A STUDY OF FAULTED JOINTS ON PORTLAND CEMENT CONCRETE PAVEMENTS ON IOWA PRIMARY HIGHWAYS

By

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Background

Many years ago faulted joints were recognized by Highway Engineers as a form of pavement distress which could substantially reduce pavement serviceability. Faulted joints can have many effects on the highway user ranging from riding discomfort to a safety hazard. As a result, considerable research has been done on the cause, physical action, and effect of joint faulting. A brief explanation of faulting is given in Appendix "A".

Purpose

No attempt will be made in this report to confirm or refute any research undertaken in the past. The report will, however, attempt to indicate the magnitude of joint faulting on Iowa's Primary Roads and recommendations will be made as to the validity of our present design standards for jointed pavements with or without load transfer devices in the transverse contraction joints.

Present Design Rationale

Design Standards presently used in Iowa require load transfer devices at 20 foot spaced contraction joints when design year (20 yr.) truck traffic equals or exceeds 500 trucks per day. In addition, if design year truck traffic exceeds 1,000 trucks per day, a 4 inch subbase is required in addition to the load transfer devices. No differentiation is made between designed pavement thickness with respect to load transfer devices. In other words no structural advantage is allowed for load transfer devices in pavement thickness design. This is legitimate because there is no reinforcing in the area between the joints. Subbase does contribute to the entire pavement structure as well as the joints and as a result may allow a slightly thinner pavement when it is specified. It should be noted here, however, that very conservative values are assigned to subbases in Iowa pavement designs. The Portland Cement Association Method for concrete pavement design is used in Iowa.

Project Selection and Sampling

This report is based on a sample of 55 P.C. Concrete Pavement projects covering 406.4 miles located in all parts of the State (Figure 1). All projects were constructed after 1959 and before 1975. The projects vary in length from 2.32 miles to 15.99 miles. Truck traffic on the projects varies from 67 trucks per day to 884 trucks per day. Pavement thickness on these projects is as follows: one project at 7 inches; eight projects at 8 inches; nineteen projects at 9 inches; and twenty-seven projects at 10 inches.

The most important criteria for project selection was location. An attempt was made to insure selection of projects that were representative of all areas, soil types, and climates in the State. There are fewer projects located in North-central Iowa because fewer projects were constructed in this area between 1959 and 1975.

Some consideration was given to truck traffic in project selection. This was done so that a large number of projects would not be high traffic or low traffic roads.

There was no attempt made prior to selection to ascertain whether a project may or may not have been constructed with subbase and/or load transfer devices. It was known, however, that load transfer devices were not specified for projects built before 1968 or 1969. As it turned out, only one project had load transfer devices and fourteen projects had 4 inch granular subbase.

Because of the large number of miles to be inspected and time limitations, a method of selecting random samples within a project was necessary. On projects two miles or less in length, one section was selected. On projects seven miles or less in length, two sections were selected. On projects seven miles or longer, three sections were selected. There are some exceptions to this rule but generally this criteria was followed. Most sections were between 0.2 miles and 0.65 miles in length. The sections were tied to Mile Posts whenever possible so that they could be re-established at a later date if desired. The sections were selected before the project was inspected to reduce location prejudice. Three investigators worked two at a time to inspect all sections. For continuity, one of the three people inspected every section.

Faulting Criteria

After project sections were selected for a particular project, each joint in a section was inspected, measured and counted either as flat or faulted. The number of each was recorded. There had to be 1/8 inch differential between the two slabs at the joint to qualify as a faulted joint. Joints where the differential was 1/4 inch or more were also tabulated. All data collected are shown on Figure 2.

Data

When the field inspection was completed, truck traffic for each section was obtained from the "Volume of Traffic on the Primary Road System - 1974". This information is included on the tabulation of data (Figure 2). In addition, an attempt was made to determine from "As Built" plans whether the sections had selected soil subgrade treatments. Information was somewhat sketchy and incomplete in this area.

Data Analysis

Probably the most obvious fact to emerge from the study is, that of the 55 projects inspected, 54 exhibited faulted joints to some extent. The only project on which no faulted joints existed was built in 1974. By extrapolation this would indicate that joint faulting exists to some extent on 98% of our jointed, non-reinforced, concrete pavements. In addition, a weighted average indicates that 41.6% of the joints in the entire sample are faulted with 14.9% of the joints faulted in excess of 1/4 inch.

Personal observations of this writer have been that when joint faulting is evident, normally the integrity of the joint seal has been lost. There is some question, however, whether the joint seal fails prior to faulting or as result of the pumping action which takes place as faulting occurs. Certainly once the joint seal fails, surface water has better access to the subgrade through the joint which would enhance the potential for pumping action.

By plotting trucks per day against percent of joints faulted for each pavement thickness, it is possible to see the effect of truck traffic on a pavement with respect to joint faulting. Figures 3, 4, and 5 represent the projects with 8, 9 and 10 inch pavement thickness. The figures along the left side indicate the percentage of sections with that pavement thickness which have faulted joints at that particular truck traffic per day. For example, in Figure 5, at 300 trucks per day, 22.4% of the sections have faulted joints while at 500 trucks per day 58.6% of the sections have faulted joints.

By comparing Figures 3, 4, and 5 it can be seen that the thinner the pavement, the higher the percentage of faulted joints for a given truck traffic.

The points that are shaded in represent those sections that have a 4 inch granular subbase. As is obvious, there does not appear to be any pattern which would indicate this subbase inhibited joint faulting.

Figures 6, 7, and 8 show age plotted against percent of joints faulted for each pavement thickness. The only information to be gained here is that many pavements have faulted joints well before they have been in service 10 years. This means that there is a form of distress in our pavements before half of their expected life is used up.

Examination of Figure 1 indicates that most of the severe faulting (based on percentages) occurs in the south, the west, and easterly areas of the State. It should be noted that the majority of the subgrades in these areas of the State are constructed of loess soils or silty clays. If subgrade treatments were used, it is usually only in the cut sections. Most of these subgrades would have been built with moisture and density control in the top two or three feet of the subgrade.

The fact that fewer projects have required reconstruction in north-central Iowa may be in part due to the ready availability of glacial till for selected subgrade treatments or entire embankments. Glacial till is considered the most ideal subgrade material available in Iowa. It can be compacted to relatively high densities

(115 - 130 lbs/cu. ft.) which reduce capillarity and hence frost heave potential.

Conclusions

The data collected in this study indicates that most jointed, non-reinforced concrete pavements on Iowa's Primary Road System have faulted contraction joints. Certainly the data also indicates that the daily volume of truck traffic is a contributing factor. Because most of Iowa's soils are not particularly well suited for highway embankment construction, these soils are also a contributing factor in joint faulting. Pavement, like most other products exposed to the elements and other external forces (traffic), tends to deteriorate with age and so this then also becomes a contributing factor in joint faulting.

Over the years on roads with low to moderate traffic, Iowa design has depended primarily on aggregate interlock at the contraction joints for good joint performance. However, with a seasonal temperature range of up to 100° F. and 20 foot contraction joint spacing, this rationale is somewhat unsound. Considering the 100° F. temperature range, in order to maintain aggregate interlock, contraction joint spacing would have to be 8 feet to 9 feet.

There is always the question of how bad is bad? At what point are faulted joints considered a discomfort or a hazard to traffic?

Brokaw[1] in his research on plain, non-reinforced pavements in Iowa, Wisconsin, Minnesota, and North Dakota, indicates that when joint faulting exceeds 1/4 inch it is objectional to the road user, and especially to trucks. Have we any pavements which have failed or become extremely objectional because of faulted joints? Yes. The most classic example which comes to mind was U.S. 30 in Benton and Linn Counties. Several years ago the joint faulting became so severe that an attempt was made to break and seat the 20 foot pavement panels prior to resurfacing. There are other examples, such as the Walcott interchange on I-80 in Scott County, where the ramps had to be resurfaced because of excess joint faulting due to high truck traffic.

Considering we cannot change the traffic, soils, climate and aging process, what are the alternatives available to reduce the potential for joint faulting? There are three which can be considered and they are as follows: 1. Thicker pavement sections; 2. Subbases; 3. Load transfer devices (C-D Joints).

Thicker pavement sections reduce deflections due to loads and thereby inhibit the pumping action necessary for faulting to occur.

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[1] M. P. Brokaw, Performance and Design of Concrete Pavement, Without Dowels and Distributed Reinforcement, As Related to Serviceability and Roughness at Traverse Joints.

Subbases essentially act in the same manner as thicker pavement sections in that they add to the pavement structure to reduce deflections. They may be less subject to erosion from pumping than would be a soil subgrade.

Load Transfer Devices (C-D joints) reduce pavement deflections at the joint which inhibits the pumping action necessary for faulting. They also inhibit curling of the pavement at the joints which may be contributing to faulting.

Of course, all three or any two of these alternatives may be used in combination. We presently use the latter two in our designs for high traffic Primary Roads.

<u>Recommendations</u>

The following are recommended changes to present pavement design standards:

1. When it is determined that P.C. Pavement thickness should be 10 inches, then load transfer device should be specified when design year (20 yr.) truck traffic is 300 or more per day.
2. When it is determined that P.C. Pavement thickness should be 8 inches to 9½ inches, then load transfer devices should be specified when design year (20 yr.) truck traffic is 250 or more per day.
3. Subbase should be specified when design year (20 yr.) truck traffic equals or exceeds 1,000 per day.

4. Contraction joint design should be revised and the joint filler material upgraded.

These recommendations are based on the data in this report and especially that shown in Figures 3, 4 and 5. These figures give some indication of the potential faulting which could be eliminated if load transfer devices are used for the levels of truck traffic indicated in the above recommendations.

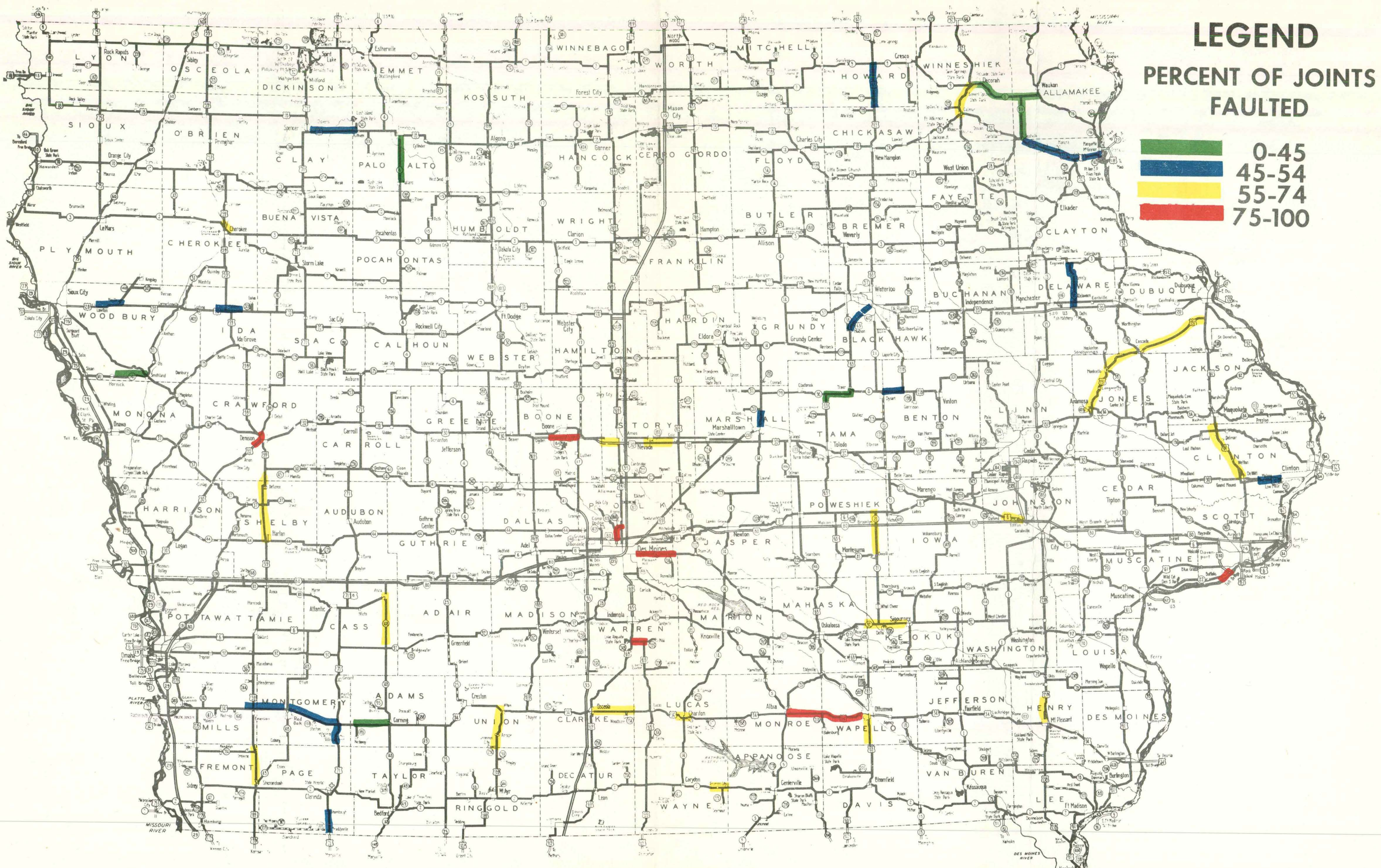


FIGURE 1 PROJECT LOCATION

PAVEMENT THICKNESS (INCHES)	CONCRETE CLASS	COUNTY ROUTE	LOCATION	PROJECT NUMBER	YEAR BUILT	AGE (1976 YEARS)	PROJECT LENGTH (MILES)	SURVEY LENGTH	OBSERVED SECTIONS: FAULTS					1974 TRAFFIC		DESIGN TRUCK TRAFFIC		SUBGRADE TREATMENT ON PROJECT	ANY SUBBASE ON PROJECT	REMARKS
									FLAT	LESS THAN 1/4"	MORE THAN 1/4"	% LESS THAN 1/4"	% MORE THAN 1/4"	TOTAL TRAFFIC (V.P.D.)	TRUCK TRAFFIC (T.P.D.)	PROGRAM YEAR	DESIGN YEAR (20)			
10"	C	BLACK HAWK U.S.63	FROM IA 412 N.E. TO RANDALL ST.	FU-63-6(8)	1968	8YRS	4.006 MI.	.45 MI. .55 MI.	82 99 181	39 19 58	22 13 35	27.2 14.5	15.3 9.9	5560 4650	591 575	272	452	NO	NO	
10"	C	BLACK HAWK U.S.63	1/2 MI. SOUTH OF HUDSON N.E. TO IA 412	F-1119(2)	1961	15 YRS.	5.559 MI.	.43 MI. .45 MI.	67 80 147	30 22 52	12 7 19	27.5 14.5	11 6.4	1980 3960	341 500	153	198	YES	NO	M.&D.
10"	C	BOONE U.S.30	DES MOINES RIVER TO JORDAN CORNER	F-936(7)	1964	12 YRS.	7.776 MI.	.6 MI. .4 MI. .4 MI.	28 29 27 84	33 54 53 140	34 29 34 97	34.7 48.2 46.4	35.7 25.8 29.8	4270 6400 5900	430 440 530	761	1219	YES	NO	
10"	C	CLAYTON U.S.18	POSTVILLE EAST TO GIARD	F-18-9(2)	1966	10 YRS.	14.409 MI.	.45 MI. .3 MI. .4 MI.	79 54 86 219	19 29 18 66	14 37 13 64	16.9 24.1 15.3	12.5 30.8 11.1	3640 1740 1810	682 451 470	235	364	NO	NO	
10"	C	CLINTON U.S.30	FROM MALONE EAST TO IA. 291	F-30-9(2)	1969	7 YRS.	4+ MI.	.4 MI. .4 MI.	77 63 140	24 33 57	0 6 6	21.6 32.3	5.8	3510 3660	769 765	859	1317	NO	NO	
10"	C	CLINTON U.S.61	FROM DEWITT, NORTH TO JACKSON CO. LINE	F-292(2)	1961	15 YRS.	15.99 MI.	.4 MI. .4 MI.	48 29 77	27 20 47	23 23 46	27.5 27.7	23.4 31.9	4270 4290	761 761	253	408	NO	NO	M.&D.
10"	C	CRAWFORD U.S.30	2.3 MI. S.W. OF DENISON N.E. TO JCT. 30, 141, 59	F-232(10)	1962	14 YRS.	2.35 MI.	2.35 MI.	65	60	52	33.8	29.3	3205	524	950	950	NO	NO	M.&D.
10"	C	CRAWFORD U.S.30	N. JCT. U.S.30 IN DENISON N.W. 2.6 MI.	F-59-5(3)	1967	9 YRS.	3.436 MI.	1.8 MI.	39	70	55	42.6	33.5	2700	330	517	661	NO	NO	
10"	C	HENRY U.S.218	FROM U.S.34 IN MT. PLEASANT N. 5.2 MI.	F-218-2(2)	1968	8 YRS	5.044 MI.	.35 MI. .4 MI.	62 58 120	30 41 71	7 11 18	30.3 34.3	7 9.1	3750 3250	373 390	491	741	YES	NO	M.&D.
10"	C	IDA U.S.20	E. LIMITS OF HOLSTEIN WEST APP. 4 MI.	F-248(5)	1964	12 YRS.	3.899 MI.	.55 MI. .4 MI.	104 55 159	33 24 57	13 33 46	22 18.1	8.6 25	2170 1710	312 433	281	449	YES	YES	M.&D.
10"	C	IDA U.S.20	E. LIMITS OF HOLSTEIN E. .2 MI.	F-445(3)	1964	12 YRS.	5.708 MI.	.4 MI. .25 MI.	69 43 112	16 14 30	15 11 26	16 20.5	15 16.1	2890 1670	536 413	281	449	YES	YES	M.&D.
10"	C	JONES U.S.151	ANAMOSA TO MONTICELLO	FN-86	1960	16 YRS.	10.27 MI.	.4 MI. .45 MI. .25 MI.	44 77 31 122	21 27 11 59	30 17 18 65	22.1 22.3 18.3	31.5 14 30	4130 4200 4180	409 520 530			YES	NO	M.&D.
10"	C	DUBUQUE-JONES U.S.151	MONTICELL TO CASCADE	FN-86(3)	1960	16 YRS.	9.69 MI.	.2 MI. .5 MI. .4 MI.	14 59 60 135	13 12 21 46	15 35 22 72	29.5 13.9 20.3	34 41 21.3	4560 2450 3260	498 493 489	274	439	YES	NO	M.&D.
10"	C	KEOKUK IA. 92	MAHASKA CO. LINE E. TO SIGOURNEY	F-34(5)	1963	13 YRS.	10.117 MI.	.3 MI. .3 MI. .3 MI.	39 41 41 121	25 34 47 106	13 11 3 27	32.4 39.5 51.6	16.8 12.7 3.2	1760 1570 1720	203 158 158	226	385	YES	NO	M.&D.
10"	C	LUCAS U.S.34	1/2 MI. W. OF CHARITON TO 1 MI. E.	F-63(15)	1960	16 YRS.	3.388 MI.	.5 MI.	58	34	16	31.4	14.8	2093	288	135	250	YES	NO	M.&D.
10"	C	MARSHALL IA. 14	MARSHALLTOWN NORTH 2.5 MI.	F-14-5(5)	1967	9 YRS.	2.471 MI.	.4 MI.	70	25	16	22.5	14.4	6505	457	745	964	YES	NO	M.&D.
10"	C	MONROE U.S.34	IA. 60 EAST TO WAPELLO CO. LINE	F-1027(8)	1964	12 YRS.	8.904 MI.	.4 MI. .4 MI.	33 37 70	46 40 86	27 29 56	43.3 37.7	25.4 27.3	3270 2560	285 267	114	182	YES	YES	M.&D.
10"	C	POLK IA. 163	3 MI. E PLEASANTHILL CORP. LIMITS E. TO JASPER CO. LINE.	F-216(8)	1964	12 YRS.	5.658 MI.	.55 MI. .7 MI.	44 30 74	58 45 103	19 67 86	47.9 31.6	15.7 47.1	4550 5110	868 884	366	567	NO	YES	M.&D.
10"	C	POLK IA. 415	PINE HILL DR. TO IA. 160	F-132(8)	1961	15 YRS.	2.488 MI.	.35 MI. .2 MI.	16 19 35	34 31 65	31 20 51	41.9 44.2	38.2 28.5	13,120 5470	495 177	501	602	YES	NO	M.&D.
10"	C	POWESHIEK IA. 21	DEEPRIVER TO U.S.6	F-1032(4)	1963	13 YRS.	11.405 MI.	.35 MI. .25 MI. .35 MI.	40 41 56 137	40 21 28 89	0 6 1 7	50 30.8 32.9	8.8 1.1	1300 1390 620	194 238 105	109	176	YES	NO	
10"	C	SCOTT IA. 22	S. CORP LIMITS OF DAVENPORT TO U.S.61	FU-221(1)	1961	15 YRS.	3.138 MI.	.35 MI. .2 MI.	48 20 68	27 49 76	23 25 48	27.5 52.1	23.4 25.5	3620 3860	522 535	651	1071	YES	NO	M.&D.

FIGURE 2

Pavement Thickness (Inches)	Concrete Class	County / Route	Location	Project Number	Year Built	Age (1976 Years)	Project Length (Miles)	Survey Length	Observed Sections: Faults: Flat	Less than 1/4	More than 1/4	% Less than 1/4	% More than 1/4	1974 Traffic: Total Traffic (V.P.D.)	Truck Traffic (T.P.D.)	Design Truck Traffic: Program Year	Design Year (20)	Subgrade Treatments on Project	Any Subbase on Project	Remarks
10"	C	Story U.S.30	1 Mi. W. Co. Rd. S-14 E. to .105 Mi. W. U.S. 65	F-FG-1065(15)	1964	12 yrs.	8.715 mi.	.5 mi. .6 mi. .45 mi.	38 45 49 132	60 72 42 174	38 16 23 77	44.1 54.1 40.3	27.9 12 22.1	5040 4950 3250	621 622 635	373	918	Yes	Yes	M.&D.
10"	C	Wapello U.S.34	Monroe Co. East to Ottumwa	F-1027(9)	1961	15 yrs.	8.894 mi.	.45 mi. .4 mi.	42 37 79	47 40 87	37 31 68	37.3 37	29.3 28.7	2930 4960	275 312	160	264	No	Yes	
10"	C	Wapello U.S.63	Davis Co. North to Ottumwa	F-42(7)	1965	11 yrs.	4.18 mi.	.45 mi. .45 mi.	64 58 122	44 46 90	20 14 34	50 38.9	15.6 11.8	4570 5320	480 504	371	581	Yes	No	M.&D.
10"	C	Winneshiek U.S.52	Calmar to Decorah	F-98-(8)	1961	15 yrs.	9.441 mi.	.45 mi. .4 mi. .45 mi.	54 60 61 175	26 26 25 77	26 21 32 79	24.5 24.2 21.1	24.5 19.6 27.1	2720 2440 2340	359 501 601	269	425	Yes	No	M.&D.
10"	C	Woodbury U.S.20	Lawton to Moville	FN-2(2)	1964	12 yrs.	6.007 mi.	.45 mi. .35 mi.	66 60 126	19 10 29	11 11 22	19.7 12.3	11.4 13.5	4610 3990	549 378	591	1029	No	No	M.&D.
10"	C	Woodbury IA.141	Hornick to Smithland	F-1083(3)	1960	16 yrs.	8.353 mi.	.5 mi. .4 mi.	109 89 198	17 15 32	6 7 13	12.8 13.5	4.5 6.3	1390 1290	265 265	79	127	Yes	No	
9"	C	Adams U.S.34	1/2 Mi. W. IA 55 to 1 1/2 Mi. E. of Corning	F-1128(10)	1965	11 yrs.	10+ mi.	.5 mi. .65 mi. .55 mi.	107 123 97 327	21 24 29 74	7 7 18 32	15.5 15.5 20.1	5.1 4.5 12.5	1760 1850 2600	256 352 346	197	303	No	No	
9"	C	Allamakee IA.9	Winneshiek Co. Line to Jct. 13 South of Waukon	F-9-9(2)	1968	8 yrs.	6.586 mi.	.5 mi. .5 mi.	90 110 200	28 18 46	10 3 13	21.8 13.7	7.8 2.2	2095	335	263	407	No	No	M.&D.
9"	C	Allamakee IA.51	3 Mi. N. of Postville N. to IA.9	F-51-1(2)	1967	9 yrs.	7.47 mi.	.5 mi. .5 mi. .5 mi.	63 73 79 215	15 10 13 38	2 5 3 10	18.7 11.3 13.6	2.5 5.6 3.1	1060 1060 1060	139 139 139	168	258	No	No	
9"	C	Clarke U.S.34	Osceola East to Lucas Co.	F-FG-34-5(1)	1966	10 yrs.	10.139 mi.	.55 mi. .5 mi. .5 mi.	70 73 72 215	57 41 40 138	20 6 19 45	38.7 34.1 30.5	13.6 5 14.5	4830 2110 1740	525 439 302	174	256	No	No	
9"	C	Clay U.S.18	Jct. U.S. 71 E. to Palo Alto Co.	F-729(2)	1966	10 yrs.	11.584	.3 mi. .35 mi.	59 70 81 210	17 16 14 47	10 21 16 47	19.7 14.9 12.6	11.6 19.6 14.4	3040 2370 2570	319 275 336	245	337	No	No	
9"	C	Clayton U.S.18	W. Edge of Giard N.&E. to 1.5 Mi. W. of McGregor	F-18-9(4)	1969	7 yrs.	4.099 mi.	.45 mi. .5 mi.	92 89 181	28 18 46	13 19 32	21 14.2	9.7 15	1920 2560	402 382	229	427	No	No	
9"	C	Dubuque U.S.151	Cascade NE. 9.1 Mi.	EF-151-3(14)	1971	5 yrs.	9.579 mi.	.45 mi. .35 mi. .40 mi.	60 56 49 165	25 28 27 80	17 18 28 63	24.5 27.4 25.9	16.6 17.6 26.9	3460 2840 2190	518 433 417	252	436	No	No	
9"	C	Dubuque U.S.151	151 & 61 Inter-S. 8.7 Mi.	EF-151-5(15)	1971	5 yrs.	8.726 mi.	.45 mi. .45 mi. .65 mi.	73 74 73 220	26 24 41 91	27 23 57 107	20.6 19.8 23.9	21.4 19 33.3	2190 2570 2830	417 415 452	234	434	No	No	M.&D.
9"	C	Howard U.S.63	Chickasaw Co. Line N. to IA.9	FN-63-9(1)	1970	6 yrs.	11.48 mi.	.4 mi. .45 mi. .5 mi.	79 70 97 246	37 31 31 99	9 11 13 33	29.6 27.6 21.9	7.2 9.8 9.2	1940 1420 1600	413 340 320	216	320	Yes	No	M.&D.
9"	C	Mills-Montgomery U.S.34	1 Mi. W. U.S. 59 to 1 Mi. W. IA.48	F-1128(6)	1965	11 yrs.	8.891 mi.	.35 mi. .5 mi. .3 mi.	70 87 53 210	23 21 27 71	12 12 6 30	21.9 17.5 31.3	11.4 10 6.9	2280 2160 2480	313 284 304	120	166	No	No	M.&D.
9"	C	Montgomery U.S.30	1 1/2 Mi. E. of Red Oak S.E. to U.S. 71	F-1128(8)	1965	11 yrs.	9.492 mi.	.5 mi. .35 mi. .5 mi.	103 62 93 258	25 23 26 74	12 11 12 35	17.8 29.3 19.8	8.5 11.4 9.1	2310 1160 1700	270 74 242	134	186	Yes	Yes	M.&D.
9"	C	Palo Alto IA.4	Mallard North to Emmetsburg	F-17-5(2)	1967	9 yrs.	10.616 mi.	.45 mi. .5 mi. .5 mi.	97 103 108 308	13 16 15 44	5 6 4 15	11.3 12.8 11.8	4.3 4.8 3.1	1130 1560 2110	158 118 185	239	309	Yes	Yes	M.&D.
9"	C	Shelby U.S.59	1 Mi. S. of Harlan to Co. Rd. F22	FN-59-4(9)	1970	6 yrs.	8.014 mi.	.6 mi. .5 mi. .6 mi.	66 64 70 200	44 40 52 136	33 25 11 69	30.7 31 39	23 19.3 8.2	2800 2410 2030	517 293 391	231	309	No	No	
9"	C	Story U.S.30	Boone Co. E. to 1/2 Mi. W. of State Ave.	F-30-5(17)	1972	4 yrs	1.556 mi.	.5 mi.	72	42	19	31.5	14.2	3930	581	518	1010	Yes	Yes	
9"	C	Tama U.S.63	1/2 Mi. S. Jct. 96 N. to Traer	FN-63-5(7)	1968	8 yrs.	6.803 mi.	.5 mi. .5 mi.	109 113 222	16 17 33	2 1 3	12.5 12.9	1.5 0.7	2130 2260	253 275	242	371	Yes	Yes	

FIGURE 2 (Continued)

PAVEMENT THICKNESS (INCHES)	CONCRETE CLASS	COUNTY / ROUTE	LOCATION	PROJECT NUMBER	YEAR BUILT	AGE (1976 YEAR)	PROJECT LENGTH (MILES)	SURVEY LENGTH	OBSERVED SECTIONS: FAULTS FLAT	LESS THAN 1/4"	MORE THAN 1/4"	% LESS THAN 1/4"	% MORE THAN 1/4"	1974 TRAFFIC: TOTAL TRAFFIC (V.P.D.)	TRUCK TRAFFIC (T.P.D.)	DESIGN TRUCK TRAFFIC: PROGRAM YEAR	DESIGN YEAR (20)	SUBGRADE TREATMENTS ON PROJECT	ANY SUBBASE ON PROJECT	REMARKS
9"	C	UNION U.S. 169	RINGGOLD CO. LINE N. TO AFTON	FN-169-2(1)	1969	7 YRS.	9.469 MI.	.4 MI. .45 MI. .25 MI.	72 62 17 151	15 32 30 77	4 6 25 35	16.4 32 41.6	4.3 6 34.7	830 900 1080	95 85 94	122	167	YES	NO	
9"	C	WARREN U.S. 65	U.S. 69 E TO IA. 205	F-US-3(1)	1967	9 YRS.	3.046 MI.	.65	63	66	25	42.8	16.2	3080	245	326	450	YES	NO	
9"	C	WAYNE IA. 2	APPANOOSE CO. W. 4 3/4 MI.	F-150(5)	1962	14 YRS.	4.818 MI.	.35 MI. .5 MI.	47 52 99	35 29 64	7 8 15	39.3 32.5	7.8 8.9	1500 1650	308 343	290	475	YES	NO	M.&D.
9"	C	WINNESHIEK IA. 9	U.S. 52 E. TO ALLAMAKEE CO.	F-9-8(5)	1968	8 YRS.	11.384 MI.	.4 MI. .5 MI. .45 MI.	83 78 99 260	18 15 20 53	12 13 3 28	15.9 14.1 16.3	10.6 12.2 2.4	2590 1890 1460	202 214 170	346	414	NO	YES	
8"		BENTON IA. 8	TAMA CO. LINE E. TO U.S. 218	FN-8-2(3)	1971	5 YRS.	4.985 MI.	.5 MI. .35 MI.	106 76 182	34 39 73	0 6 6	24.2 32.2	 4.9	880 880	360 360	159	242	YES	NO	
8"		CASS IA. 148	JCT. IA. 92 N. TO ANITA	FN-148-3(5)	1972	4 YRS.	12.4 MI.	.35 MI. .5 MI. .4 MI.	26 84 54 164	42 33 59 134	9 8 2 19	54.5 26.4 51.3	11.6 6.4 1.7	570 830 1110	67 71 88			YES	NO	
8"		CHEROKEE IA. 3	CHEROKEE BYPASS	F-1082(4)	1961	15 YRS.	3.018 MI.	.35 MI. .4 MI.	44 44 88	23 17 40	19 43 62	26.7 16.3	22.0 41.3	1580 1320	290 279	88	114	YES	NO	M.&D.
8"	A	FREMONT - PAGE U.S. 59	IA. 2 N 7 MI. TO IA. 184	F-422(8)	1960	16 YRS.	7.129 MI.	.3 MI. .6 MI.	34 83 117	30 45 75	24 23 47	34 29.8	27.2 15.2	3020 3106	284 230	33	51	YES	NO	
8"	C	MITCHELL IA. 9	OSAGE E. TO E. JCT. 218	FN-9-6(2)	1974	2 YRS.	3.727 MI.		NO FAULTS					2977	216	450	615	YES	NO	M.&D.
8"	C	MONTGOMERY U.S. 71	PAGE CO. N. TO U.S. 34	F-FG-71-2(8)	1972	4 YRS.	5.222 MI.	.4 MI. .6 MI.	63 96 159	30 40 70	11 11 22	28.8 27.2	10.5 7.4	1560 1620	187 192	206	242	NO	NO	
8"	C	PAGE U.S. 71	MISSOURI N. TO 1 MI. N. OF SHAMBAUGH	F-71-1(2)	1972	4 YRS.	7.096 MI.	.4 MI. .4 MI.	78 77 155	19 34 53	14 29 43	17.1 24.2	12.6 20.7	1600 1590	225 143	220	256	YES	NO	M.&D.
8"	C	SHELBY U.S. 59	CO. RD. F-32 TO CRAWFORD CO.	F-59-4(10)	1971	6 YRS.	7.249 MI.	.55 MI. .55 MI. .5 MI.	63 68 75 206	41 43 43 127	27 23 10 60	31.2 32 33.5	20.6 17.6 7.8	1720 1720 1680	323 373 361	227	310	YES	NO	
7"	A	DELAWARE IA. 38	U.S. 20 N TO IA. 3 IA. 38	F-934-(3)	1960	16 YRS.	10.318 MI.	.4 MI. .45 MI. .6 MI.	86 47 87 220	19 40 37 96	1 18 17 36	17.9 38 26.2	0.9 17.1 12	1080 830 700	160 128 128	34	53	NO	YES	
		JOHNSON U.S. 6	APP. 3 MI. WEST OF TIFFIN E. TO CORALVILLE	F-289-(6)	1960	16 YRS.	5.977 MI.	.7 MI. .35 MI.	41 30 71	16 19 35	9 21 30	24.2 27.1	13.6 30	2520 2880	161 245	190	304		YES.	

FIGURE 2 (Continued)

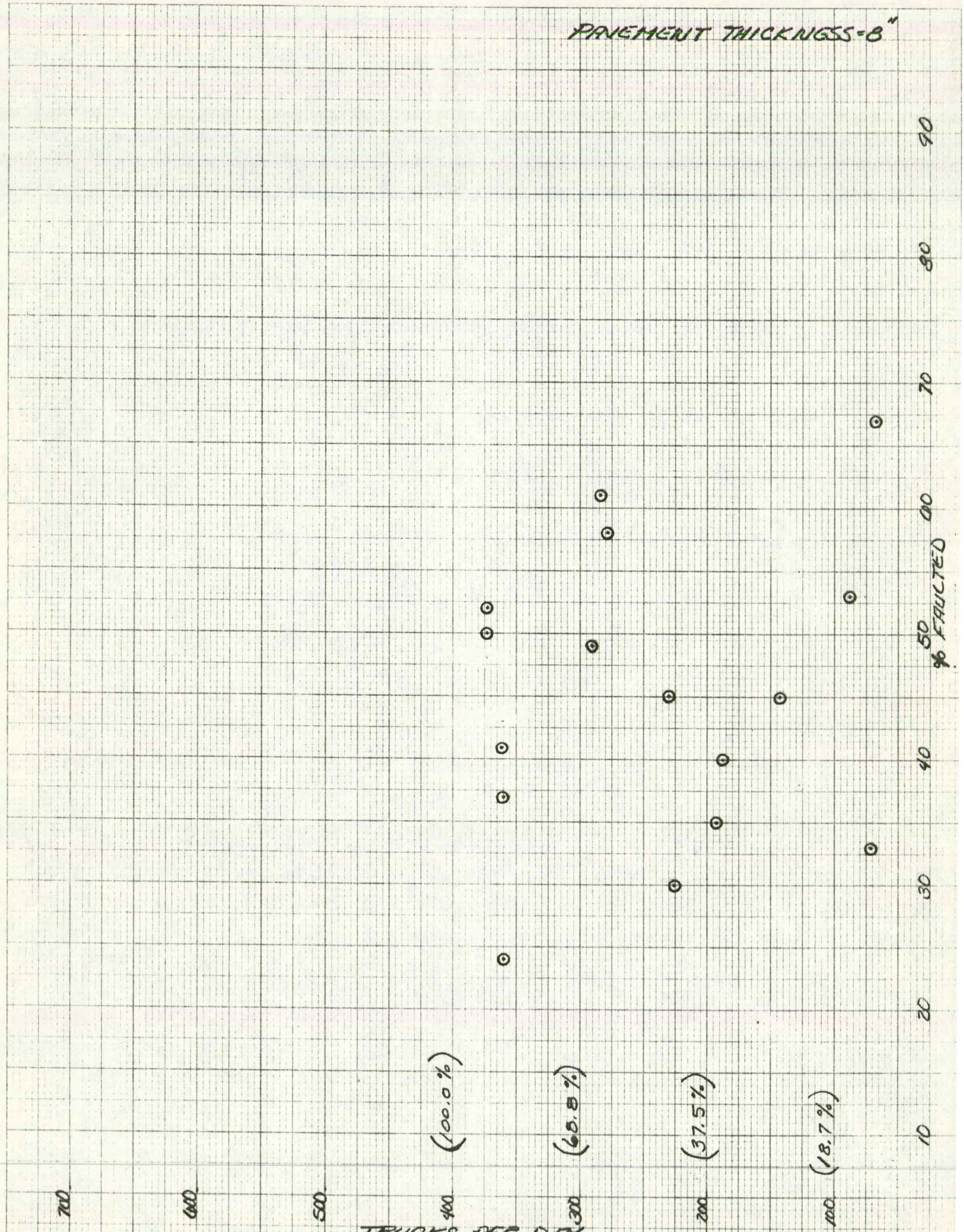

PAVEMENT THICKNESS=8"
% FAULTED
10
20
30
40
50
60
70
80
90
TRUCKS PER DAY
100
200
300
400
500
600
700
(18.7%)
(37.5%)
(68.8%)
(100.0%)

FIG. 3

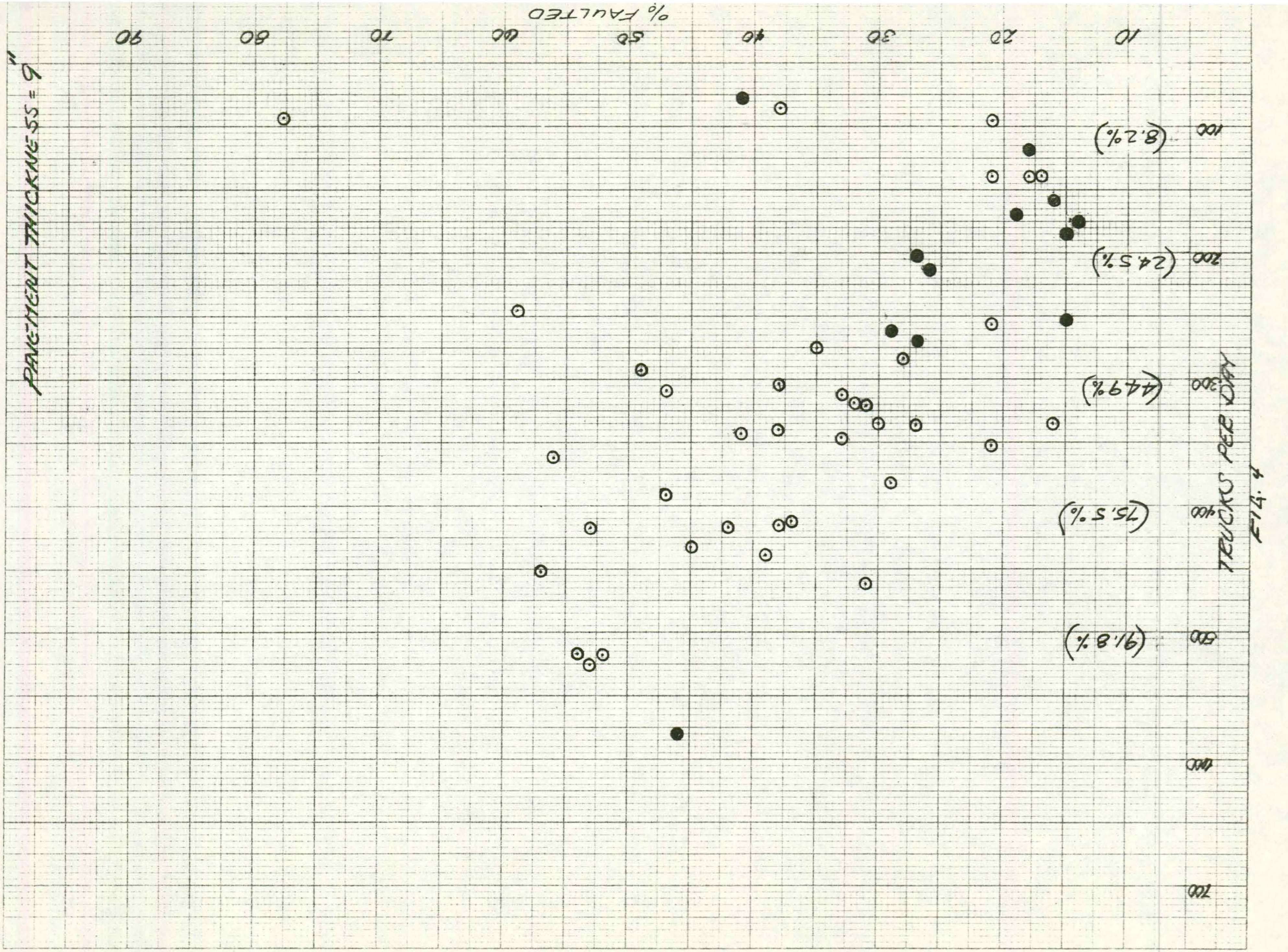

PAVEMENT THICKNESS = 9"
% FAULTED
10
20
30
40
50
60
70
80
90
TRUCKS PER DAY
100
200
300
400
500
600
700
(8.2%)
(24.5%)
(44.9%)
(75.5%)
(91.8%)

FIG. 4

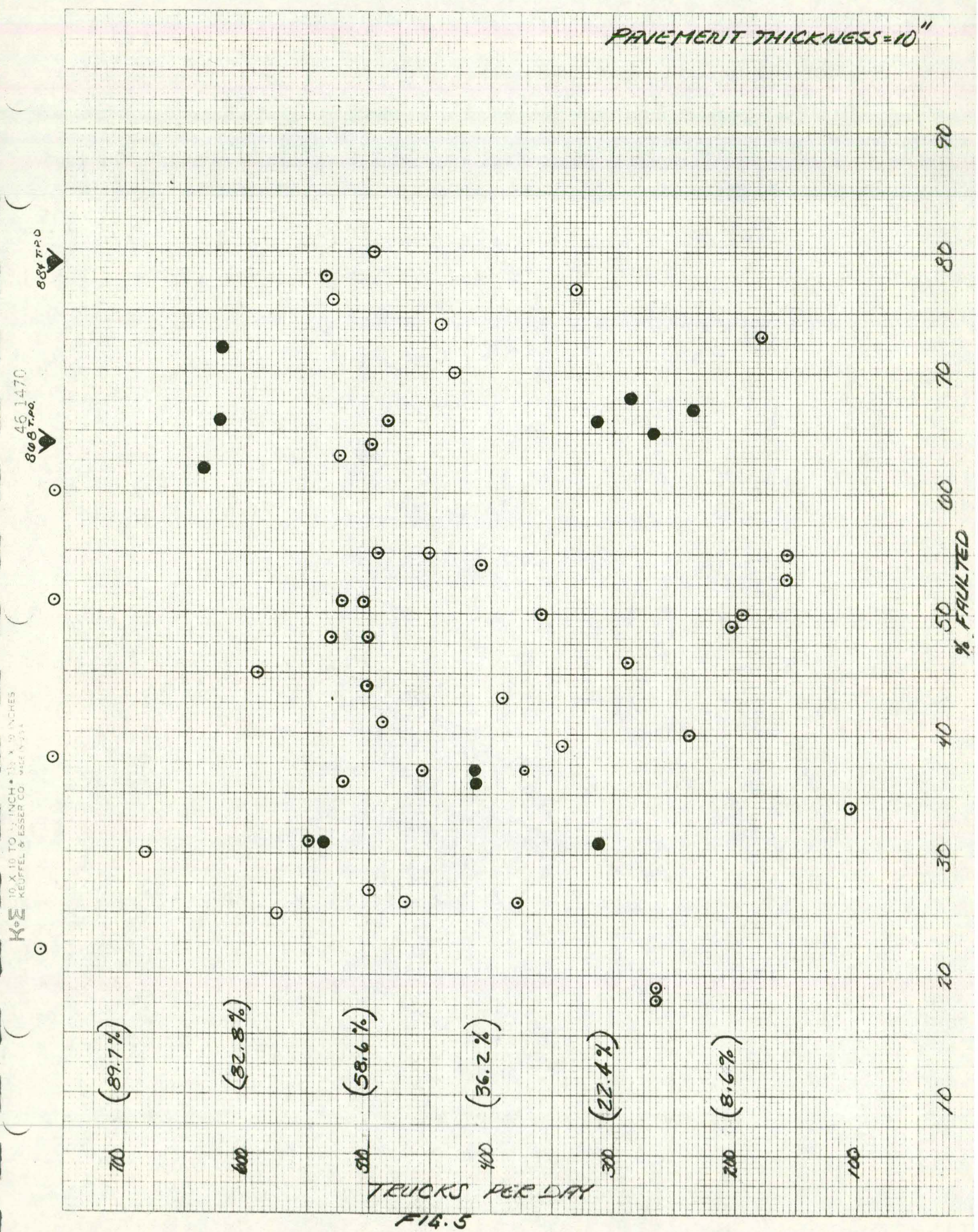
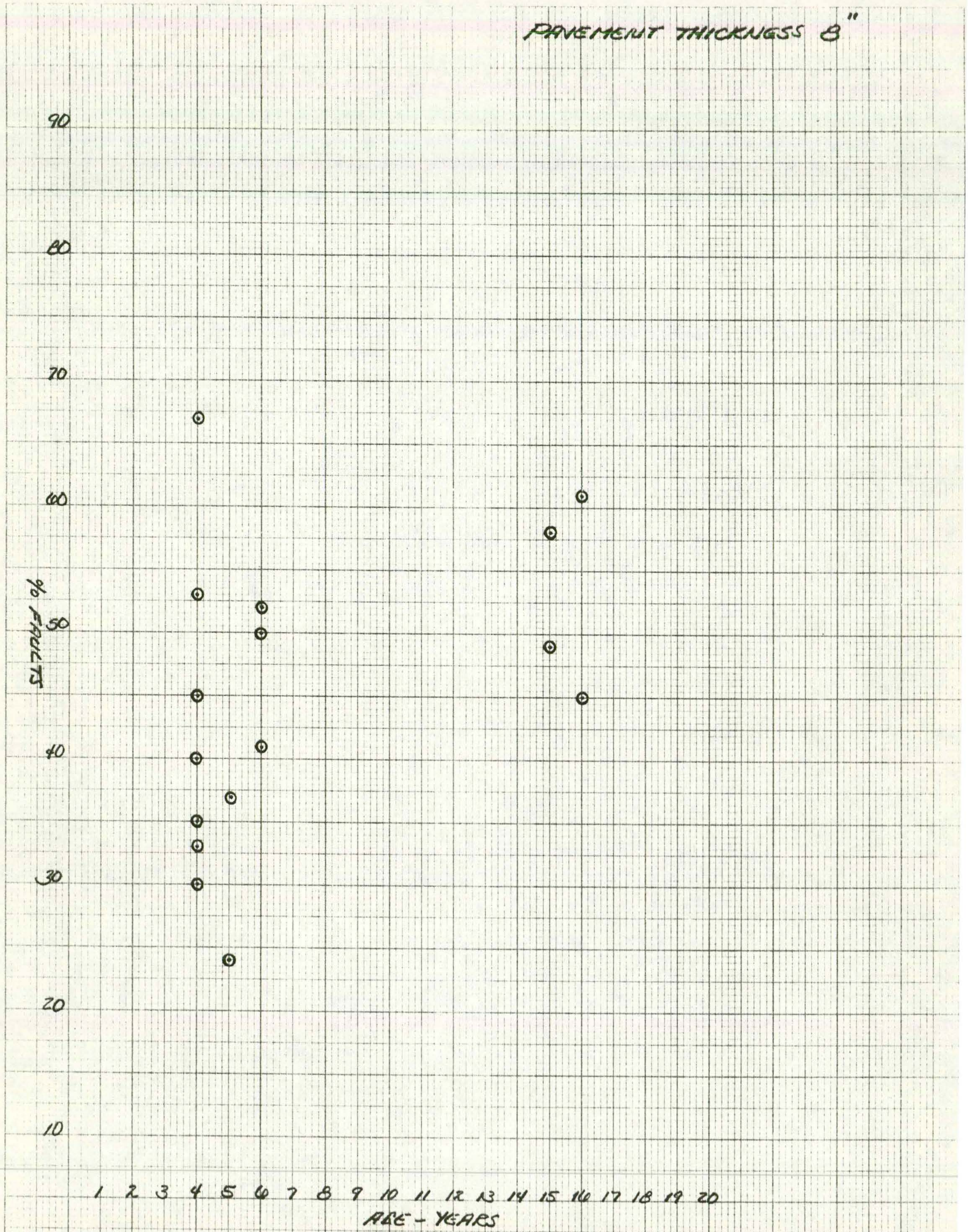

PAVEMENT THICKNESS=10"
% FAULTED
TRUCKS PER DAY
(89.7%)
(82.8%)
(58.6%)
(36.2%)
(22.4%)
(8.6%)
884 T.P.D
808 T.P.D.

FIG. 5



PAVEMENT THICKNESS 8"
% FAULTS
90
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
AGE - YEARS
PROJECTS WITH SUBBASE

FIG. 6

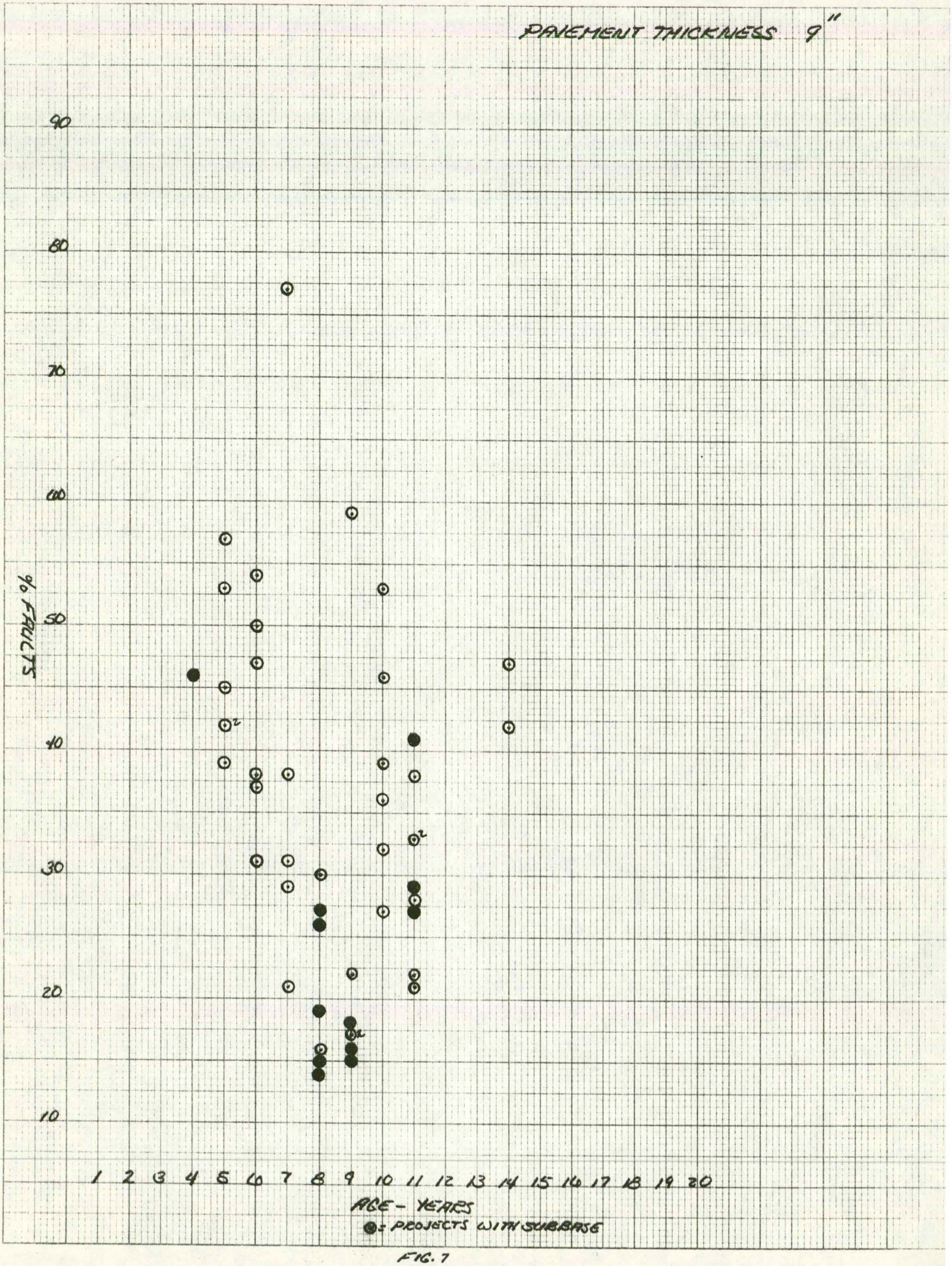
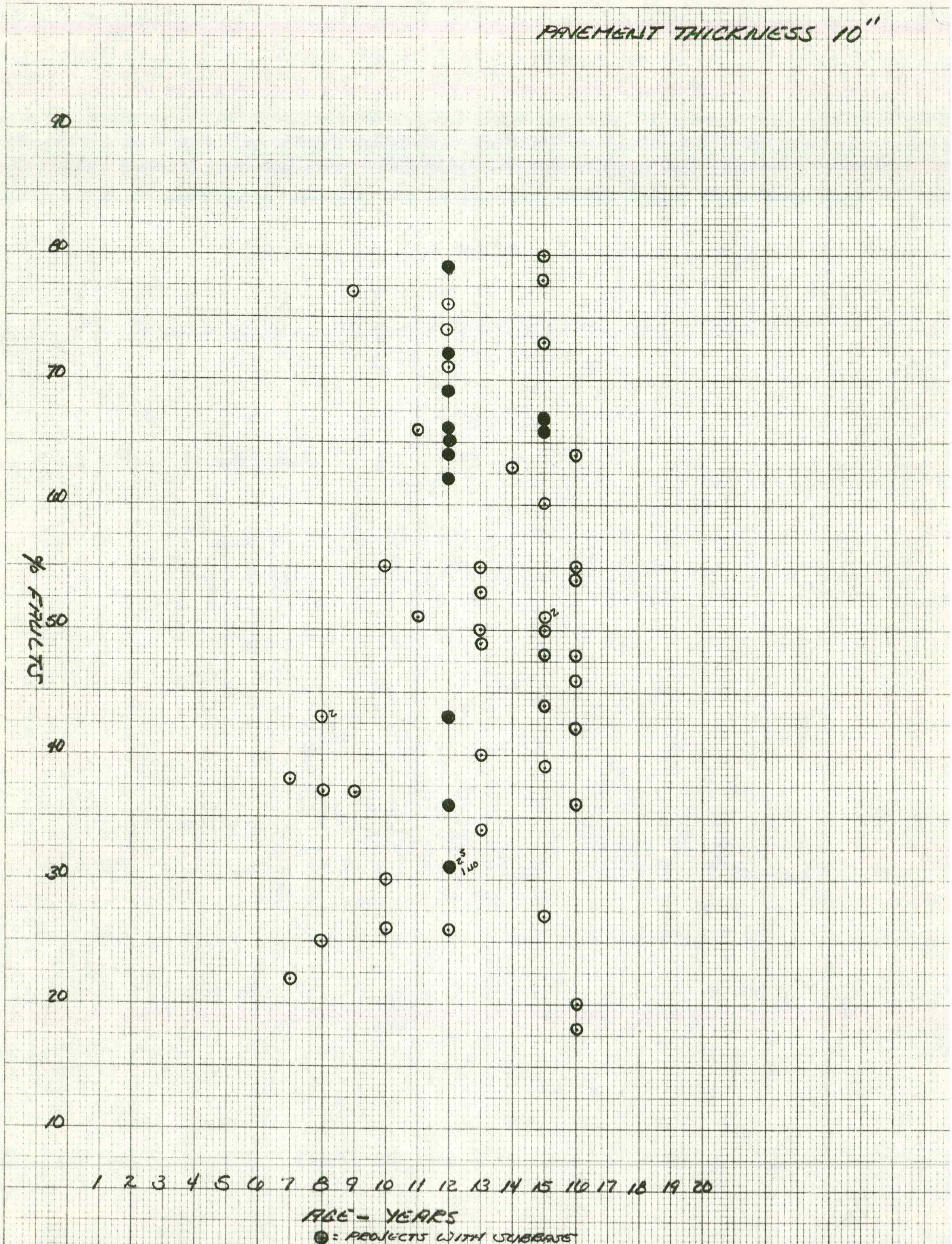

PAVEMENT THICKNESS 9"
% FAULTS
90
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
AGE - YEARS
⊙= PROJECTS WITH SUBBASE

FIG. 7



PAVEMENT THICKNESS 10"
90
80
70
60
% FAULTS
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
AGE - YEARS
● : PROJECTS WITH SUBBASE

FIG. 8

APPENDIX A

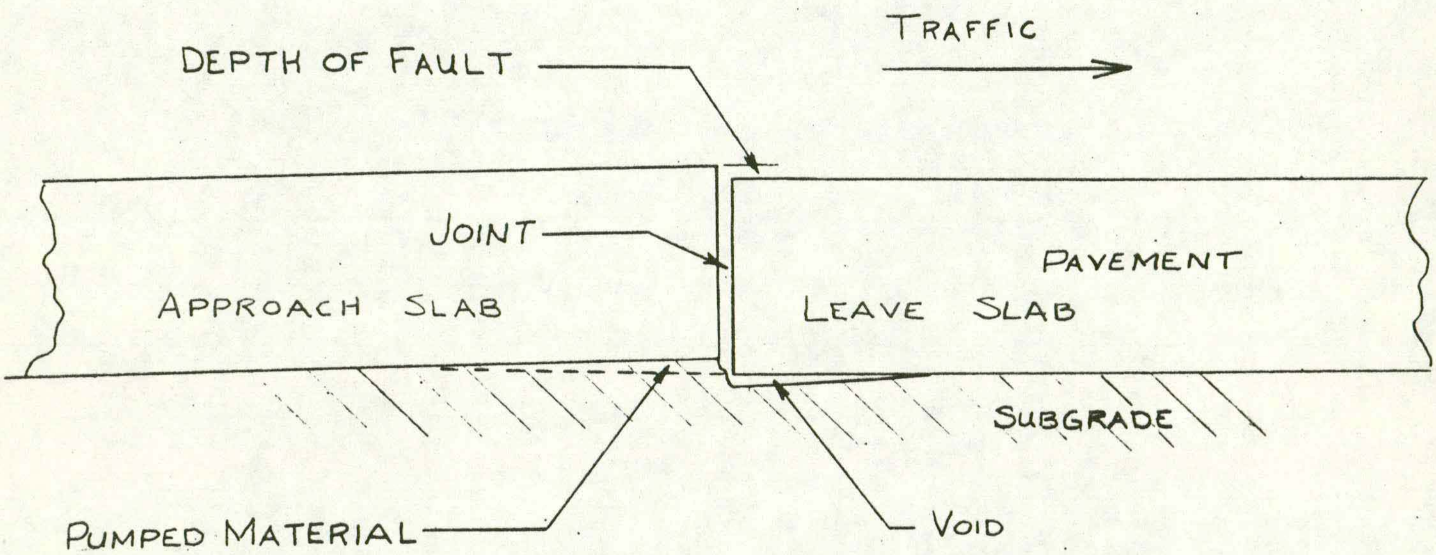
Faulting is a difference in elevation from one side of a joint or crack to the other side. Figure 9 shows a typical faulted joint.

The faulted joint is the result of pavement deflection and pumping. As a wheel load approaches a joint, the pavement deflection travels toward the joint on the approach slab. If there is moisture available under the approach slab, it is driven (pumped) toward the leave slab. As the wheel load passes unto the leave slab immediate deflection in the leave slab drives any moisture available under it plus the moisture from under the approach back toward the approach slab at very high velocity. The rapid movement of this moisture causes erosion of the subgrade under the leave slab. As the subgrade particles are carried under the approach slab, it tends to raise up slightly while a slight void is created under the leave slab. Because of this action, an elevation differential is created at the pavement surface between the approach slab and the leave slab.

When an elevation differential has been created, the pumping action under the leave slab becomes more severe since in addition to the rapid pavement deflection there is now an impact loading created by the wheel load "dropping off" of the approach slab.

The moisture in the subgrade referred to above does not necessarily occur as free water. It is basically slightly more than the moisture needed to achieve optimum compaction.

However, the action of repeated pavement deflection causes a "puddling" effect much the same as occurs in "puddling" concrete. This action tends to bring moisture to the surface at the subgrade-pavement interface. It is then available for the pumping action necessary for faulting to occur.



TYPICAL FAULTED JOINT

FIG. 9