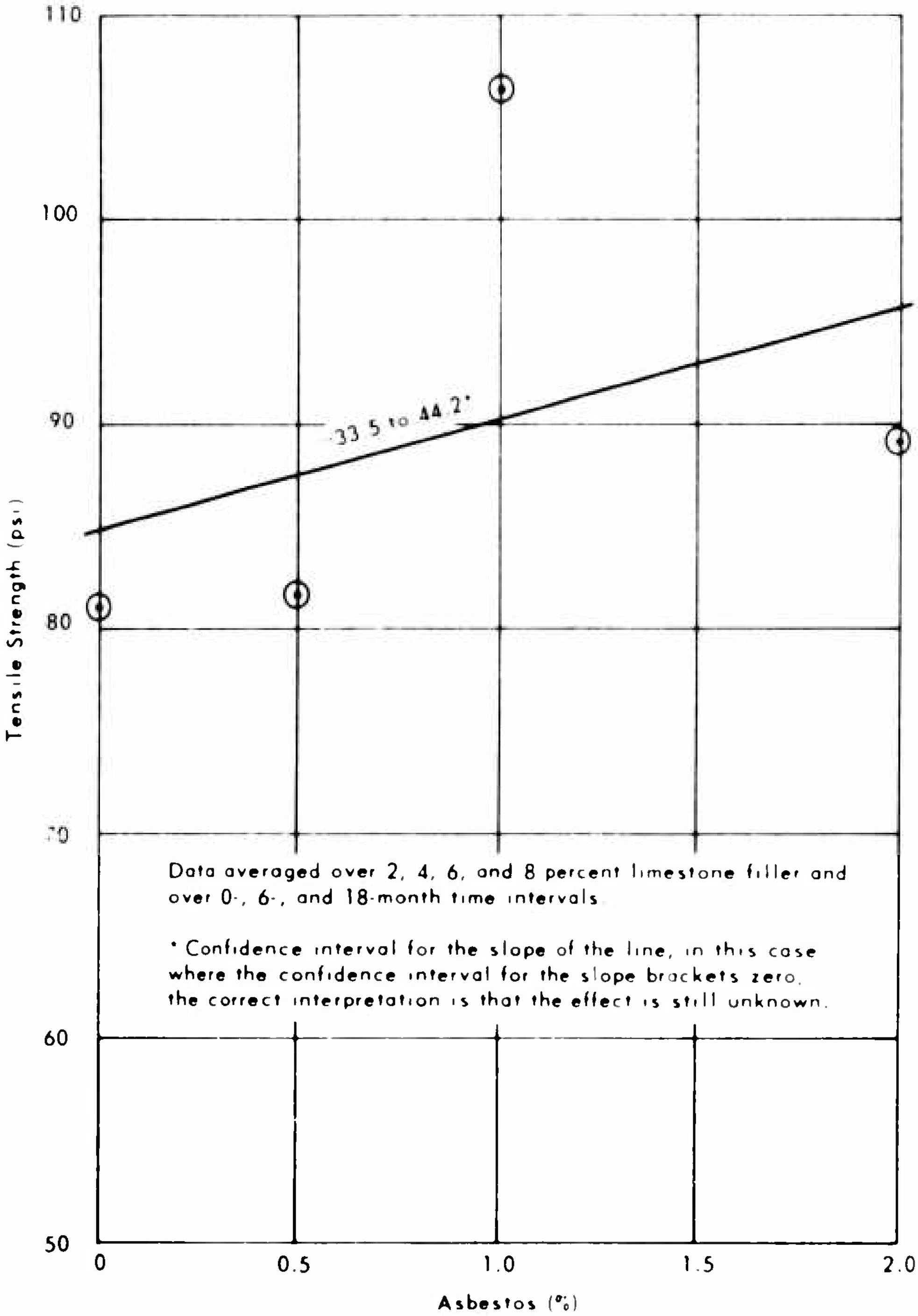

Figure 10. Tensile strength of asphaltic concrete versus percent asbestos.

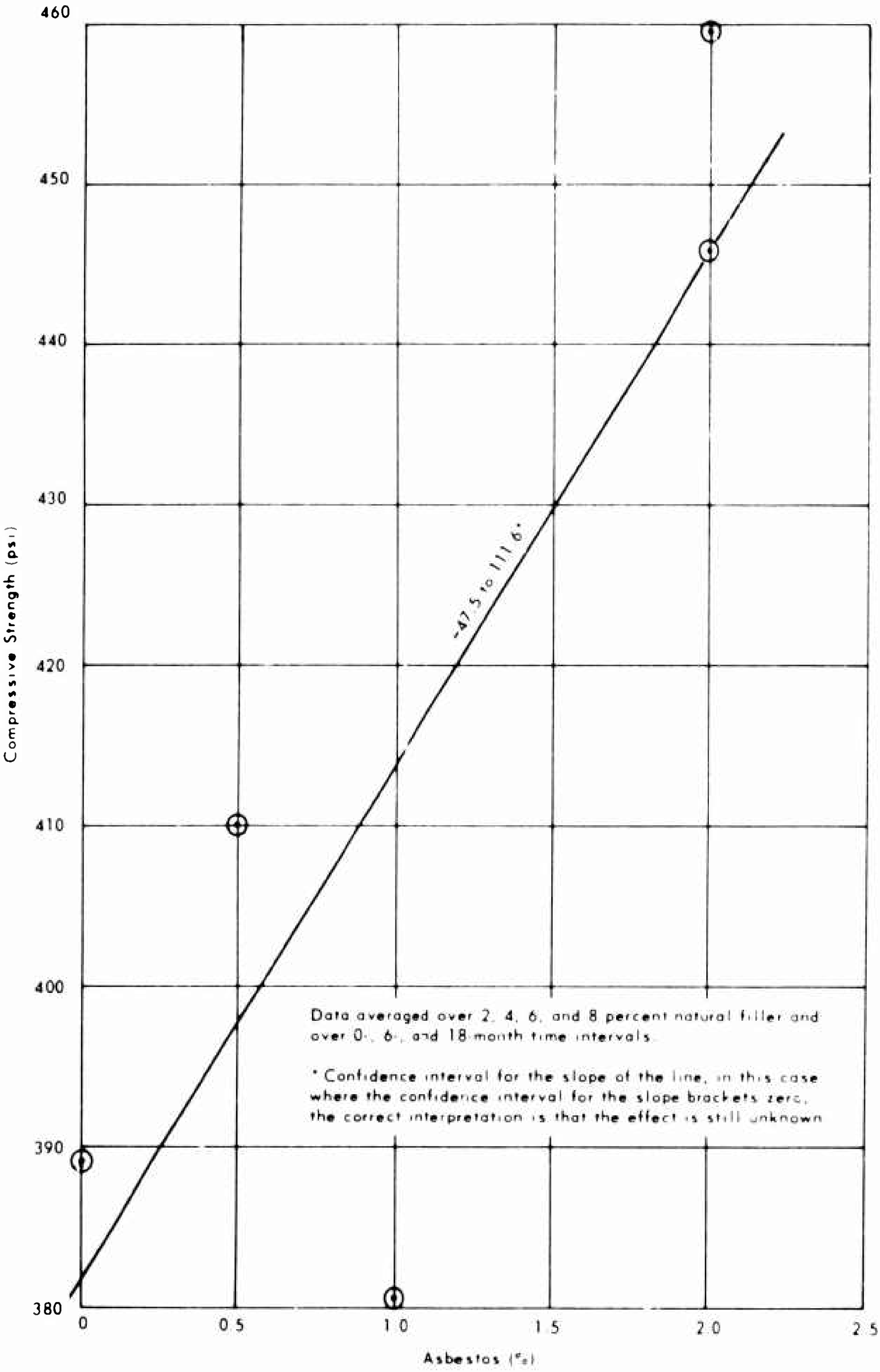

Figure 11. Compressive strength of asphaltic concrete versus percent asbestos.

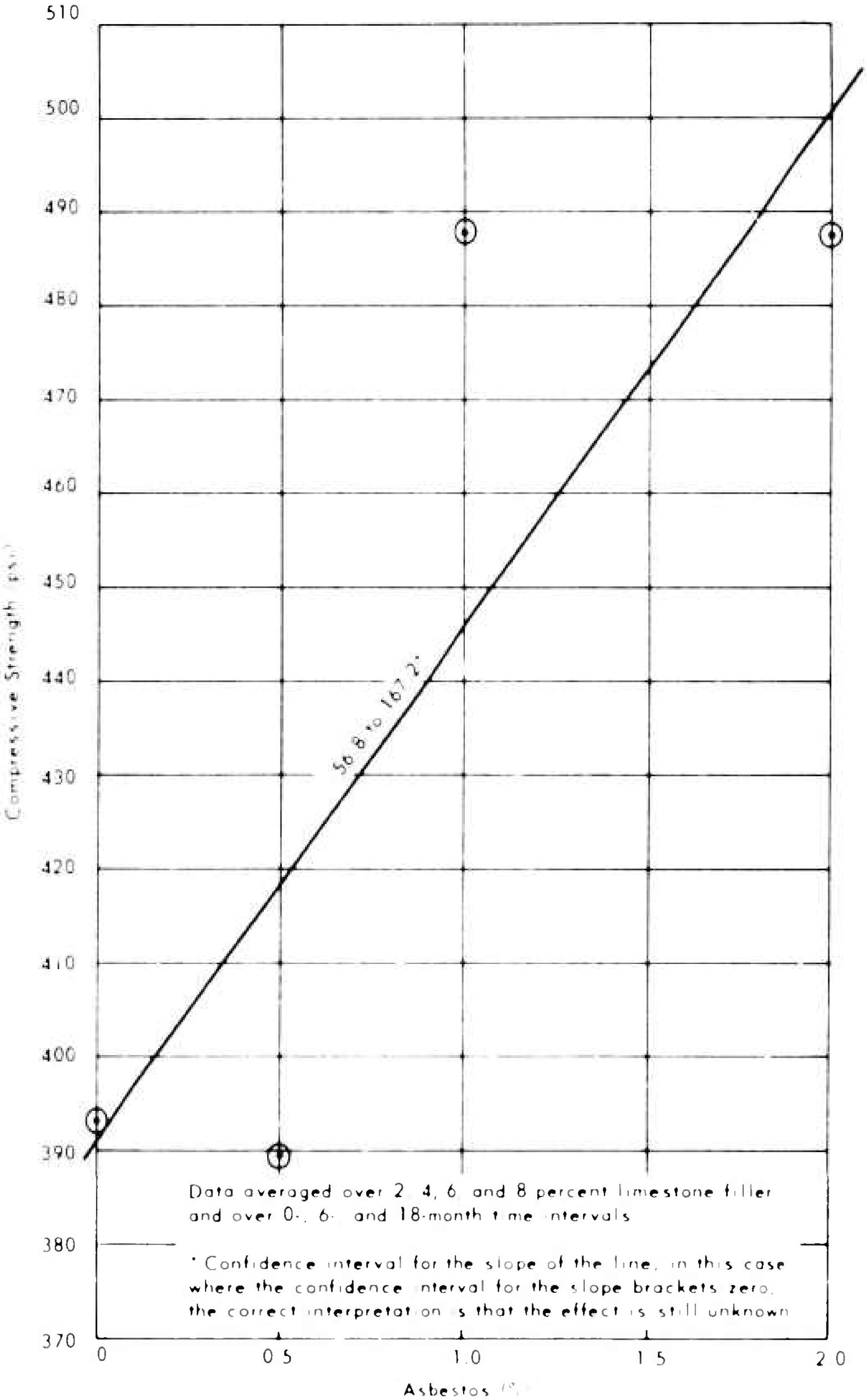

Figure 12. Compressive strength of asphaltic concrete versus percent asbestos.

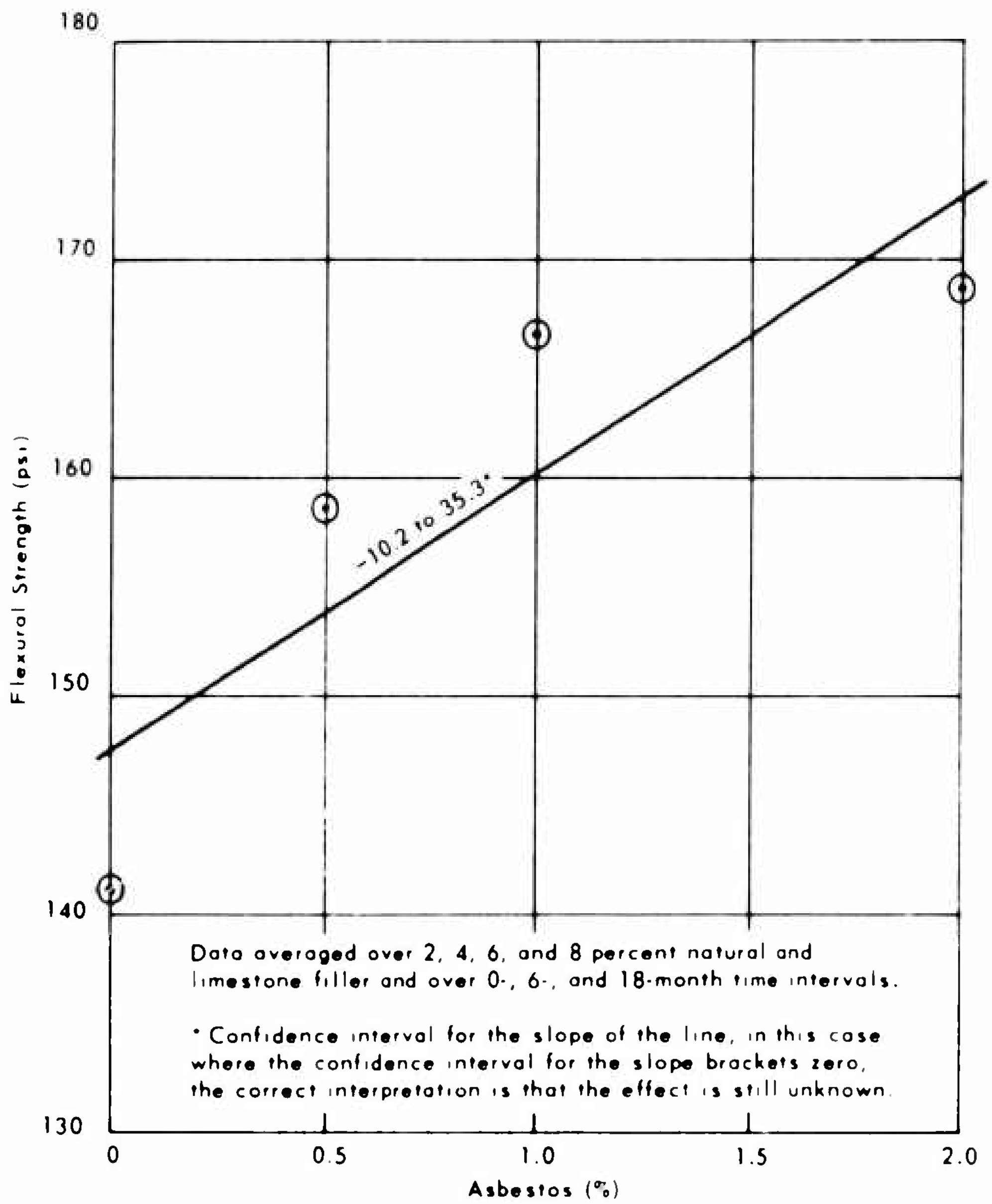

Figure 13. Flexural strength of asphaltic concrete versus percent asbestos.

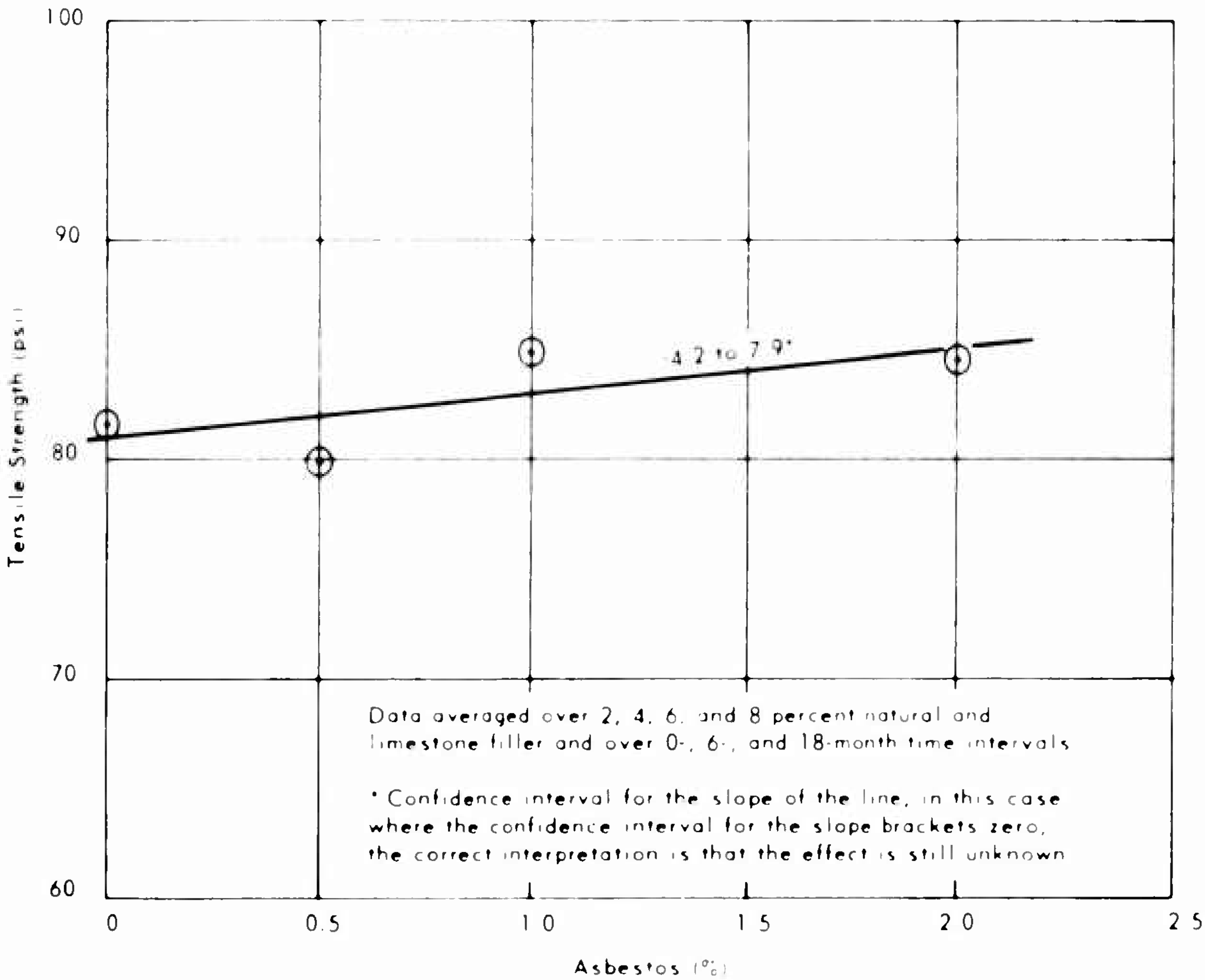

Figure 14. Tensile strength of asphaltic concrete versus percent asbestos.

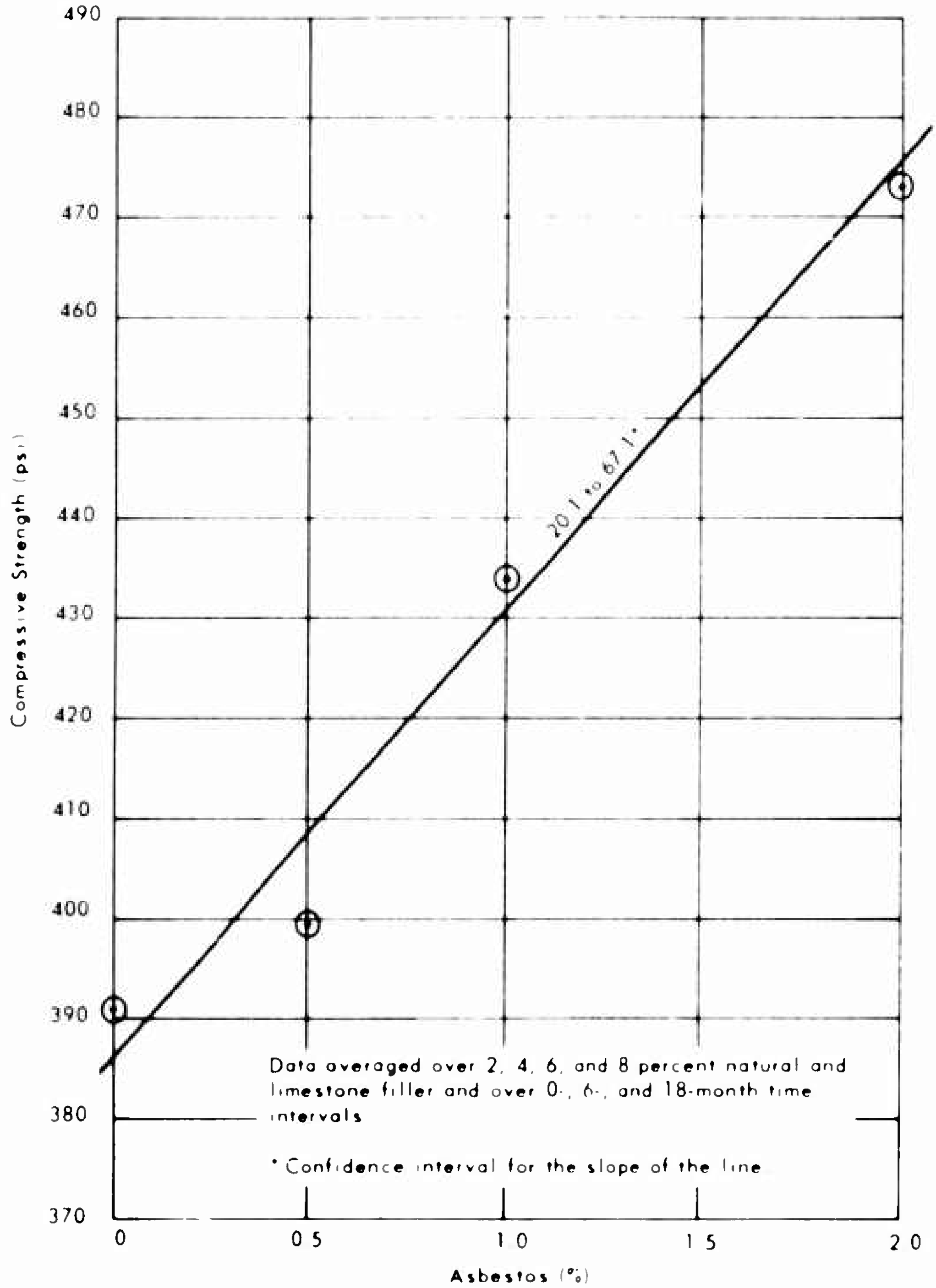

Figure 15. Compressive strength of asphaltic concrete versus percent asbestos.

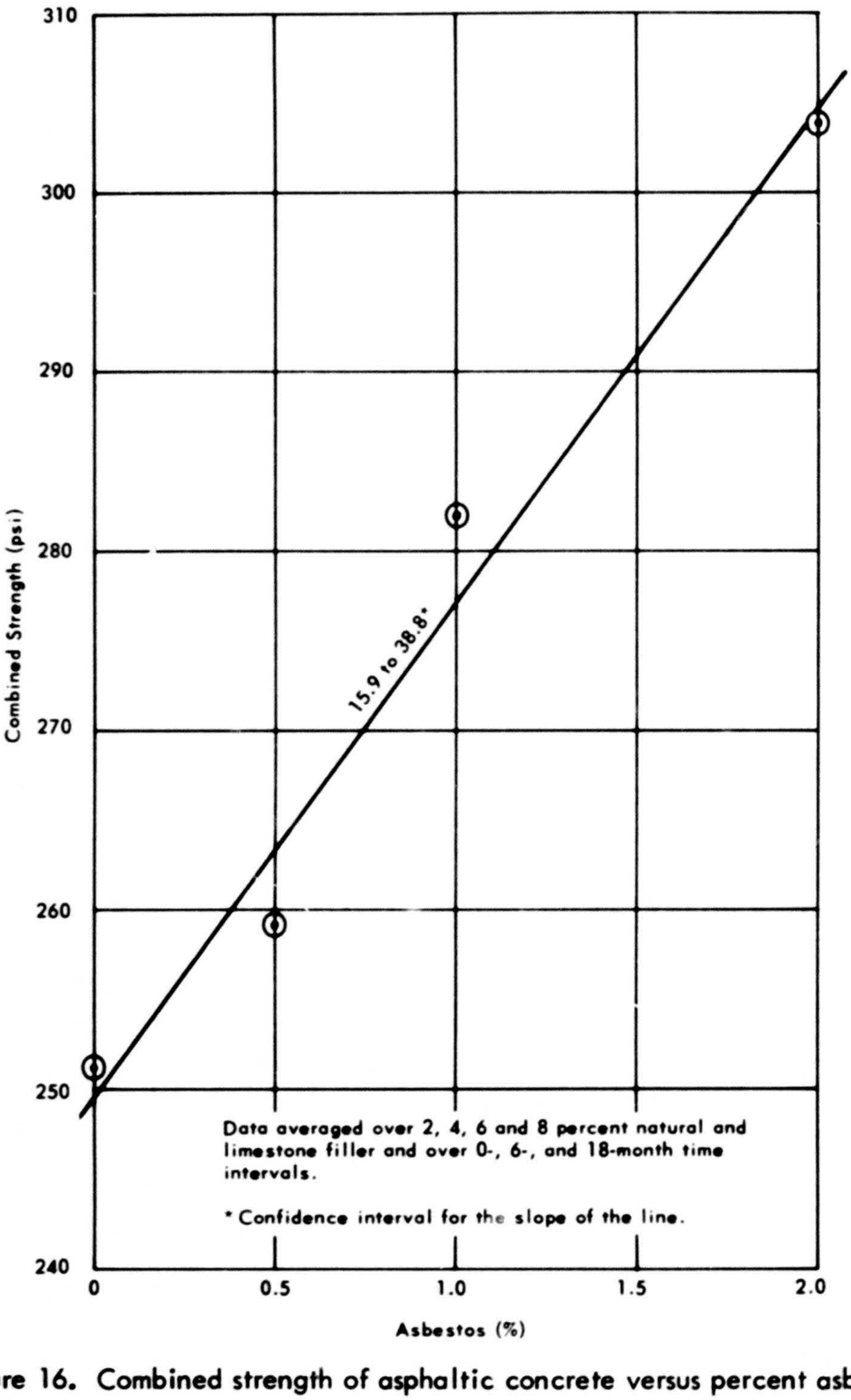

Figure 16. Combined strength of asphaltic concrete versus percent asbestos.

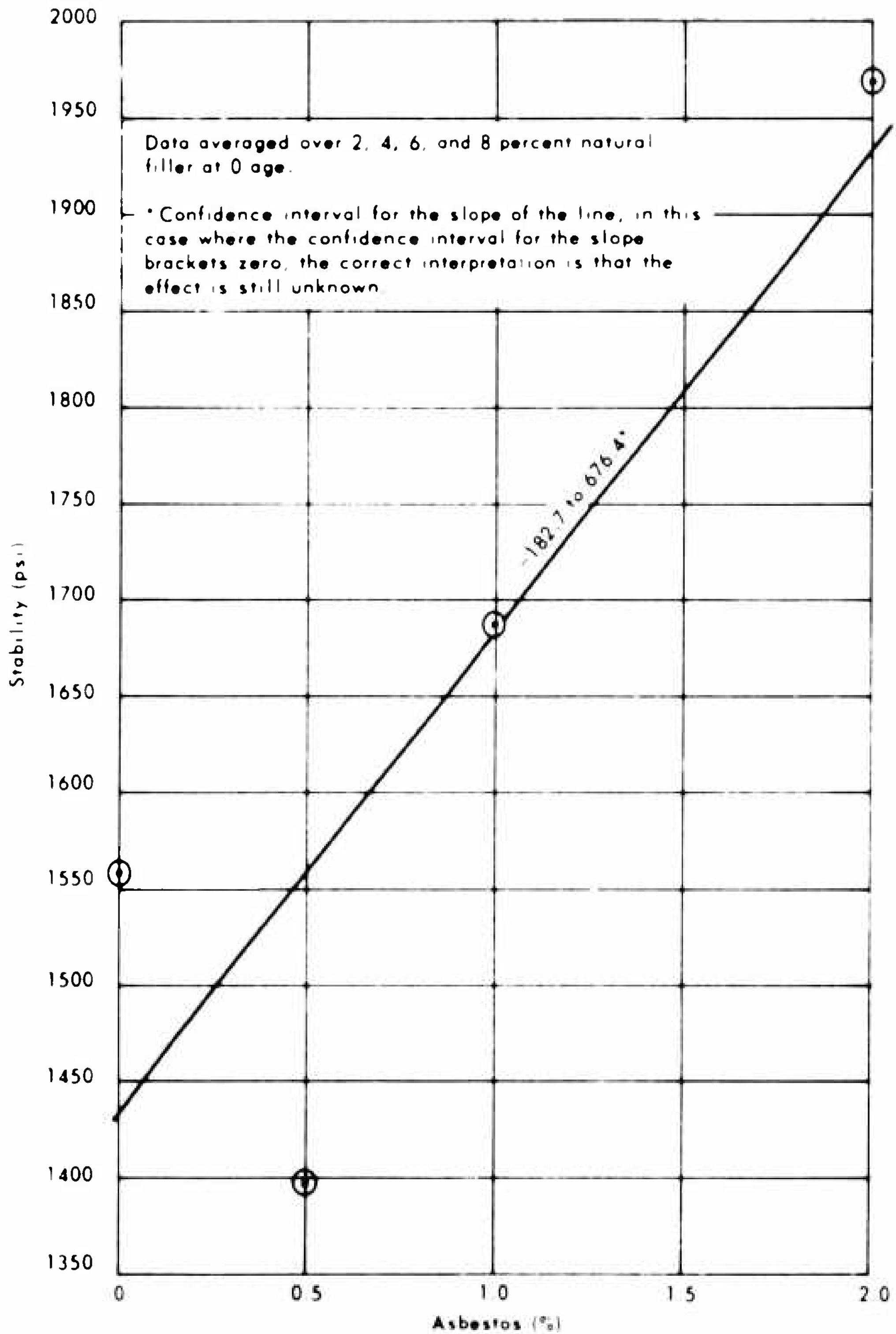

Figure 17. Marshall stability versus percent asbestos.

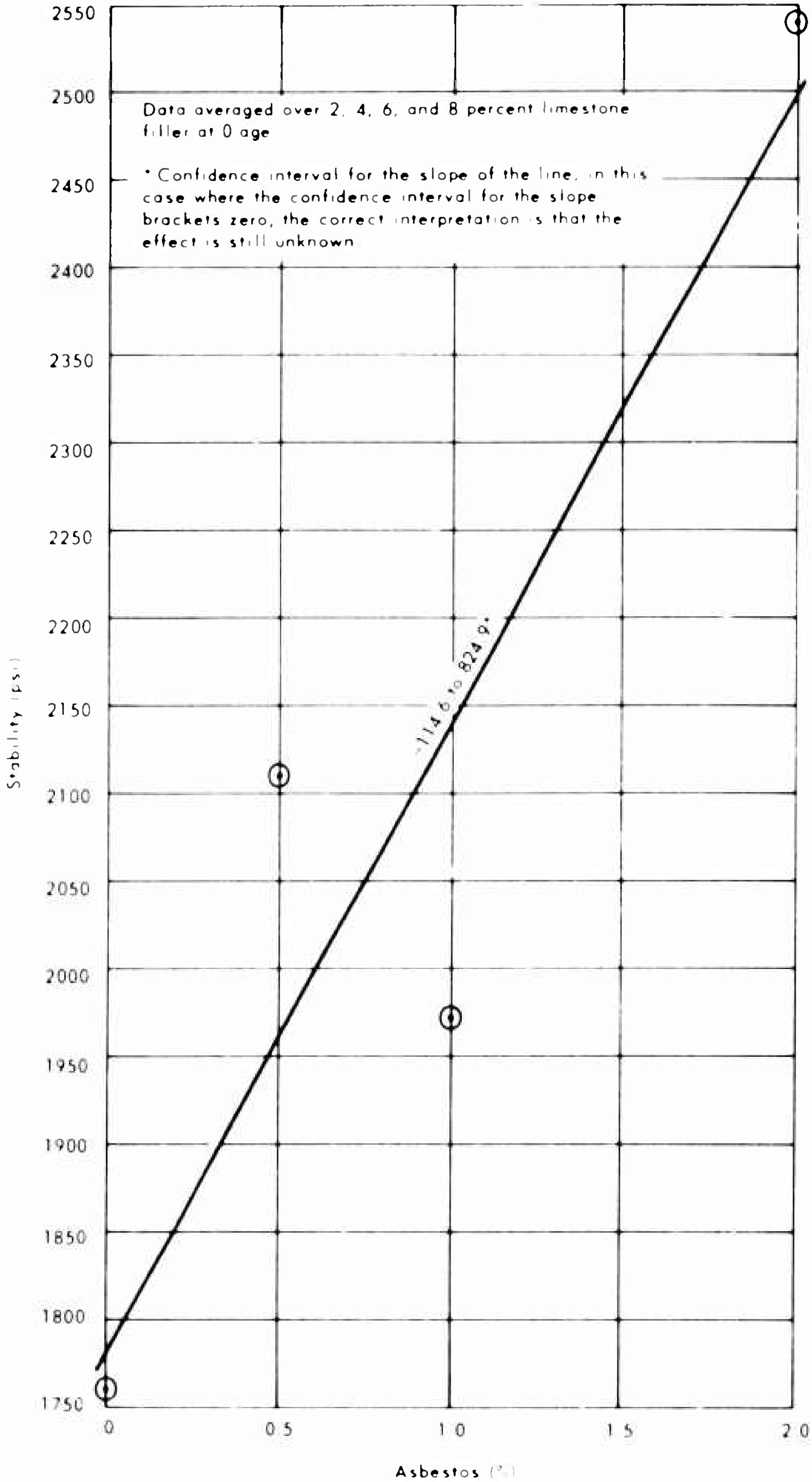

Figure 18. Marshall stability versus percent asbestos.

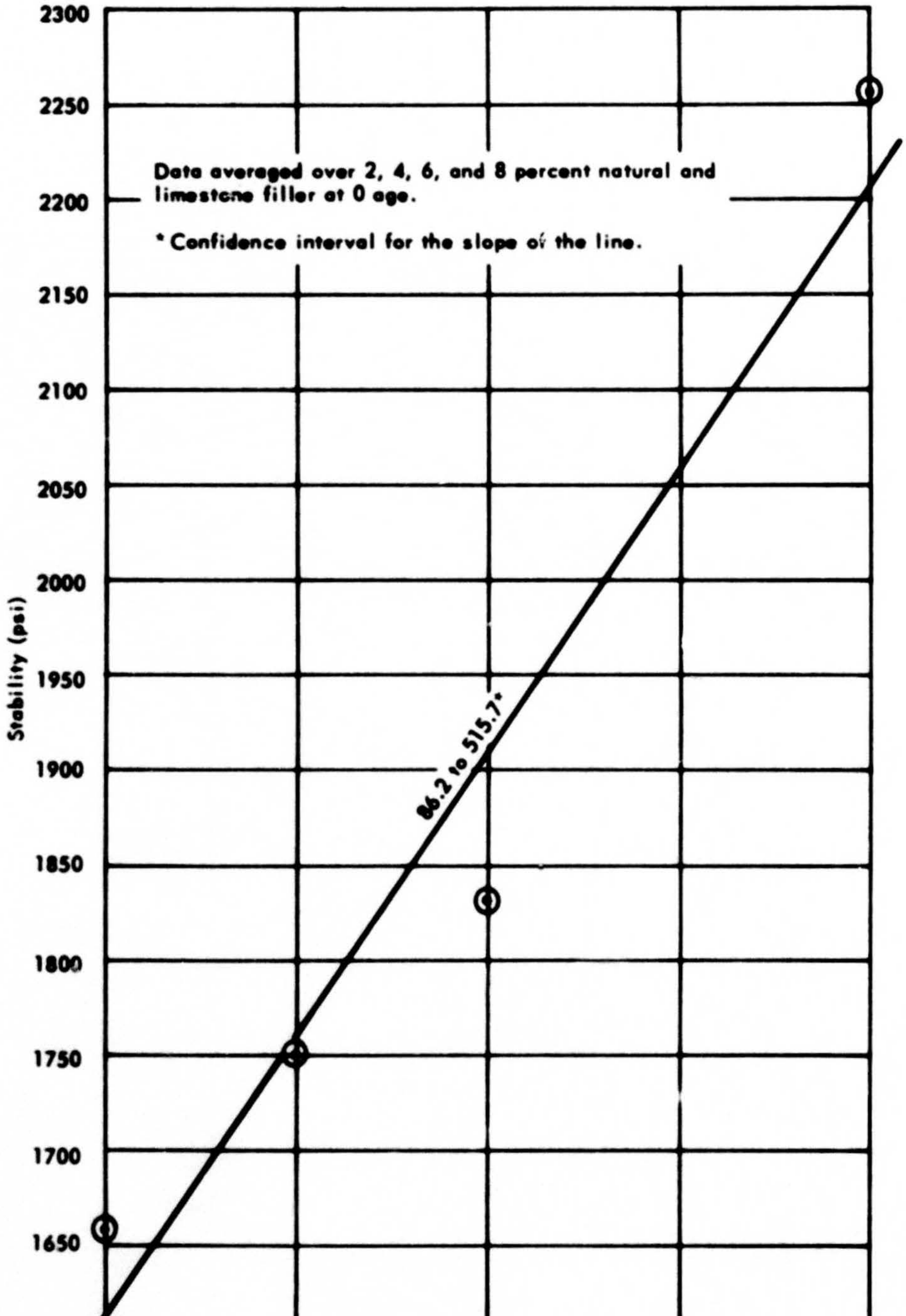

Figure 19. Marshall stability versus percent asbestos.