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16. ABSTRACT
This is the fifth and final report on this project. It has been found that faulting begins almost immediately after a pavement is open to traffic. To prevent or reduce the problem, it is necessary to eliminate as many of the factors as possible which lead to faulting. Of utmost importance is elimination of the major sources of transportable fines, i.e., erodible base, and untreated shoulder material. Lean concrete base (LCB) shows great potential for providing a non-erodible base. Some of the experimental shoulder treatments described herein may be effective, but need to be tried in conjunction with the improved base. Rapid removal of free water from under the slab is highly desirable and two types of drainage systems are described.

Further research is still considered necessary. In an effort to accelerate findings, plans are under way to construct near full scale laboratory model studies. It is hoped that a faulted condition can be generated in as little as month or two of repetitive loading. Should this be successful, it will then be possible to evaluate various design features in a similar time span.

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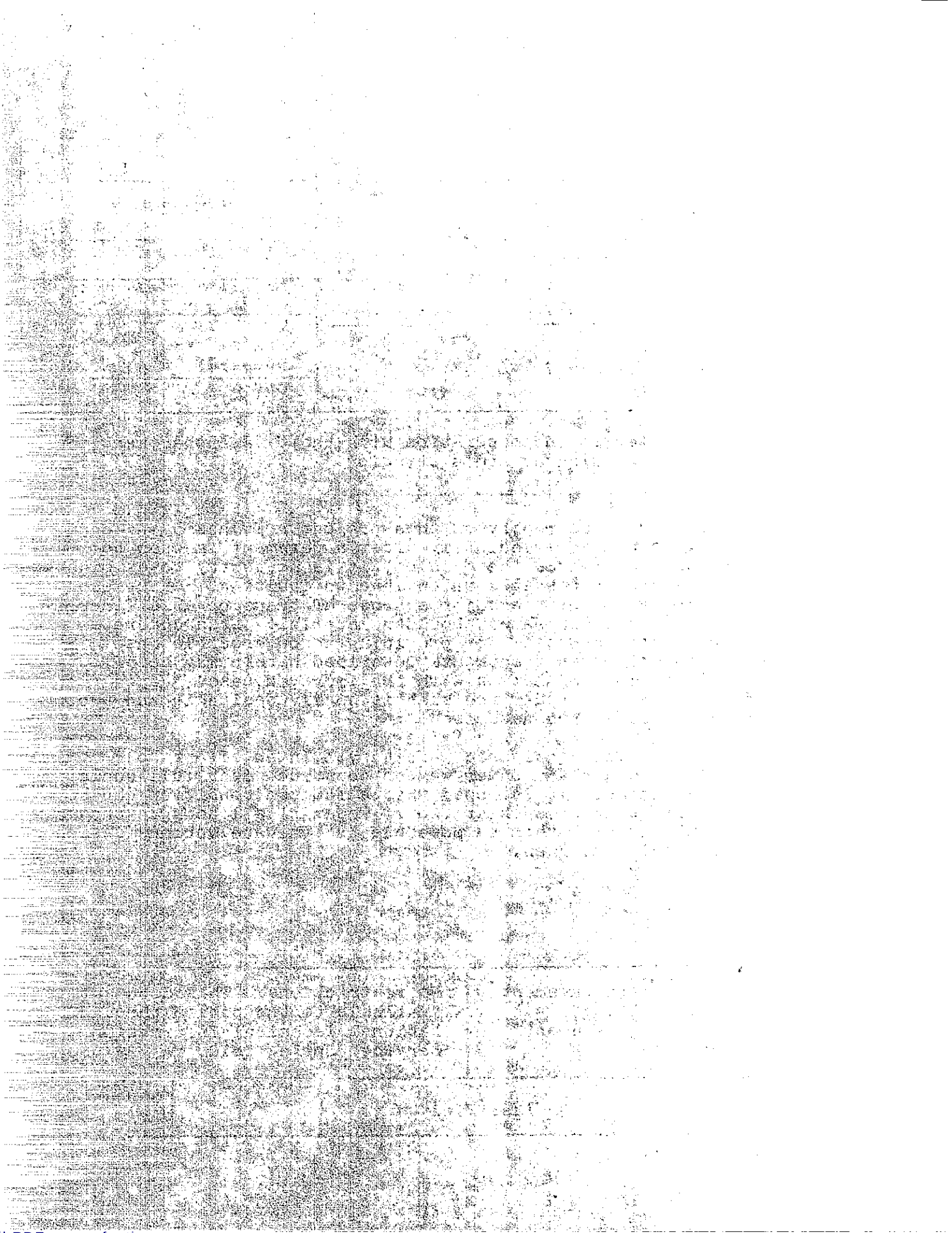

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

July 1977

635167
D-3-32

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

FAULTING OF PORTLAND CEMENT
CONCRETE PAVEMENTS

Study made by	Roadbed & Concrete Branch
Under the Supervision of	D. L. Spellman
Principal Investigator	J. H. Woodstrom
Co-Investigator	B. F. Neal
Report Prepared by	B. F. Neal J. H. Woodstrom

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment
BFN:cb

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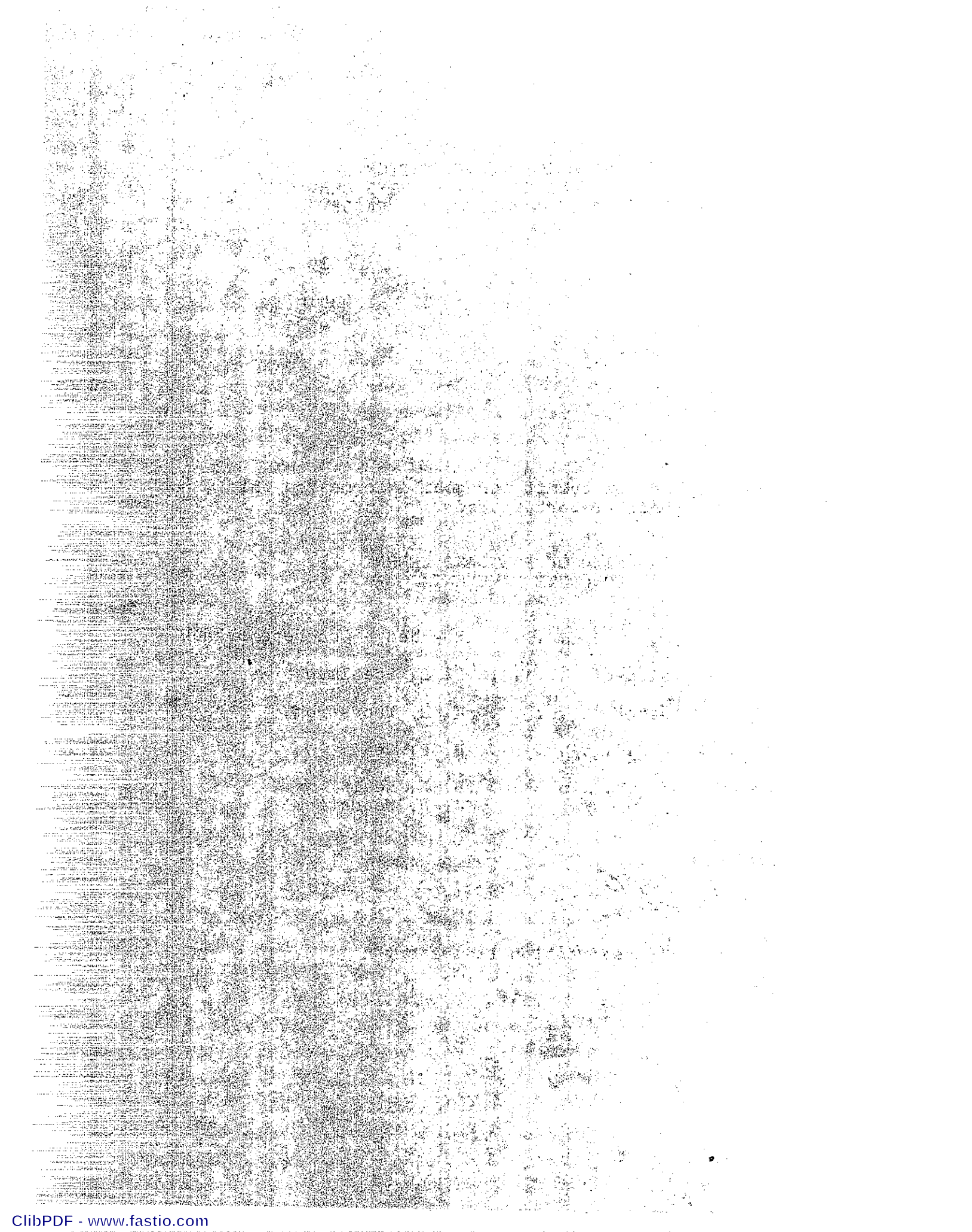

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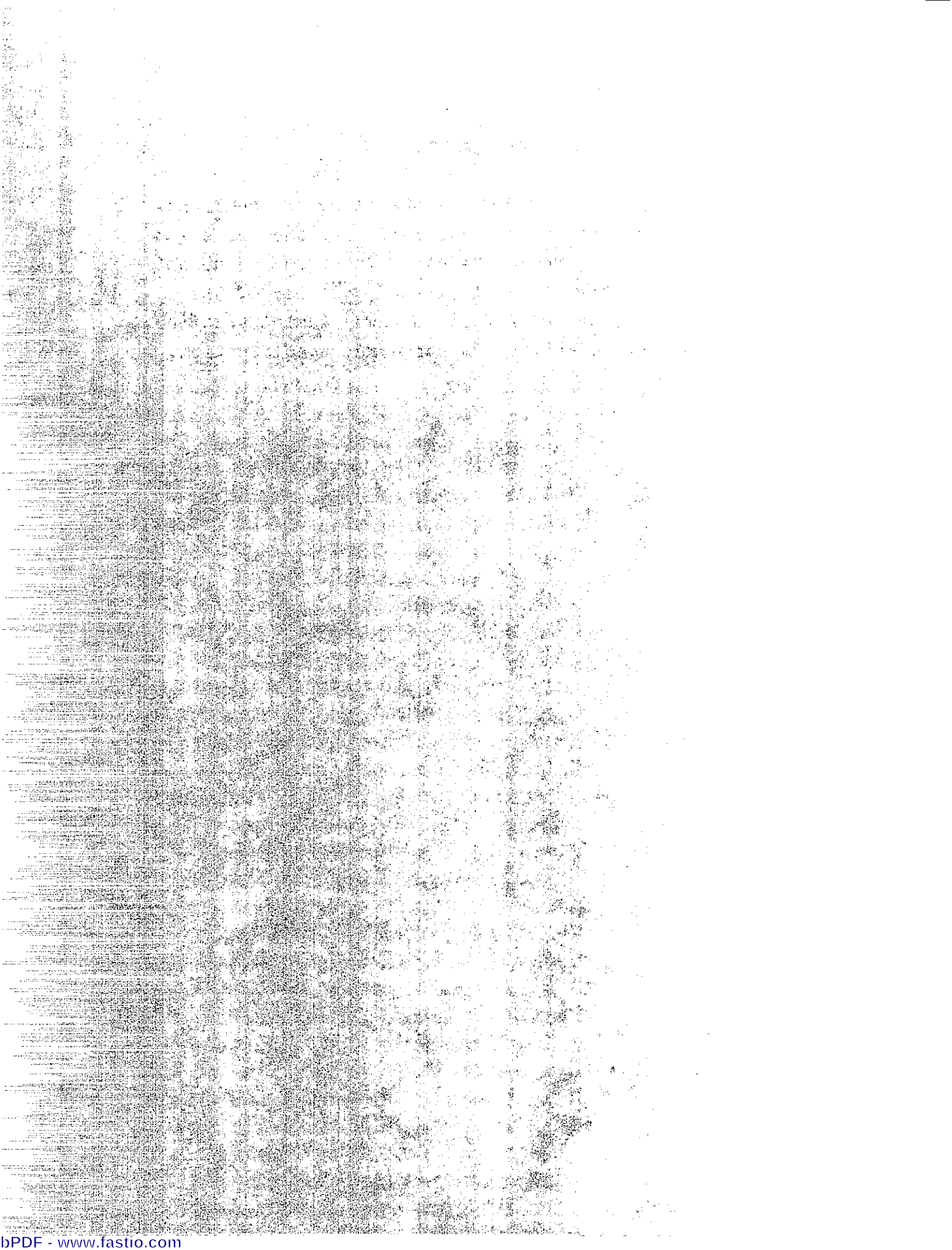

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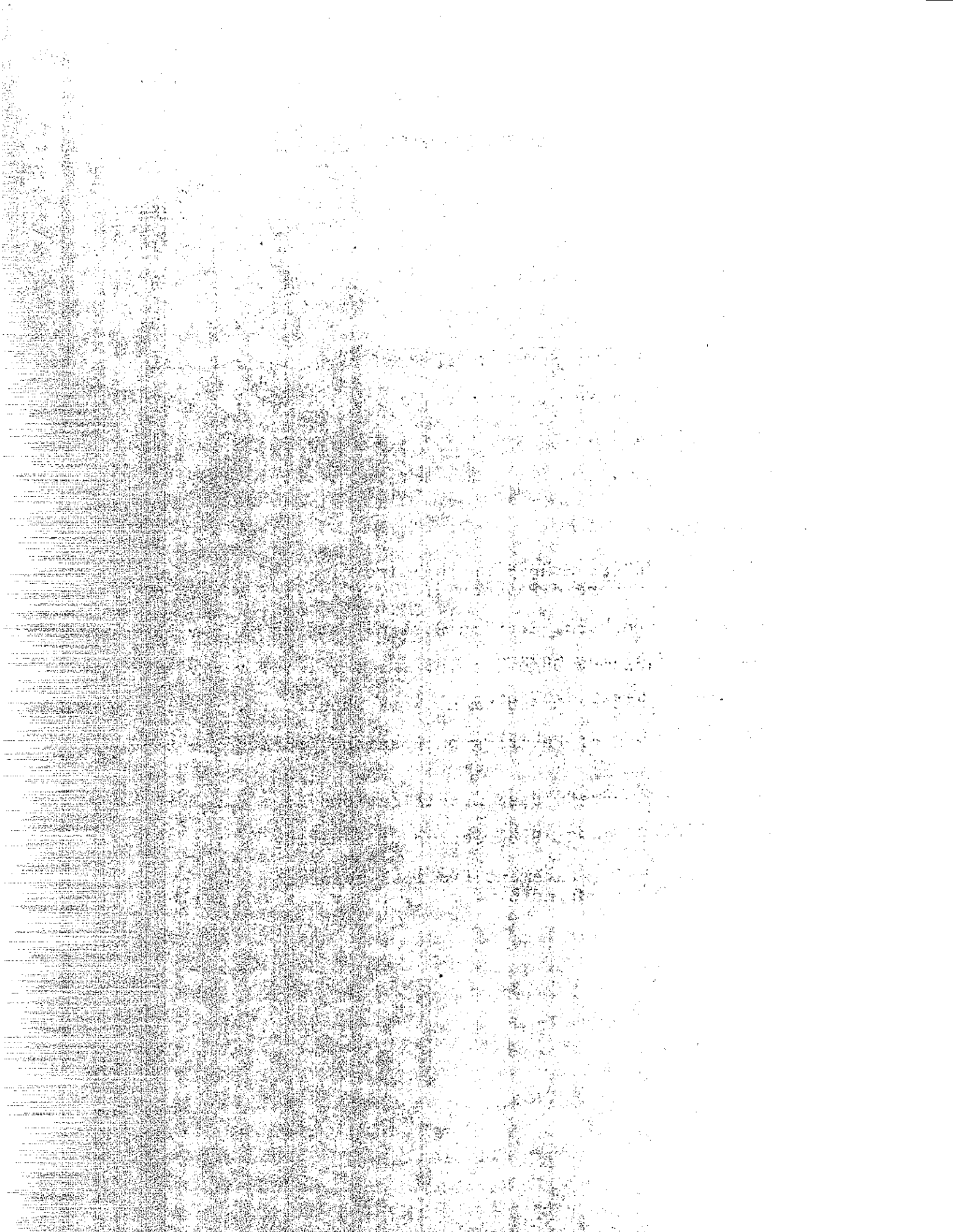

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FAULTING OF PORTLAND CEMENT CONCRETE PAVEMENTS

BACKGROUND

In the past twenty years or so thousands of lane miles of concrete pavements have been constructed and for the most part, have carried considerably heavier traffic loads than were anticipated in the design stage. In general, these pavements have performed as expected, although there have been a variety of problems and some surprises associated with each of the approaches that have been used in concrete pavement design and construction. As examples, steel corrosion has been a great concern in continuously reinforced pavements; extending cement treated bases a foot beyond the edge of pavement has not totally prevented pumping; and jointed pavements develop step-off (faulting) at the joints.

Concrete pavements can be classified in one of the following categories:

1. Continuously reinforced

2. Jointed reinforced (sometimes including dowelled joints)

3. Non-reinforced with closely spaced contraction joints, dowelled and undowelled

4. Prestressed (still regarded as experimental in most states)

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Despite vast differences in theoretical concepts, design justifications, construction practices, and cost of pavements in the above categories, there are also many similarities.

1. Nearly all pavements are between 8" and 10" thick (203 mm and 229 mm).

2. Nearly all are constructed on a stabilized base.

3. The amount of longitudinal reinforcement, when used, is usually 0.6%.

Assuming similarity of traffic loads in the US and design procedures used that reasonably account for loads, it is not surprising that similar structural designs for each type of pavement are developed.

An infinite variety of paving details, many of which deal with the joint between slabs, have been incorporated into design systems in an effort to achieve a "zero maintenance" pavement. That worthwhile goal is, however, yet to be attained.

California's experience with concrete pavements is almost totally limited to the nonreinforced type with "short" joint spacing. Slab lengths are in a repeated pattern of 12, 13, 19, and 18 feet (3.65, 3.95, 5.81 and 5.5 m). Weakened plane joints are skewed counter clockwise 2 feet (0.6 m) in 12 feet (3.65 m) and are constructed to a depth of 2 inches (50 mm) by sawing, or using a tape insert in the plastic concrete. Concrete is designed to achieve a modulus of rupture of 550 psi (3.8 MPa) at 28 days. A stabilized layer, referred to as cement-treated base (CTB), underlies the pavement and

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extends outward one foot (0.3 m) on each side of the slab. A subbase layer usually underlies the cement-treated base. Shoulder construction consists of asphalt concrete surfacing over untreated base material.

Concrete pavements in California are considered to have performed quite well in that the design life of the pavement in terms of traffic is usually achieved and, in most cases, is exceeded. One characteristic of pavement performance that is manifestly apparent in the design currently used, is that of faulting or step-off that occurs at transverse joints. All of our pavements eventually develop some degree of faulting, the magnitude and rate of which varies considerably. For the most part, it remains within tolerable limits and goes unnoticed by the traveling public for many years. In some cases, faulting can be measured as early as a year or two after opening to traffic, although riding quality may not be seriously affected for several years. Pavements 12 to 15 years old are occasionally found to have a step-off of 1/4 inch (6 mm) or more and the riding quality of the highway is adversely affected. In nearly all concrete pavements that have reached a "terminal" condition, severe faulting has developed. Varying degrees of shoulder distress are directly linked to the faulting condition.

The development of faulting appears to be fairly consistent within the limits of a given construction project. Whether in cut or fill, or on the high or low side of superelevation, there is normally no significant difference in the degree of faulting. Its occurrence is primarily limited to the outer lane although it is sometimes present in the outer two lanes.

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Extensive research has been conducted on the subject of faulting of joints(1, 2, 3, 4). For this malady to occur the following conditions must exist:

1. The pavement slab condition must be such that deflection will occur under load. (Thermal gradients and differential drying within the slab can cause upward warping at the edges. This warping reduces base support and may actually result in the separation of the slab from the base at joints or edges.)

2. Free water must be present.

3. Heavy wheel loads must cross the joint, first depressing the approach side of the joint, then allowing a sudden rebound, while instantaneously impacting the leave side of the joint, causing a violent pumping action of the free water.

4. Pumpable fines must be present. (Untreated shoulder base material, the surface of the stabilized base, and foreign material entering the joints are sources of pumpable fines.)

As a result of the action described under (3) above, any loose fine material available is driven in the direction opposite to that of traffic flow and deposited under the approach side of the joint. In many cases the depth of buildup of these fines has been found to exactly coincide with the measured step-off on the pavement surface. Waterborne fines are sometimes ejected onto the pavement surface and shoulders, and can also be eroded from the shoulder area and deposited under the adjacent approach slab.

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Typical stages in the life of a concrete pavement are shown in Figure 1. In Stage 1, the initial step-off, say less than 1/16 inch (1.5 mm), is accompanied by shoulder cracking located primarily on the down traffic side of the joint. As the step-off increases in Stage 2, the cracking is extended longitudinally and is accompanied by a shoulder depression in the vicinity of the joint. It is at this point that maintenance of the shoulder becomes necessary. The depressions are filled with localized patches and the cracks are filled with a hot-poured sealer. The depression of the shoulder is an indication that the underlying material is being moved.

In Stage 3, the riding quality of the road is seriously affected. It may be necessary to grind the pavement, removing a tapered segment from the slab surface. Shoulder maintenance may call for a continuous patch one to two feet (0.3 to 0.6 m) in width.

In Stage 4, the slabs can no longer carry traffic without breaking up because of the nonuniform support conditions. While cracks in the concrete may follow a somewhat irregular pattern, they quite often start on the outside edge of pavement, 5 or 6 feet (1.5 or 1.8 m) down traffic from the joint and are skewed to the left. Step-off is in the range of 1/8 to 1/4 inch (3 to 6 mm) with occasional joints in excess of 3/8 inch (9 mm). An overlay is necessary at this point to restore riding quality.

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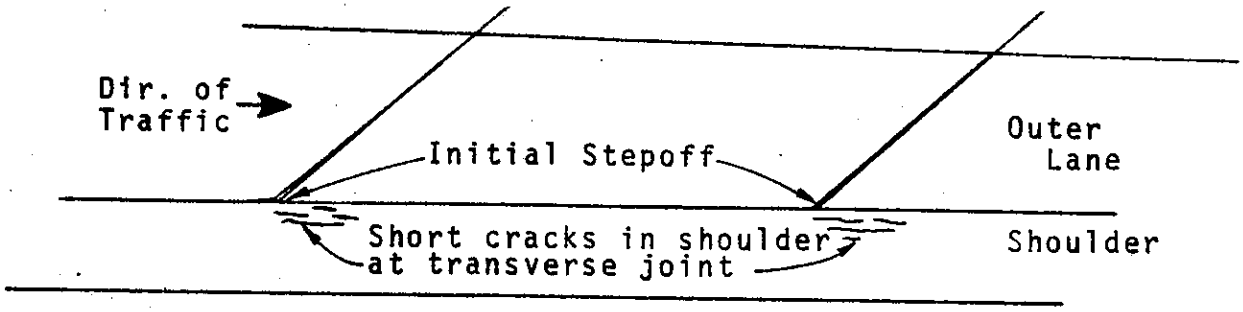
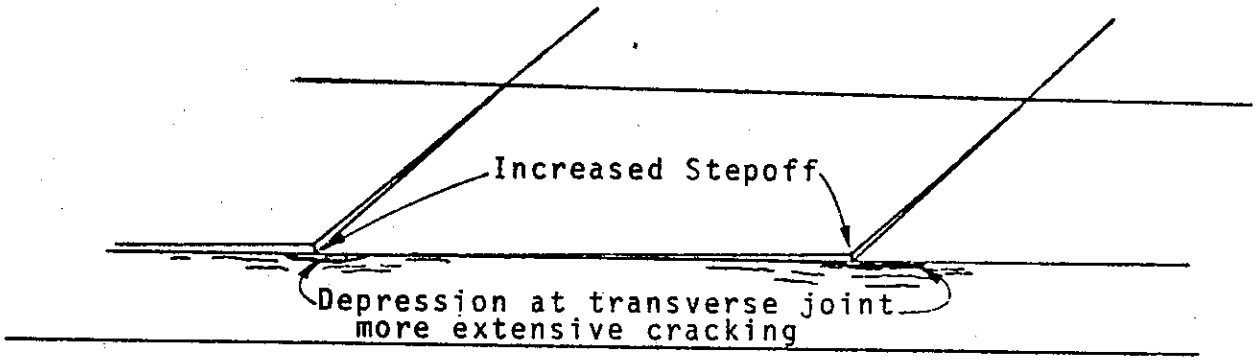


STAGE 1



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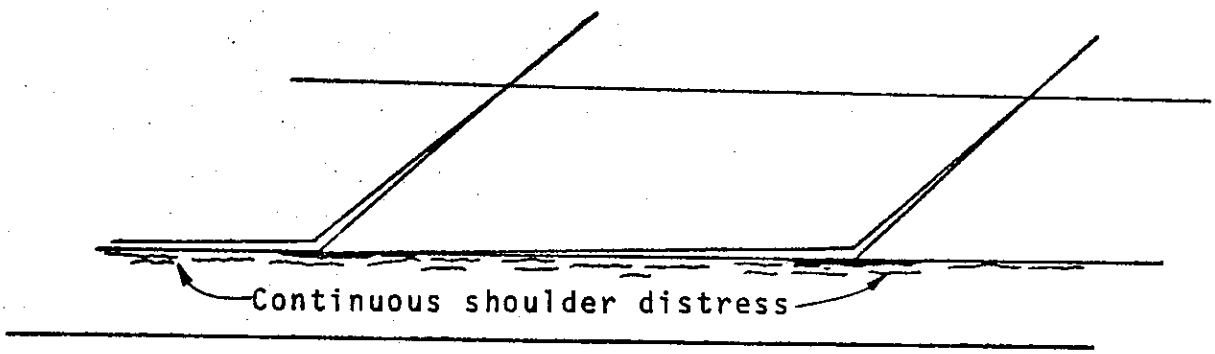
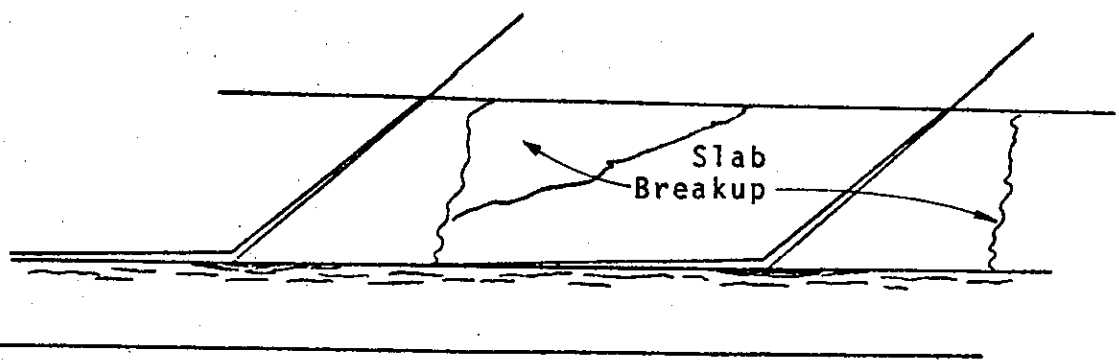


STAGE 3



STAGE 4

Figure 1

TYPICAL STAGES IN THE LIFE OF A CONCRETE PAVEMENT

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The structural design of pavements is based on assumptions about conditions that may exist only a short period after construction. Uniform support of the subgrade is one example of a condition that changes, sometimes drastically. The underlying problem affecting pavement performance and service life is therefore, related to physical changes that are occurring beneath the concrete slab which are usually caused by repetitions of axle loadings that are heavy enough to cause slab deflections. While this conclusion is arrived at from experience with non-reinforced slabs and short joint spacing, similar conditions could well exist in reinforced slab and continuously reinforced pavements with a comparable adverse effect on performance. There may be other causes of nonuniform support such as expansive soils, settlements or frost heave.

Compacted bases under the slab and in shoulders often have low permeability and create what is referred to as a "bathtub" section. When free water is available, it has little opportunity to escape, and some adverse effects on the pavement are likely to occur.

Most highway engineers have not adequately recognized the need for giving full consideration to the effects of surface water entering the structural section. Cedergren's book, "Drainage of Highway and Airfield Pavements"(5), thoroughly documents this concern by a few engineers over an extensive period of time and yet little progress has been made.

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CONCLUSIONS

Based on the findings from this research project, the following conclusions are considered warranted.

1. The faulting process starts almost immediately after a pavement is opened to traffic.

2. Faulting is caused by the transportation of available fine material by water moved under the action of heavy wheel loads(1). The rate of increase in faulting appears to be dependent mainly on the availability of erodible material under and adjacent to the slabs (assuming water and heavy loads are present also).

3. The major sources of available fines are (a) erodible base, and (b) untreated shoulder material adjacent to the slab(1).

4. The elimination of only one source of fines will not necessarily stop the faulting action.

5. Either lean concrete or AC base would provide a more erosion resistance surface than CTB, and would eliminate one source of fine material which is usually involved in the faulting process.

6. Some type of shoulder treatment, such as metioned in the report, should also be constructed to eliminate that area as a source of fines.

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7. Water should be removed from under the pavement as readily as possible. (It is recognized that joint sealing is beneficial, but so far, sealing joints has not prevented all water from entering the base.) The two types of drainage systems tried, slotted pipes and a permeable open graded AC placed along the edge of the pavement, have satisfactorily removed water rapidly.

8. Faulting per joint of half-length slabs is about half that of normal length slabs. Construction of shorter slabs may be an effective method of reducing ride roughness.

9. As shown in Reference 7, riding quality of faulted pavements can be restored economically by grinding. The service lives of several pavements were shown to be significantly extended by this method.

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IMPLEMENTATION

Provisional specifications have been adopted which allow Contractors the option of using lean concrete base (LCB) in lieu of cement treated base (CTB). On some projects, LCB is now specified. Its use is expected to eliminate one source of erodible fine material which contributes to the faulting problem.

District design and materials engineers have been apprised of the problems caused by water under pavements. Formal presentations by Laboratory engineers explain that water not only contributes to faulting but other distress in the pavement and shoulder. Drainage systems are now being provided in many rehabilitation and new construction projects.

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EXPERIMENTAL STRUCTURAL SECTION FEATURES

The experimental features to be discussed consist of either replacement materials for all or a portion of the standard untreated shoulder base material or inclusion of new design elements that allow the base material to function as the designer presumed.

Shoulder Treatment

Six such features are shown in Figure 2. All of the items have been constructed at one or more locations as experimental sections and their effect on the development of faulting is being monitored. Items 1 and 2 do not improve the drainage condition but provide a barrier between the free water and the erodible shoulder base material, blocking movement of fines to the underside of the slab.

Items 3 and 4. An asphalt treated permeable material is non-erodible and effectively drains free water from beneath the pavement slab. Outlets for removal of water contained in the permeable material are necessary to prevent its acting merely as a reservoir. Where outlets are not provided, some advantage is still realized as water is readily removed from the vicinity of the joint and is distributed longitudinally in the shoulder area where it may have a better chance to percolate into the ground.

Item 5. The concrete shoulder certainly solves the problem of an erodible shoulder base and may assist in drainage of water from beneath the traffic lanes. Slab curl in the shoulder would be expected to be similar to that of the main

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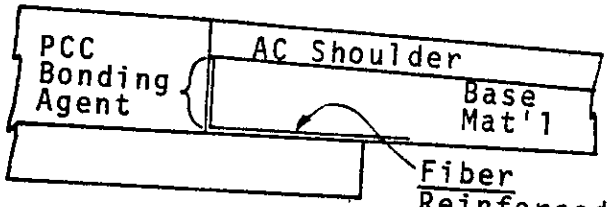
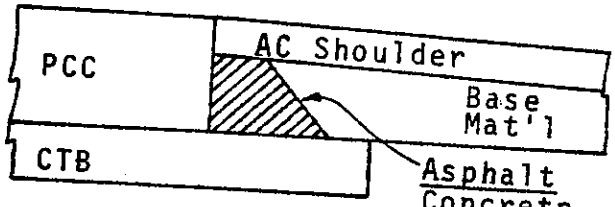
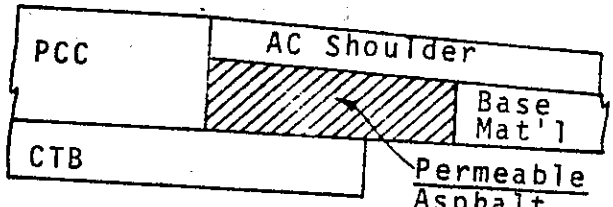
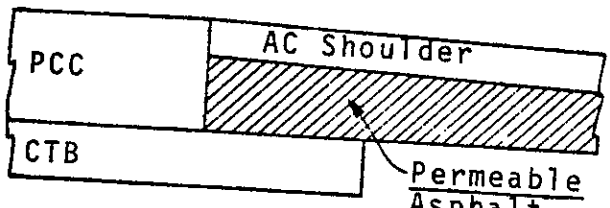
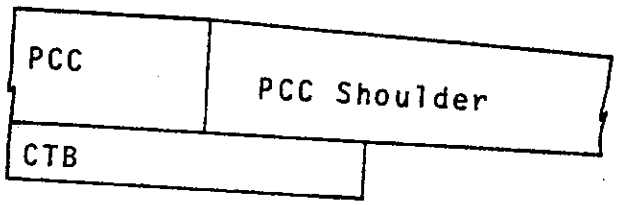
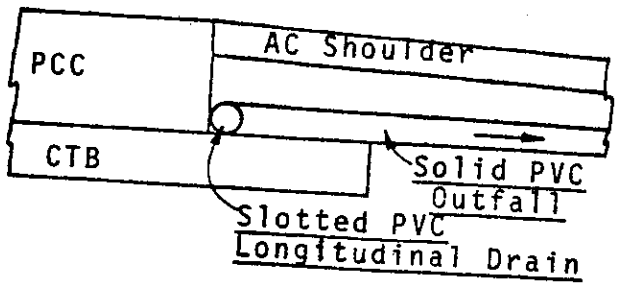
DESIGN FEATURE	COMMENT
 ITEM #1	Two foot wide strip is bonded to edge of pavement prior to shoulder construction. Membrane prevents base fines from migrating under pavement slab.
 ITEM #2	Asphalt concrete wedge provides non-erodible material adjacent to pavement slab. Also provides support to shoulder edge.
 ITEM #3	Performs as Item 2, above, used on existing highway in effort to arrest progression of faulting. Permeable material distributes water along shoulder allowing percolation throughout.
 ITEM #4	Drains free water from beneath slab and is non-erodible. Water must be allowed to escape at outer shoulder edge.
 ITEM #5	Provides non-erodible shoulder and supplies structural support to outer pavement slab.
 ITEM #6	Slotted longitudinal drain collects free water from beneath pavement slab. Water is discharged through outfall lines at appropriate intervals. Note: 1 ft = 0.3m

Figure 2

STRUCTURAL SECTION DESIGN FEATURES

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slab allowing free water to flow to the outer edge of the concrete shoulder. Additional load carrying capacity in the outer traffic lane is also expected with the use of concrete shoulders if it is tied or keyed to the pavement edge.

Item 6. A low cost drainage system can be easily incorporated into new construction. The slotted polyvinylchloride (PVC) longitudinal drain is the same product commonly used in horizontal drains. The pipe is laid on top of the CTB adjacent to the outer edge of the pavement slab where it is readily accessible to receive free water. Solid PVC pipe outfalls have been installed at 100 ft. (30.5 m) and 200 ft. (61 m) intervals on the two projects where this type of drainage system has been used. Collected water has been discharged onto the slopes of the shallow fills in the test sections. "Conventional" shoulder construction is used atop the drains.

Observations of drainage effectiveness have been quite impressive in the two years since the initial installations. Discharge during rainfall has been as high as 100 gallons per hour (105 ml/s) on individual outfalls, and more significantly, flow was found to stop shortly after the cessation of rainfall, greatly minimizing the saturation period for the structural section as well as the embankment and shoulders. Free water can remain in the structural section for days, or even weeks after a prolonged rain, therefore, drainage accomplished in one or two hours is expected to produce a significant improvement in performance.

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A fairly extensive installation of the longitudinal drainage system is presently under way on a large project near Sacramento and the completed portions appear to be performing satisfactorily. In addition to the details shown in the simplified sketch in Figure 2, various collector line arrangements become necessary as the highway is located in cut and fill sections. On high fills free discharge cannot be tolerated if the fill slopes are subject to erosion. Treatment of the shoulder on the high side of superelevation is open to question. It is currently believed desirable to place the drain in the same position at such locations to afford maximum protection to the outer, truck carrying lanes. Faulting has been observed in these areas though it has not been established that much free water collects there.

Recent costs of the 1-1/2" (38 mm) dia. slotted pipe have been between $0.75 and $0.85 per ft. (0.3 m) and the solid pipe between $0.45 and $0.65 per ft. (0.3 m). It is normally purchased in 10 or 20 ft. (3 or 6 m) lengths with ends milled to provide a slip-fit connection. The only fittings required are tees to connect the outfall lines. Placement costs are nominal as very little labor is involved. A total cost, in place, of under $1.50 per foot (0.3 m) is expected, except where a collector system is necessary. This pipe is a high quality product and it may be possible to use lower grade, cheaper pipe for this purpose.

While much is still to be learned about the effect of the longitudinal drain system on the long term performance of the highway, it appears to offer a significant improvement at minimal cost.

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Non-erodible Stabilized Base

With the discovery that the surface of many cement-treated bases were erodible and were a source of fines that contributed to pavement faulting, the use of a lean concrete base (LCB) was investigated. This concept was not new, having been used in Great Britain (where it is referred to as a wet lean mix) and other foreign countries at least as early as 1957. In recent years other states, with the support of the American Concrete Paving Association, have used what is referred to as "Econocrete". Whatever term is used, the product is essentially the same, being constructed with base quality (or better) aggregate, cement contents in the range of 7 to 10%, and sufficient water to provide a plastic concrete. Mixing is done in a concrete mixer and placing is accomplished with concrete paving equipment. The fresh mix has a slump of 2 to 4 inches (50 to 100 mm) and forms a tightly knit uniform surface without requiring additional finishing behind the slipform paver. A regular concrete curing seal adds further to the superior surface. It differs significantly from cement treated base (CTB) which is placed with a much lower cement content, contains only minimal moisture, and is compacted with rollers. The CTB is often trimmed to grade which results in loose material on the surface that is easily eroded by water and traffic action.

In 1973, a preliminary laboratory investigation was conducted to determine target strength levels and appropriate mix proportions for LCB. Following evaluation of data two paving projects were selected for large scale field trials of LCB. To provide a basis for comparison, a significant portion of each job was constructed using LCB, the remainder being CTB. These trials are documented in Reference 6.

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From the experience gained in the experimental construction, specifications were written to allow contractors the option of using LCB under PCC pavements in lieu of CTB. With additional experience, changes in the specifications have been made, and other changes will be necessary in the future. One contractor's recent proposal was to use a base quality aggregate of 3/8 inch (9.5 mm) maximum size. Laboratory tests indicated that if larger fractions of coarse aggregate were added, less cement would be needed to produce the desired strength. It is anticipated that specific requirements for lean concrete base aggregate properties will be established. Present specifications for LCB may be found in Appendix A. Since low quality aggregate requires more cement, some balance will have to be made between the cost of such aggregate and the cost of extra cement necessary to produce the specified strength. Other problems associated with grading will also have to be considered such as effect of higher water demand on shrinkage or difficulty of dispersing cement in finely graded material with the short mixing times used.

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PROGRESSION OF FAULTING

One of the objectives of this research was to study the progression of faulting on pavements of various ages and in different regions of the State. To do this, a faulting gauge (see Figure 3) was used to measure the displacement at 25 consecutive joints on selected projects. Initially, measurements were made across 50 joints, but it was found that the average of any 25 consecutive measurements was not significantly different from the average of 50.

The sections selected covered all regions of the State where concrete pavements are placed. These include desert, coastal, valley and mountain areas. Pavement ages ranged from new to about 13 years at time of initial measurement. Included are joint spacings of uniform 15 ft. (4.6 m) length, our presently specified staggered lengths, and experimental joints of approximately half the presently specified length. As other experimental features were constructed, additional test sections were established.

Obtaining uniform, repeatable measurements across joints proved rather difficult because of the inherent roughness of textured concrete. The method used was to make 3 to 5 readings about 1 foot (0.3 m) from the outer edge of pavement and record the average to the nearest 0.01 inch (0.25 mm). Figure 4 shows an example of field recorded data, and Figure 5 a plot of average faulting per joint for the Rosamond project. Although individual readings may have some inaccuracy due to surface roughness, temperature, time of year, etc., the average faulting shows a very definite upward trend. This project happens to be in a desert region with little rainfall and has a small percentage of truck traffic.

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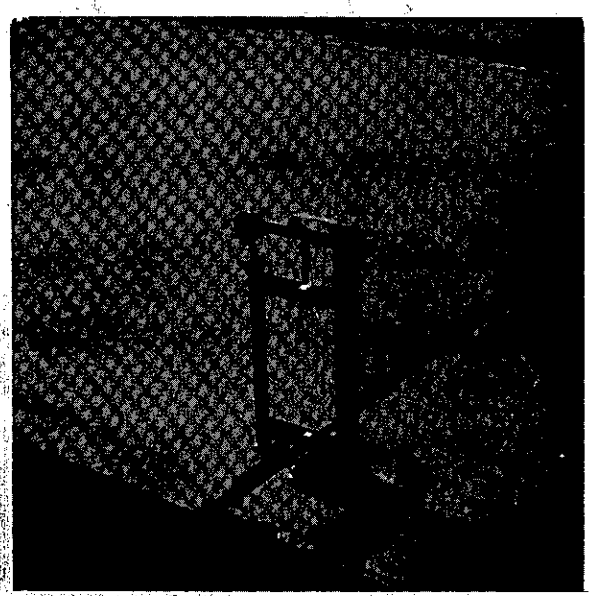

Figure 3

FAULTING GAUGE

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8" from EP

Date	5/6/71	10/13/71	1/20/72	5/16/72	10/5/72	1/11/73	5/14/73	9/24/73	1/16/74	5/20/74	9/9/74	6 hr
time	0940	1030	1615	11:00	0730	1400	1500	1445	1515	1600	1230	1515
Temp	50°	75°	60°	82°	65°	55°	85°	70°	50°	75°	90°	80°
Avg.	.041	.046	.066	.059	.070	.076	.070	.073	.081	.081	.072	.074
1	2	2	3	3	3	3	2	2	3	2	2	2
2	5	7	7	6	6	7	7	7	7	8	8	8
3	4	2	3	5	3	3	3	3	3	4	4	4
4	4	2	8	6	8	8	7	7	7	6	6	7
5	0	1	6	2	3	3	3	2	3	4	4	4
6	7	7	12	10	10	11	11	11	14	13	11	13
7	1	2	6	8	7	8	8	8	9	8	7	7
8	3	4	4	4	5	6	5	5	6	6	5	5
9	-2	3	0	0	0	1	1	2	3	4	4	5
10	6	6	7	6	7	7	7	9	9	9	9	9
11	4	5	5	5	6	6	7	7	7	8	6	5
12	4	4	11	10	11	12	13	12	13	13	13	13
13	2	6	4	5	5	5	3	4	5	4	4	4
14	7	7	10	9	10	11	10	11	11	11	9	8
15	2	0	2	2	3	5	3	3	4	4	4	4
16	4	6	5	3	6	7	7	7	8	6	6	6
17	1	2	3	2	3	3	2	3	3	4	4	4
18	7	8	11	7	10	10	9	9	9	9	9	9
19	8	8	8	6	8	9	7	7	10	11	8	8
20	0	0	2	4	4	5	5	5	6	7	3	3
21	8	9	12	9	12	13	11	11	13	12	11	11
22	10	10	13	14	18	18	18	20	20	20	16	18
23	6	6	12	11	12	13	12	12	12	13	12	12
24	4	4	6	6	7	8	8	10	10	8	9	9
25	4	5	6	5	7	8	6	6	8	8	6	6

18
13
12
19

07 LA 14 - So. of Rosamond

PM 76.00 N.B lanes (Ave B oc)

1st jt So. of 90 South

1968 PCC on CTB

Measurements are in hundredths of an inch.

Note: 1 inch = 25.4 mm

Figure 4

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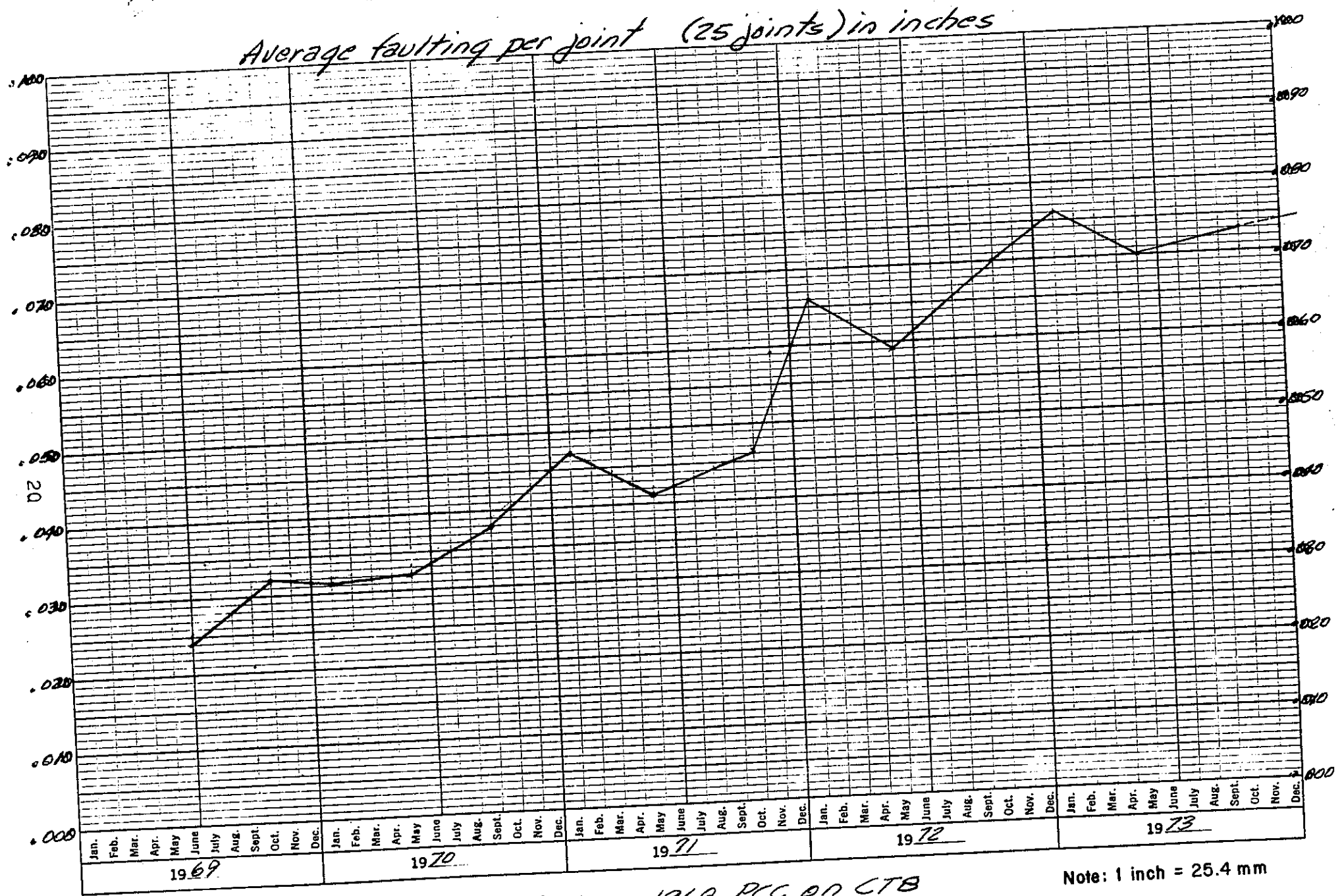
K&E 5 YEARS BY MONTHS 359-192
X 100 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.



Rosamond - 07 LA 14 PM 76.00 1968 PCC on CTB

Figure 5

Figures B-1 through B-30 in Appendix B are plots for all the test sections being monitored. While the rate of faulting increase varies, the upward trend is obvious in all cases. As shown in the data presented here, faulting begins almost immediately after the pavement is opened to traffic, and only the rate of change determines when the faulting will become noticeable or require corrective action.

There are several interesting results from the experimental construction features. Figures B-16 through B-19 show that the open graded asphalt concrete shoulder treatments slow the rate of faulting increase, but does not stop it. The reinforced plastic shoulder treatment (Figures B-19 and B-20) by itself does not appear to be significantly helpful. Perhaps if a non-erodible base had also been added, either treatment would have shown greater advantages. Figure B-21 shows an example where lean concrete base was used both with and without a shoulder treatment. Although data is limited, it appears that the combination of LCB and an AC dike against the edge of pavement has considerable promise in reducing the rate of faulting increase.

Figures B-23 and B-24 indicate that short joint spacing may also reduce the rate of increase. These joints were cut at staggered spacing with a total of 4 joints in 31 feet (9.45 m). A loaded truck was run over the pavement at an early age to induce cracking at each weakened plane. Faulting of the shorter slabs tends to be about one half that of normal length slabs, though over a given length of pavement the total amount of faulting would be about the same. And, as determined by measurements across joints, the same is true of longitudinal movements of the slabs in the two different sections. Less

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opening of the joints probably means better aggregate interlock and load transfer, and some reduction in the pumping action. This condition is comparable to continuously reinforced pavement where cracks occur 4 to 6 feet (1.2 to 1.8 m) apart but are held closely together by the steel.

The thicker pavement and concrete base sections (See Figure B-25) also show slower rate increases. The high cement factor concrete shows a very fast rate of faulting, perhaps due to greater pavement curl. One theory advanced concerning faulting relative to high strength concrete is that being stiffer, (more resistance to bending) the deflections due to loads would be less, thus reducing the pumping action.

Forming transverse joints by inserting material in the fresh concrete was expected to provide some benefits in the reduction of faulting by eliminating the reservoir left by sawing which allows water and fines to reach the base. However, Figures B-25 through B-29 do not show any advantage of inserts over sawed joints. Except in mountainous freeze-thaw areas, transverse sawed joints are rarely sealed.

Figure B-30 represents the project with experimental PCC shoulders referred to earlier and depicted in Figure 2. Full depth and width AC shoulders (outer only) were also constructed on a portion of the project. The increase in cost over normal shoulder construction was about 60% for the AC and 100% for the PCC. There is insufficient data to make any conclusions as to effect on faulting.

It appears from the project depicted in Figure B-14 and from other projects being rehabilitated, that faulting is considered intolerable for trucks when the average fault at the outer

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edge of pavement is somewhere around 0.2 inch (5 mm). (Criteria varies and greater faulting may be tolerated in some states). This is also demonstrated in Figure B-31 which shows profiles of a faulted pavement, taken in the outer wheel track before and after grinding(7). Experimental shoulder treatments were also constructed on portions of this project to see if recurrence of faulting could be prevented or delayed. In one section, a portion of the untreated base in the shoulder was replaced with dense graded AC. In another section, plastic drainpipe was installed. It is too early to determine if these treatments will have any effect.

Attempts to correlate faulting with truck traffic, rainfall or geographical area were unsuccessful. Due to the variables involved with faulting, (traffic, rainfall, materials properties, construction practices, etc.) no clear cut relationships between faulting and a single factor were observed. For example, faulting has occurred on many projects in both high and low rainfall areas.

The "control" listed in the figures refers to the standard constructed pavement of 8 or 9 inch (195 or 230 mm) thickness and shoulders of aggregate base covered by asphalt concrete.

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SUMMARY

Under normal construction procedures, faulting begins almost immediately after a pavement is open to traffic. To prevent or reduce this problem, it is essential to eliminate as many of the factors as possible which lead to faulting. Of utmost importance is elimination of the major sources of transportable fines, i.e., erodible base, and untreated shoulder material. The elimination of one source but not the other will not necessarily solve the problem. LCB shows great potential for providing a non-erodible base. AC would probably be satisfactory, also. Some of the shoulder treatments described earlier may be effective, but need to be tried in conjunction with the improved base.

The rapid removal of free water from under the slab is also considered essential, not only as an aid in solving the faulting problem, but in improving pavement and shoulder performance. Some type of drainage system, such as one of those described in this report, can readily be installed in new pavement construction. It can also be added to existing pavements, but whether this alone will deter faulting remains to be seen. It may also be possible to find some means of stabilizing the loose fines already under the slabs and thus eliminate this source of pumpable material.

Further research and large scale trial installations are needed and cost-effectiveness needs to be examined. In an effort to accelerate findings, California also plans to proceed with near full scale laboratory model studies. Simulated loading and environmental conditions will be produced in the laboratory and it is hoped that a faulted condition can be generated in as little as a month or two of repetitive loading. Should

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this phase of the project be successful, it will then become possible to quantitatively determine the benefits of various design features in a similar time span. Findings will be implemented in the design and construction of new highways as well as reconstruction and rehabilitation on older ones.

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REFERENCES

1. Spellman, D. L., Stoker, J. R., and Neal, B. F., California Pavement Faulting Study, California Division of Highways, January 1970.

2. Spellman, D. L., Woodstrom, J. H., and Neal, B. F., Faulting of Portland Cement Concrete Pavements, Highway Research Record 407, 1972, pp. 1-9.

3. Gulden, Wouter, Extent and Severity of Pavement Faulting in Georgia, Georgia Department of Transportation, August 1972.

4. Gulden, Wouter, Investigation Into the Causes of Pavement Faulting on the Georgia Interstate System, January 1974.

5. Cedergren, H. R., Drainage of Highway and Airfield Pavements, John Wiley and Sons, Inc., 1974.

6. Neal, B. F., Woodstrom, J. H., and Spellman, D. L., California Trials with Lean Concrete Base (LCB), California Department of Transportation, October 1975.

7. Neal, B. F., Woodstrom, J. H., Rehabilitation of Faulted Pavements by Grinding, California Department of Transportation, February 1976.

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APPENDIX A

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LEAN CONCRETE BASE.-- The Contractor, at his option, shall construct either lean concrete base in accordance with the following requirements, or cement treated base as provided for elsewhere in these special provisions.

Lean concrete base shall be placed to the dimensions shown on the plans for cement treated base, except that the thickness of the lean concrete base may be reduced by 0.05-foot from the thickness specified for cement treated base. If said thickness is reduced, the elevation of any underlying subgrade shall be adjusted so that the finished surface of the pavement will be at the elevation shown on the plans.

When pavement material is portland cement concrete and the thickness of portland cement concrete pavement required for some lanes is greater than the thickness required for other lanes and the Contractor elects to construct lean concrete base in lieu of cement treated base, the Contractor shall construct the base and pavement to the dimensions shown on the plans and as modified in the preceding paragraph and may, at his option, alter the plan dimensions by making the following adjustments:

1. Thickness of pavement at the outer and inner edges shall be adjusted in accordance with the following:

Adjust Outer Edge (feet)..... $+\frac{W_G}{W_T} \times t$

Adjust Inner Edge (feet)..... $-\frac{W_L}{W_T} \times t$

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Where: W_G = Width of pavement with greater thickness
W_L = Width of pavement with lesser thickness
W_T = Total width of pavement
t = Difference in pavement thickness in feet

2. Thickness of portland cement concrete shall taper uniformly from the adjusted thickness at the outer edge of pavement to the adjusted thickness at the inner edge of pavement.

3. Thickness of lean concrete base shall be constant across the full width.

4. The plane and elevation of subgrade for lean concrete base shall be adjusted so that the finished surface of portland cement concrete pavement will conform to the elevation and plane shown on the plans.

Lean concrete base shall consist of a mixture of aggregate, portland cement, water and, at the option of the Contractor, an admixture for entraining air. Air content shall not exceed 5 percent. When reclaimed material containing any asphalt is used in the production of aggregate for lean concrete base, admixtures to reduce air entrainment may be required to reduce air content to not more than 5 percent.

Portland cement, water and admixtures shall conform to Section 90, "Portland Cement Concrete", of the Standard Specifications.

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Aggregate shall be clean and free from vegetable matter and other deleterious substances and shall not be treated with lime, cement or other chemicals before being tested for Sand Equivalent value.

Aggregate shall be of such quality that, when mixed with portland cement in an amount not to exceed 300 pounds per cubic yard, and tested in accordance with Test Method No. Calif. 548, the compressive strength shall be not less than 550 pounds per square inch at 7 days.

The percentage composition by weight of aggregate shall conform to one of the following gradings when determined by Test Method No. Calif. 202, modified by Test Method No. Calif. 905 when there is a difference in specific gravity of 0.2 or more between the coarse and fine portion of the aggreage or between different aggregates of a blend:

	Percentage Passing			
	1-1/2" Maximum		1" Maximum	
Sieve Sizes	Individual Test Result	Moving Average	Individual Test Result	Moving Average
2"	100	100	--	--
1-1/2"	87-100	90-100	100	100
1"	--	--	87-100	90-100
3/4"	45-90	50-85	45-100	50-100
3/8"	35-80	40-75	35-80	40-75
No. 4	20-65	25-60	30-65	35-60
No. 30	6-34	10-30	6-34	10-30
No. 200	0-15	3-12	0-15	3-12

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Aggregate shall have a Sand Equivalent value of not less than the following when tested by Test Method No. Calif. 217:

Individual Test Result	18
Moving Average	21

Evaluation of test results shall conform to the provisions in Section 6-3.02, "Statistical Testing", of the Standard Specifications.

When reclaimed material containing any amount of asphalt is used in the production of aggregate, samples of the aggregate to be tested for Sand Equivalent value shall be air dried, not oven dried. Said air dried samples shall have both individual and moving average Sand Equivalent values not less than a value which is 3 points under the value specified for oven dried samples containing no asphalt.

The Contractor shall notify the Engineer in writing of the source and grading of the aggregate to be used in the lean concrete base. Such material shall be available to the Engineer for sampling and testing at least 30 days prior to scheduled placing of lean concrete base. Should the Contractor change his source of supply, he shall notify the Engineer in writing of the new source and grading, and make that material available for sampling and testing at least 30 days prior to intended use.

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The portland cement content of lean concrete base shall be not less than 230 pounds per cubic yard, except that, after testing samples of the Contractor's proposed aggregate supply, the Engineer may order an increase or decrease in the specified portland cement content. Compensation for any such ordered increase or decrease shall be adjusted in the same manner as for cement in cement treated base.

Proportioning for lean concrete base shall conform to the requirements of Section 90-5, "Proportioning", of the Standard Specifications, except that dividing of aggregate into sizes will not be required.

Mixing and transporting lean concrete base shall conform to the provisions of Section 90-6, "Mixing and Transporting", of the Standard Specifications, except that the second, third and fourth paragraphs of Section 90-6.06, "Amount of Water and Penetration", shall not apply. Lean concrete base shall have a nominal penetration range of 0-2 inches, and the maximum penetration shall not exceed 2-1/2 inches.

Placing, spreading, compacting and shaping shall conform to the provisions of Section 40-1.06, "Placing", and Section 40-1.07, "Spreading, Compacting and Shaping", of the Standard Specifications.

Subgrade to receive lean concrete base, immediately prior to spreading, shall conform to the compaction and elevation tolerances specified for the material involved, and shall be uniformly moist.

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The finished surface of lean concrete base shall be free from porous areas. It shall not vary at any point more than 0.05-foot above or below the grade established by the Engineer. The thickness requirements for portland cement concrete pavement as specified in Section 40-1.135, "Pavement Thickness", of the Standard Specifications shall not be modified because of the variation permitted herein for the finished surface of lean concrete base above or below the grade established by the Engineer.

Hardened lean concrete base with a surface higher than 0.05-foot above the grade established by the Engineer shall be removed and replaced with lean concrete base which complies with these specifications, or if permitted by the Engineer, high areas may be ground until the surface of lean concrete base conforms to the tolerances specified. Grinding shall be performed with diamond blade or with carborundum blade grinding equipment.

Hardened lean concrete base with a surface lower than 0.05-foot below the grade established by the Engineer shall be removed and replaced with lean concrete base which complies with these specifications, or if permitted by the Engineer, the low areas shall be filled with pavement material.

When pavement material is asphalt concrete, the low areas shall be filled with asphalt concrete conforming to the requirements for the lowest layer of asphalt concrete to be placed as pavement. This shall be done as a separate

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operation prior to placing the lowest layer of pavement, and full compensation for such filling will be considered as included in the contract price paid for cement treated base and no additional compensation will be allowed therefor.

When pavement material is portland cement concrete, the low areas shall be filled with pavement concrete at the time and in the same operation that the pavement is placed. Full compensation for such filling will be considered as included in the contract price paid for cement treated base and no additional compensation will be allowed therefor.

Lean concrete base shall be cured with white pigmented curing compound in accordance with the requirements in Sections 90-7.01B, "Curing Compound Method", and 90-7.02, "Curing Pavement", of the Standard Specifications. In addition, at the Contractor's option, lean concrete base for portland cement concrete pavement may be cured by a curing compound conforming to the specifications of AASHTO Designation: M 148, Type 2, except that the loss of water in the water retention test shall not exceed 0.040 gram per square centimeter of surface. The curing compound shall be applied at the approximate rate of one gallon per 200 square feet of area.

No traffic or Contractor's equipment will be permitted on lean concrete base before a period of 72 hours has elapsed after placing lean concrete base.

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After 72 hours, trucks with axle loads not exceeding the maximum specified in Section 7-1.02, "Weight Limitations", of the Standard Specifications may travel on completed lean concrete base. After 72 hours, irrespective of axle loads, trucks hauling portland cement concrete for pavement will be permitted to maneuver on lean concrete base for the length necessary to get into position in front of spreading equipment and to dump their loads. The minimum length necessary to accommodate field conditions and the equipment being used shall be utilized for such maneuvering.

Within the limits of the project and subject to the control of the Engineer, and provided that the Contractor at his expense shall provide such protective measures as are deemed necessary by the Engineer and shall repair any damage caused by such operations, the Contractor will be permitted to haul portland cement concrete for paving on completed lean concrete base with equipment that exceeds the size or weight limitation set forth in Division 15 of the Vehicle Code, and provided further that:

(a) the lean concrete base has cured for not less than 7 days;

(b) hauling is limited to the lane immediately adjacent to the median, in each direction; and

(c) block cracking does not occur under hauling operations.

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If block cracking occurs, the Engineer may reduce said loads so that the maximum weight upon any one wheel, or wheels, supporting one end of an axle, and resting upon the roadway, shall not exceed 10,000 pounds. The Contractor shall not be entitled to any additional compensation nor extension of contract time by reason of such load reduction.

Before placing pavement over lean concrete base, any damage resulting from the Contractor's operations shall be repaired, all loose material shall be broomed from the base, and any damaged curing compound shall be repaired by the Contractor at his expense, all as directed by the Engineer.

Lean concrete base will be paid for at the contract price per cubic yard of cement treated base of the type shown in the Engineer's Estimate, calculated from the dimensions shown on the plans for cement treated base as provided in Section 27-1.11, "Measurement", of the Standard Specifications. No deduction will be made for the allowable decrease in thickness of lean concrete base.

Curing compound will be paid for at the contract price per ton for liquid asphalt, MC-250, applied at the rate of 0.20-gallon per square yard for the area of cement treated base shown on the plans.

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The above prices and payments shall include full compensation for furnishing all labor, materials (including cement in the amount of 230 pounds per cubic yard of lean concrete base), tools, equipment, and incidentals, including subgrade modifications for the construction of lean concrete base, and doing all the work involved in constructing lean concrete base, complete in place, as specified in these special provisions, and as directed by the Engineer.

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APPENDIX B

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07 LA 14
ROSAMOND

PAVED 1968
CT BASE
(CT = Cement Treated)

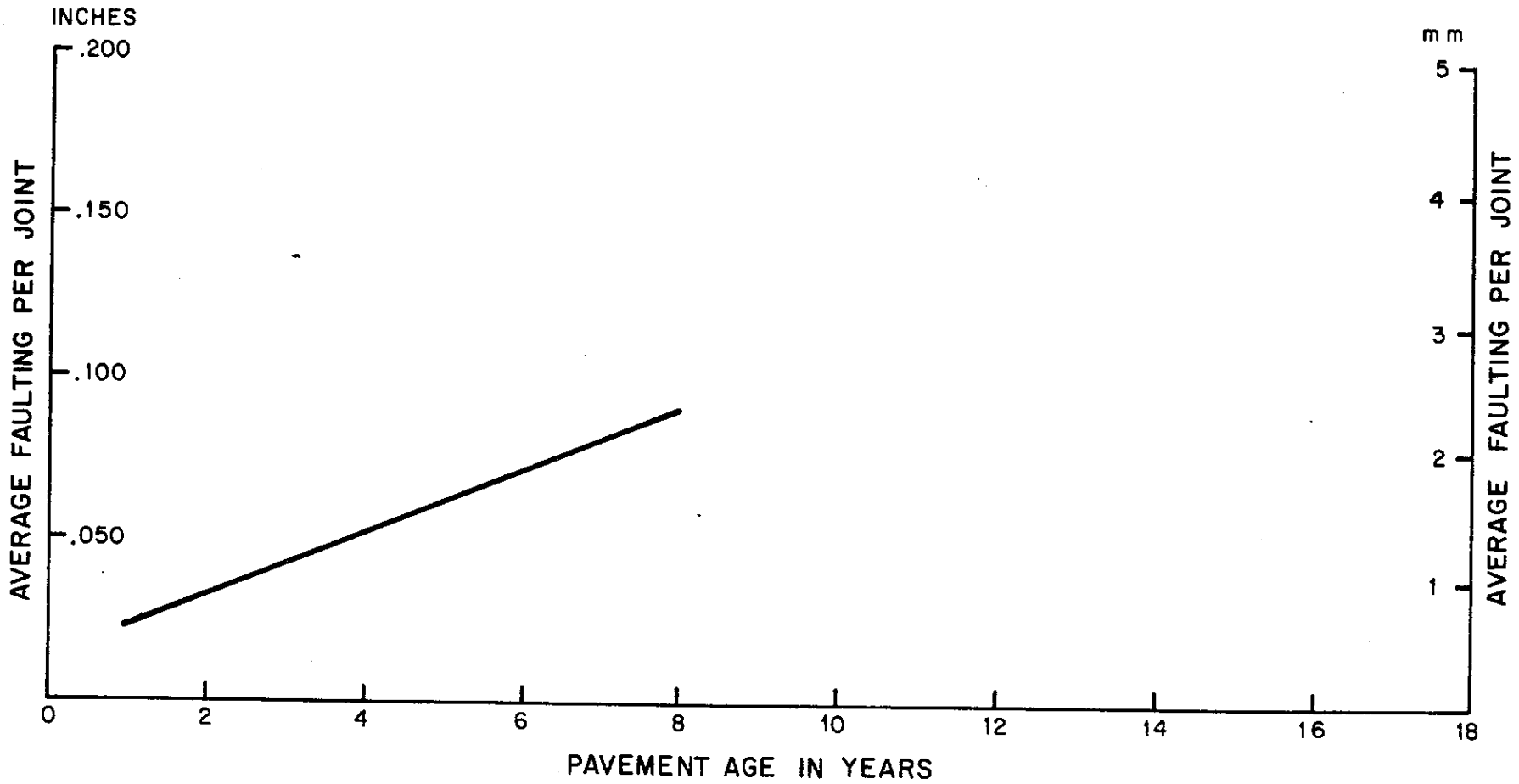

Figure B-1

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11 Riv 10
INDIO

PAVED 1972
CT BASE

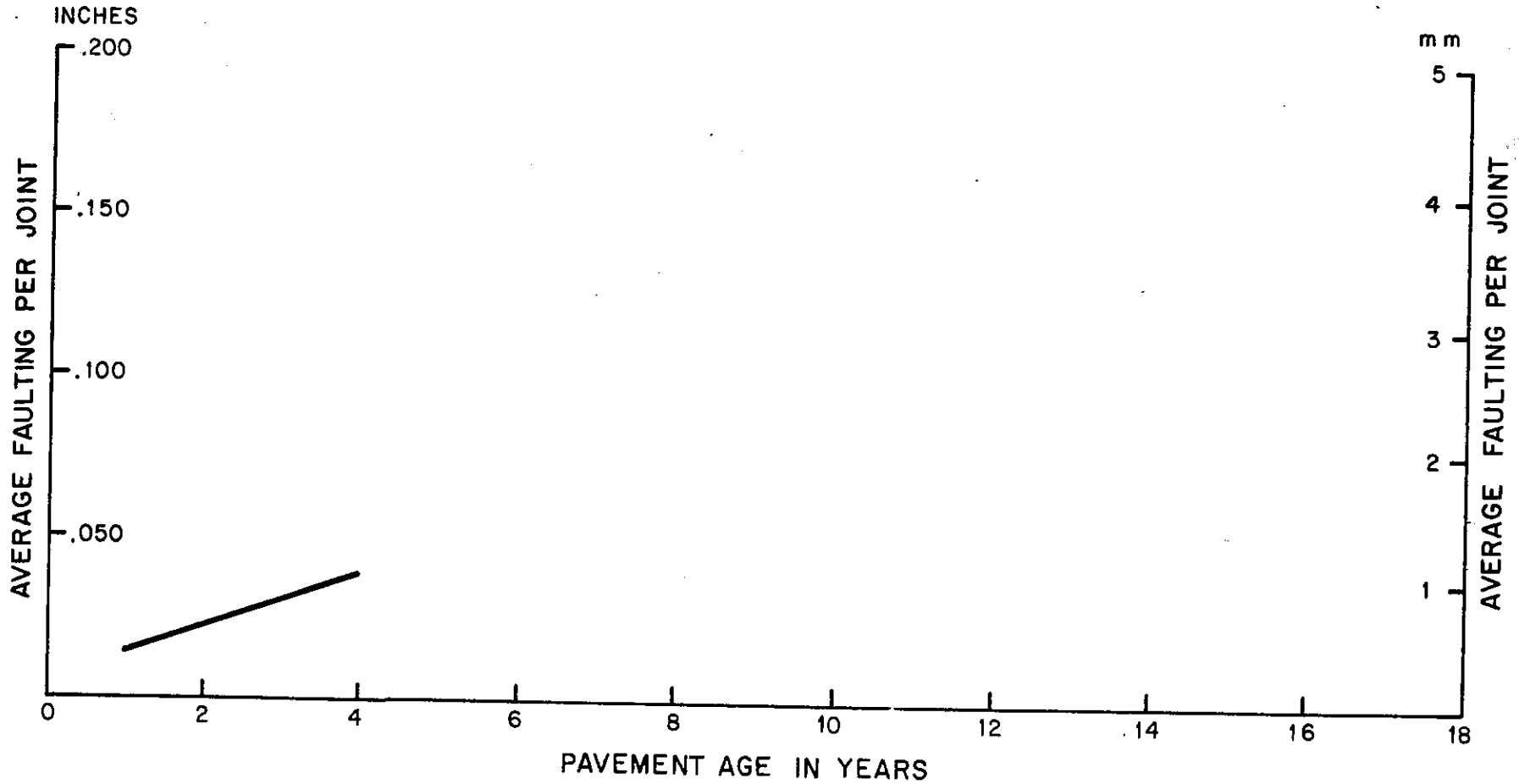

Figure B-2

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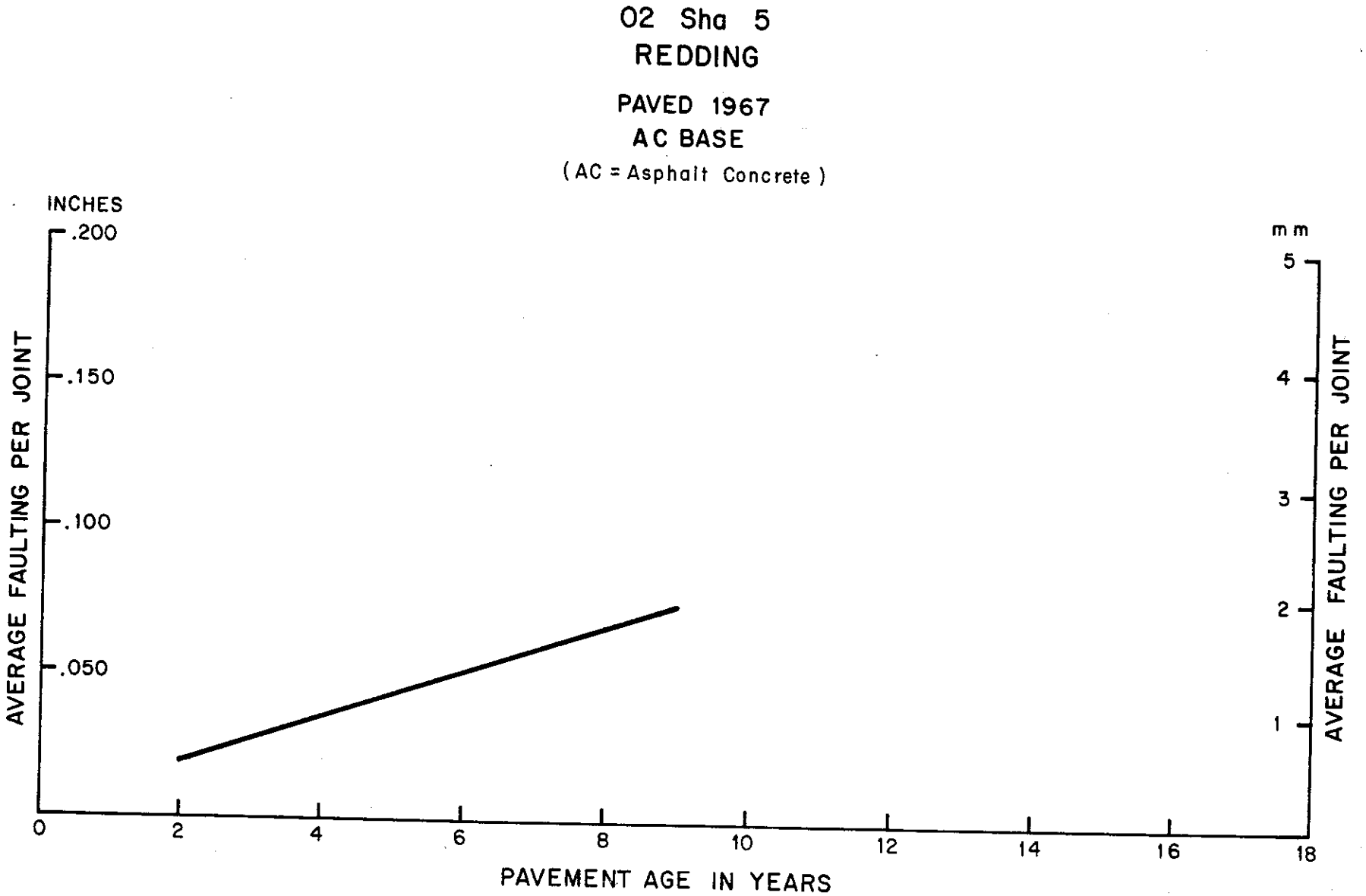

Figure B-3

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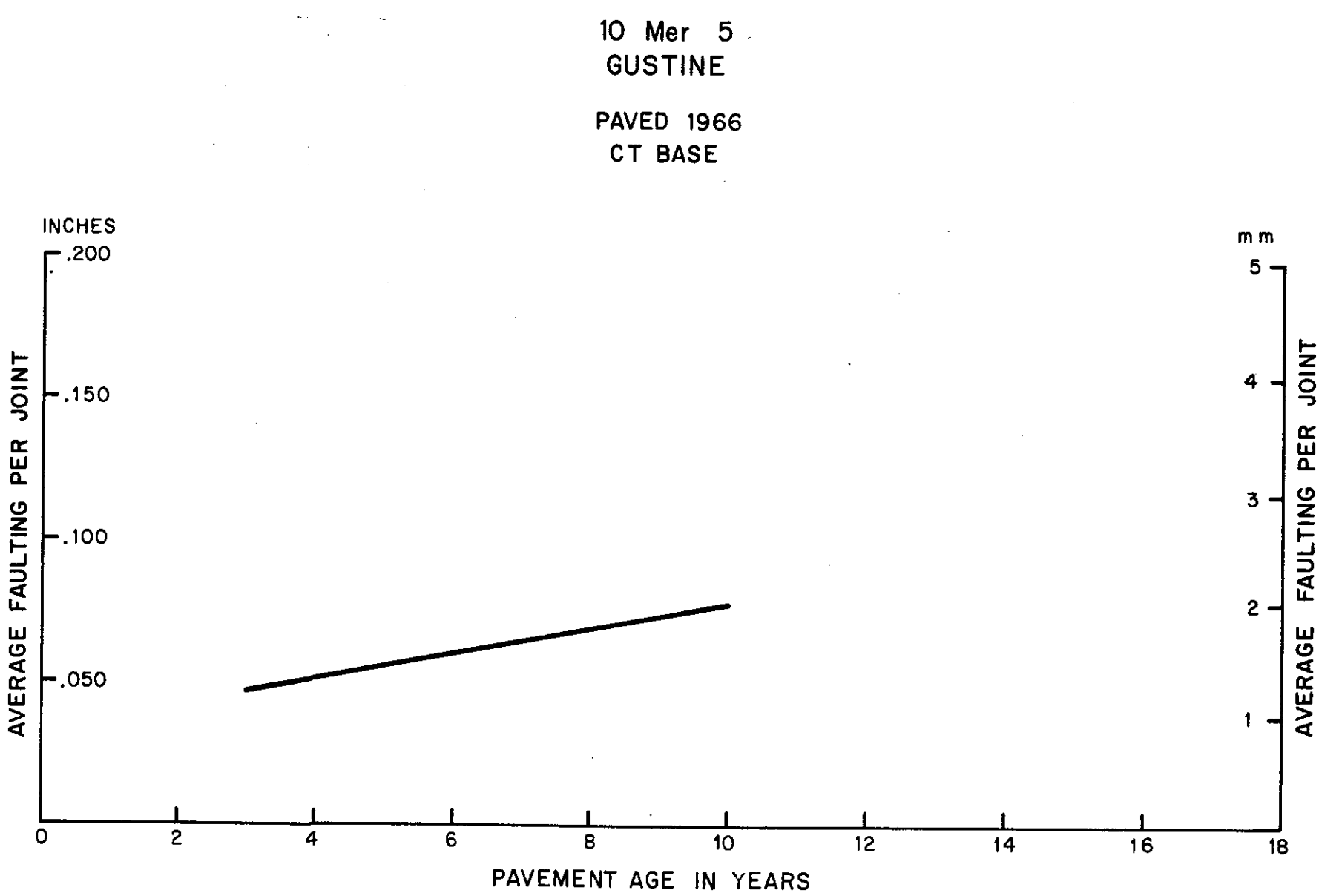

Figure B-4

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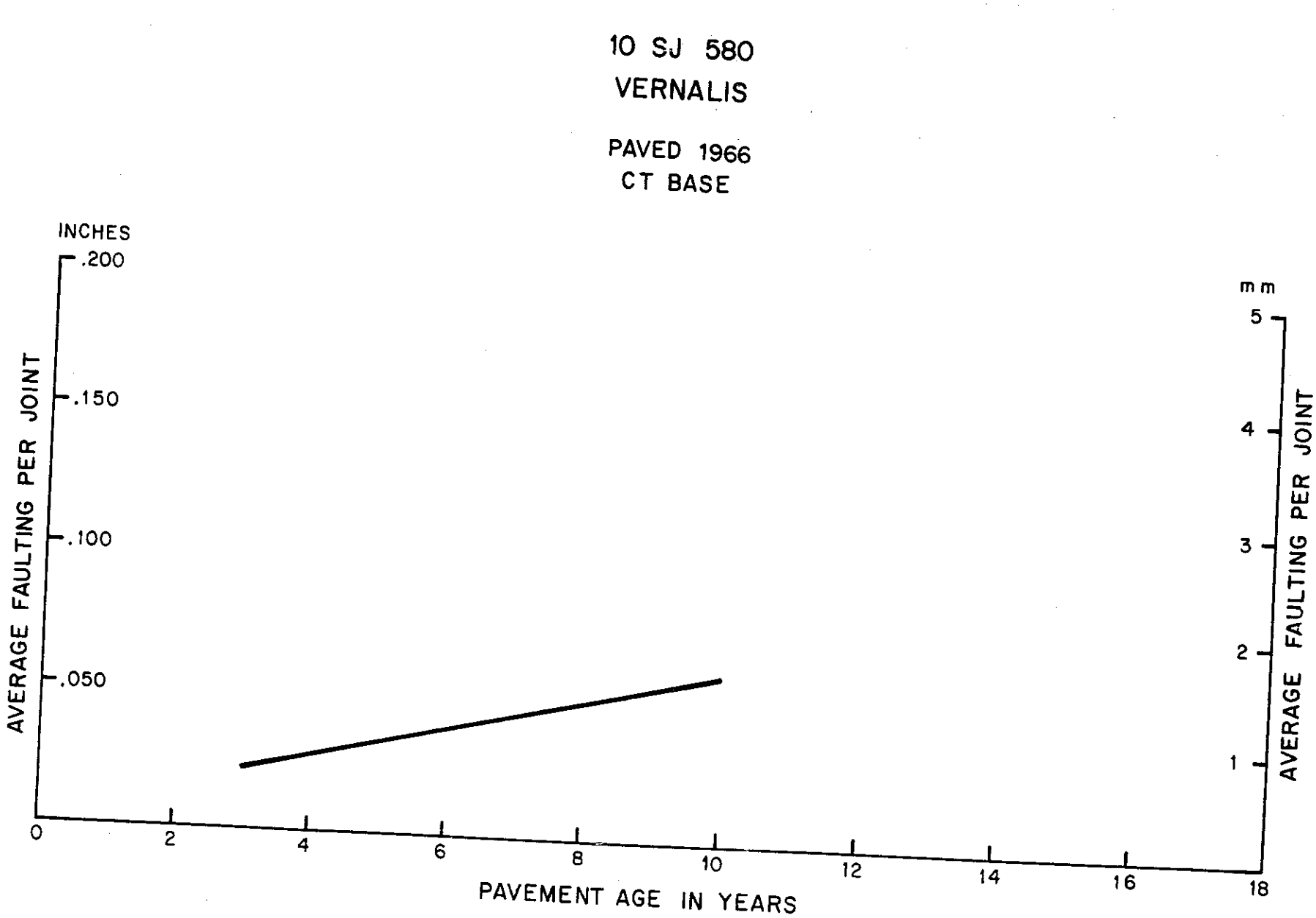

Figure B-5

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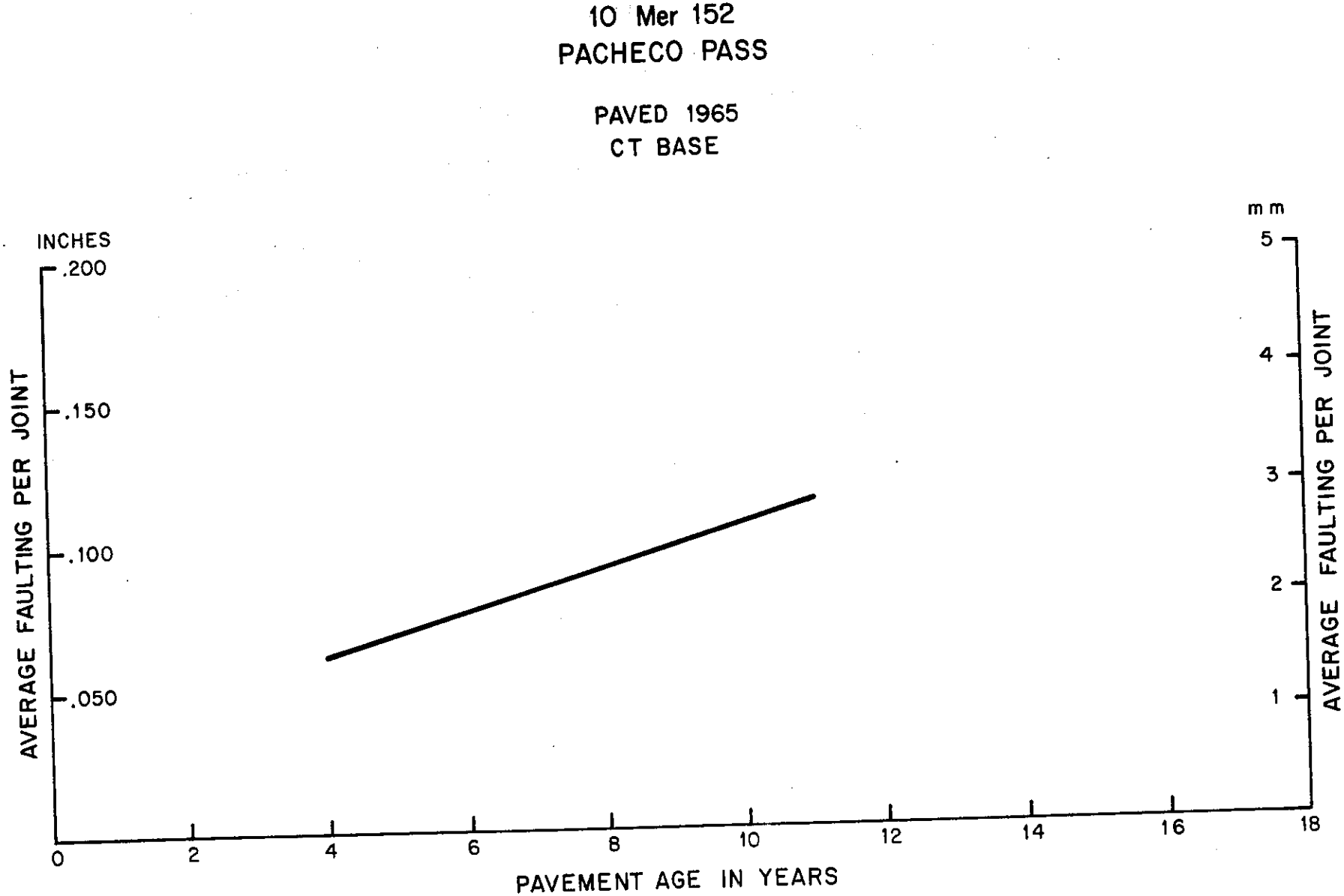

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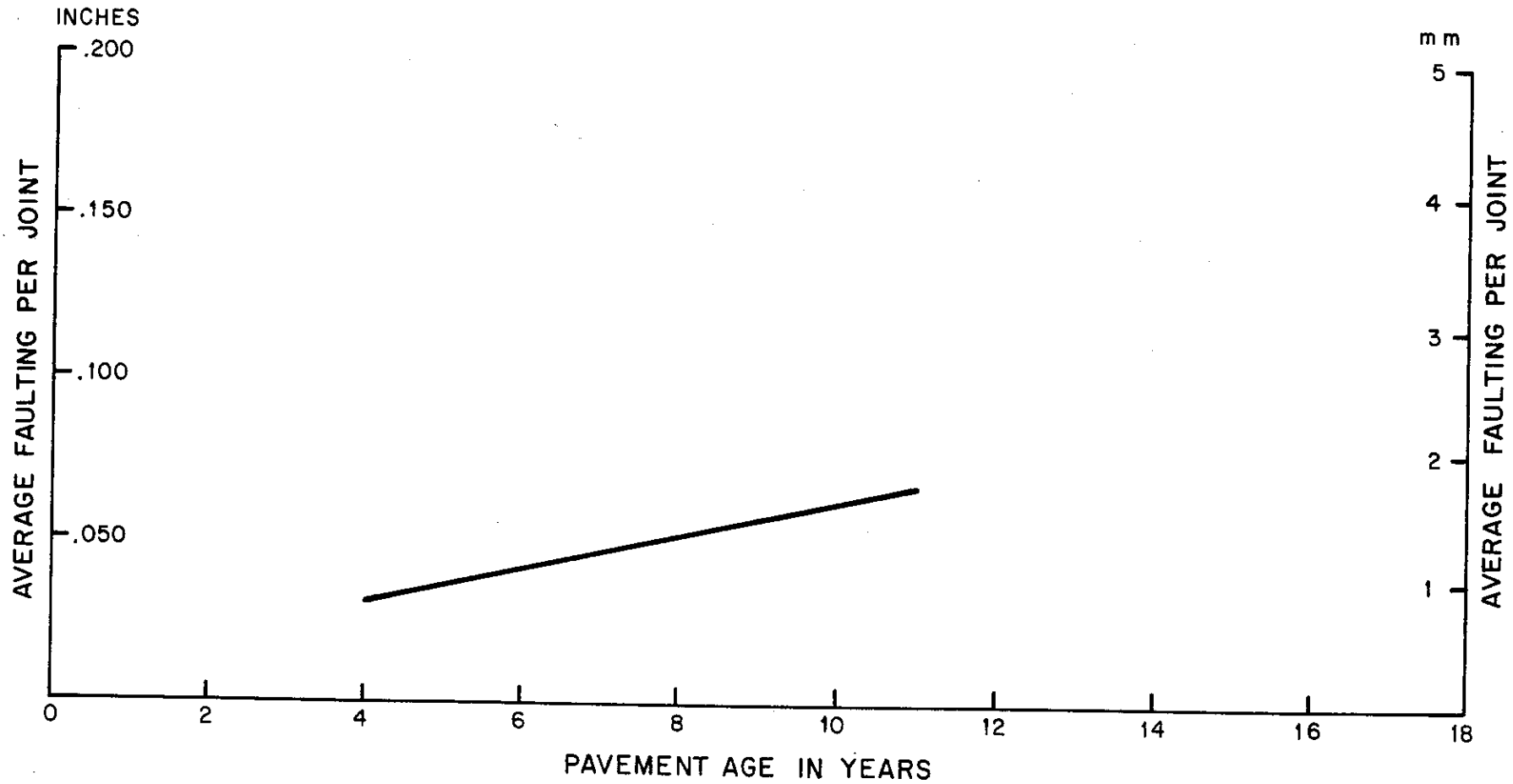

Figure B-7

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09 Ker 58
TEHACHAPI WB

PAVED 1965
AC BASE

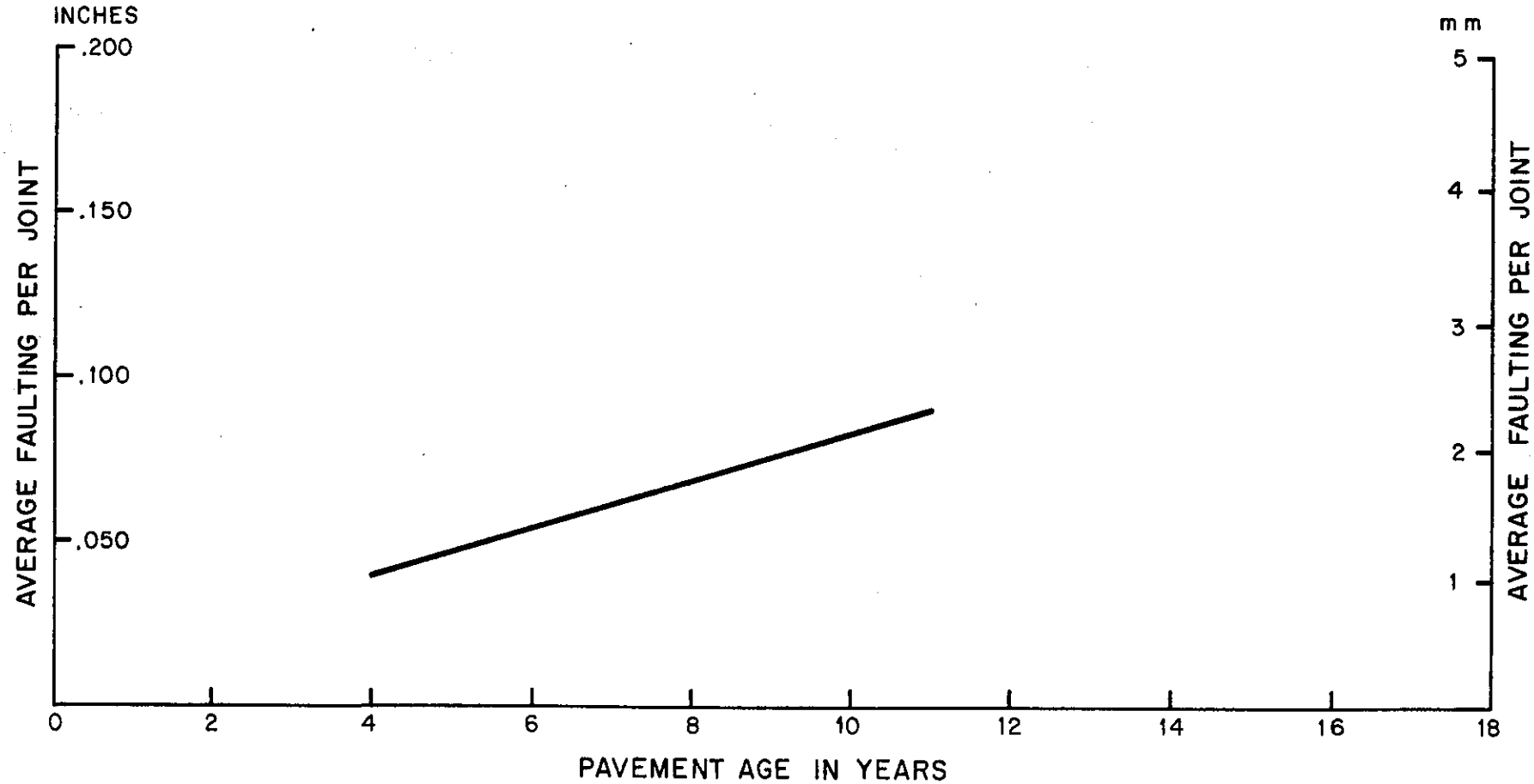

Figure B-8

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09 Ker 58
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PAVED 1965
CT BASE

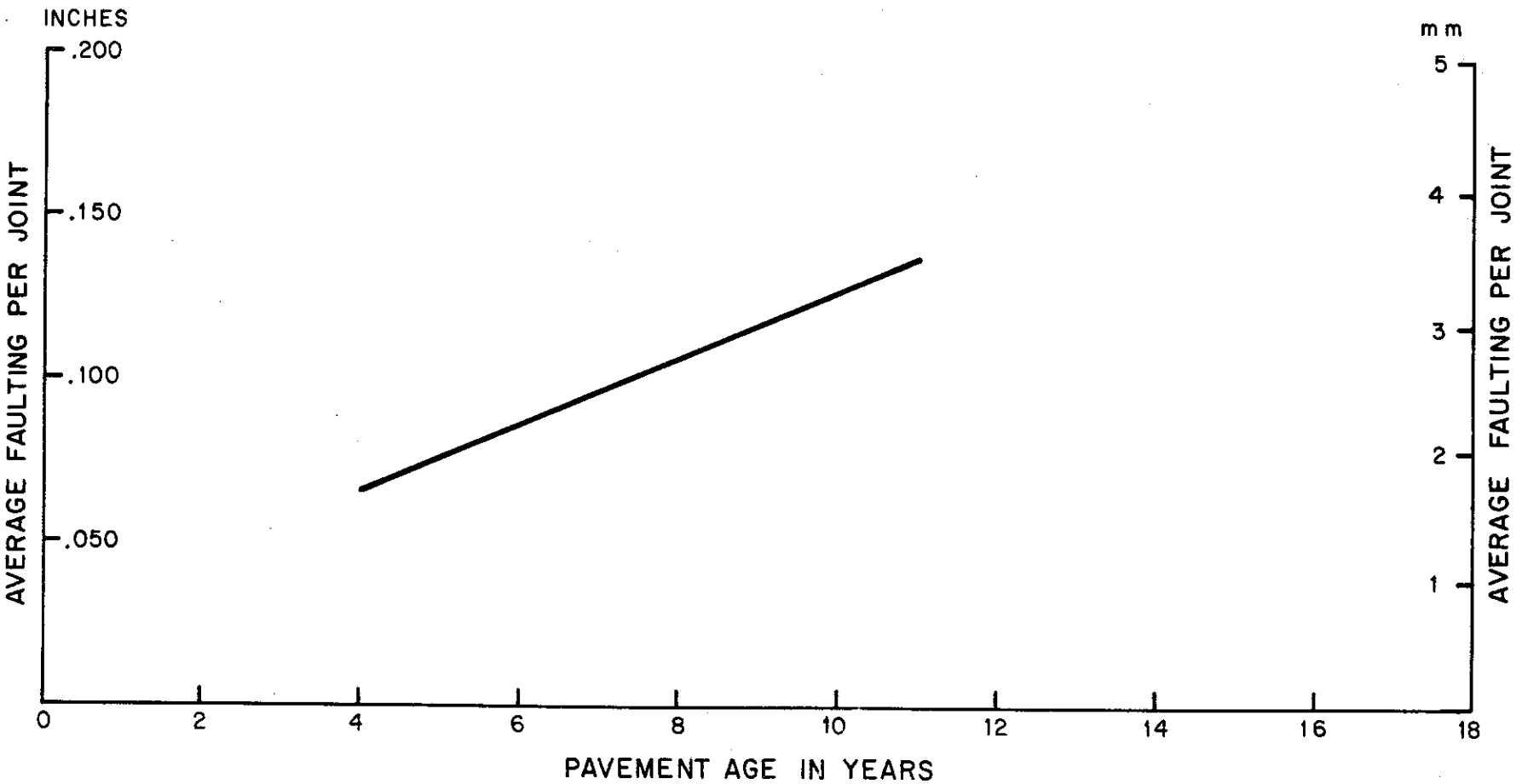

Figure B-9

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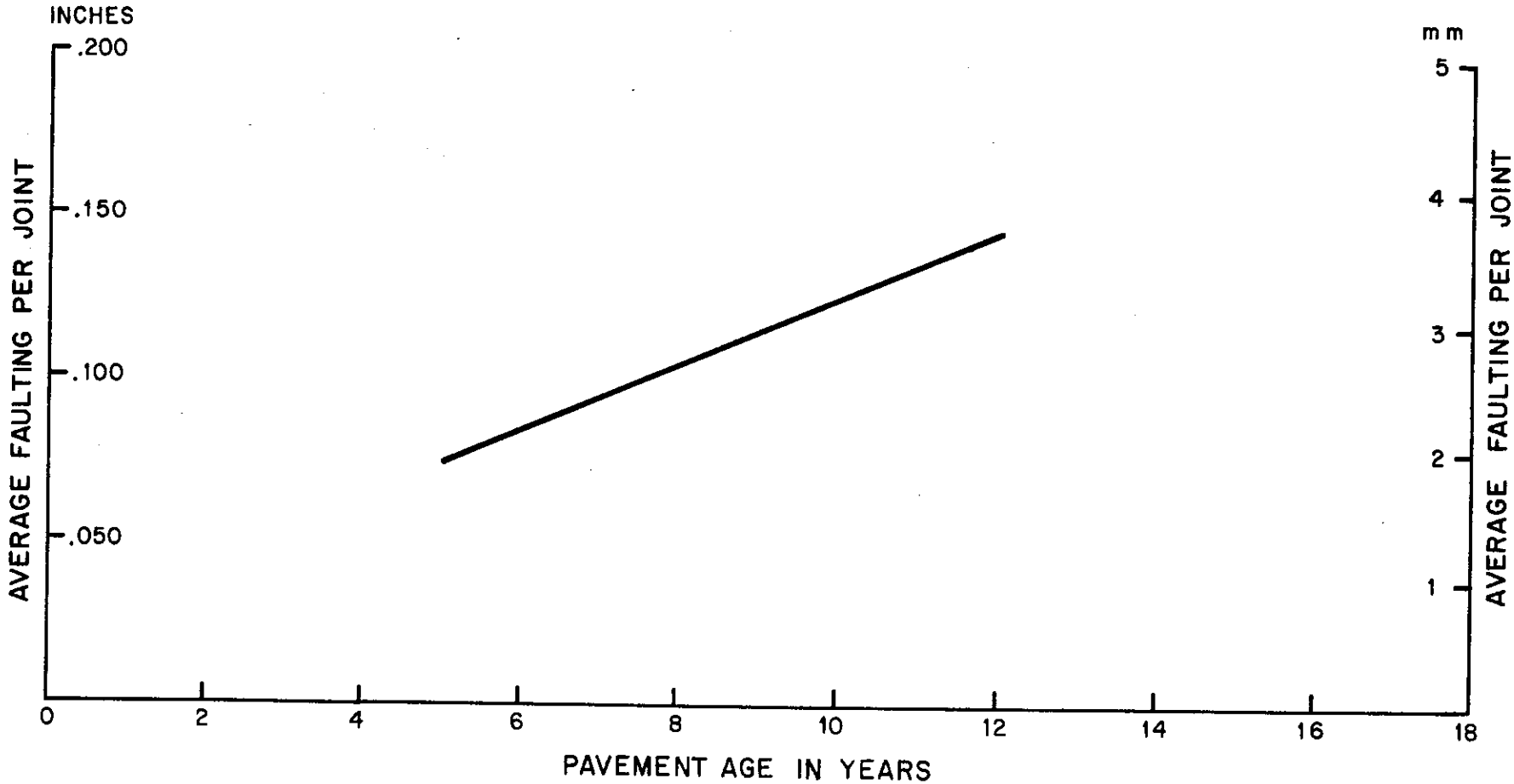

Figure B-10

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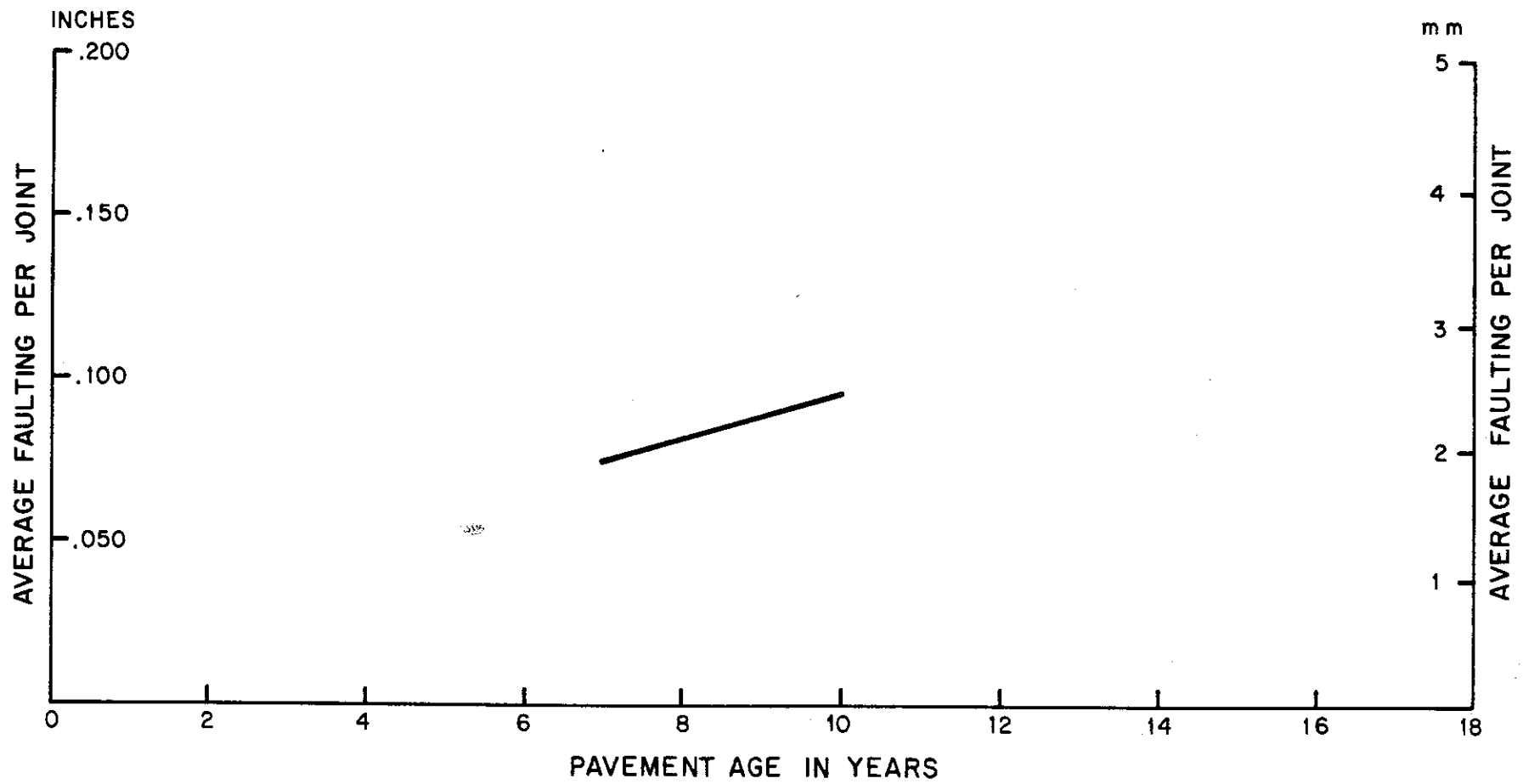

Figure B-11

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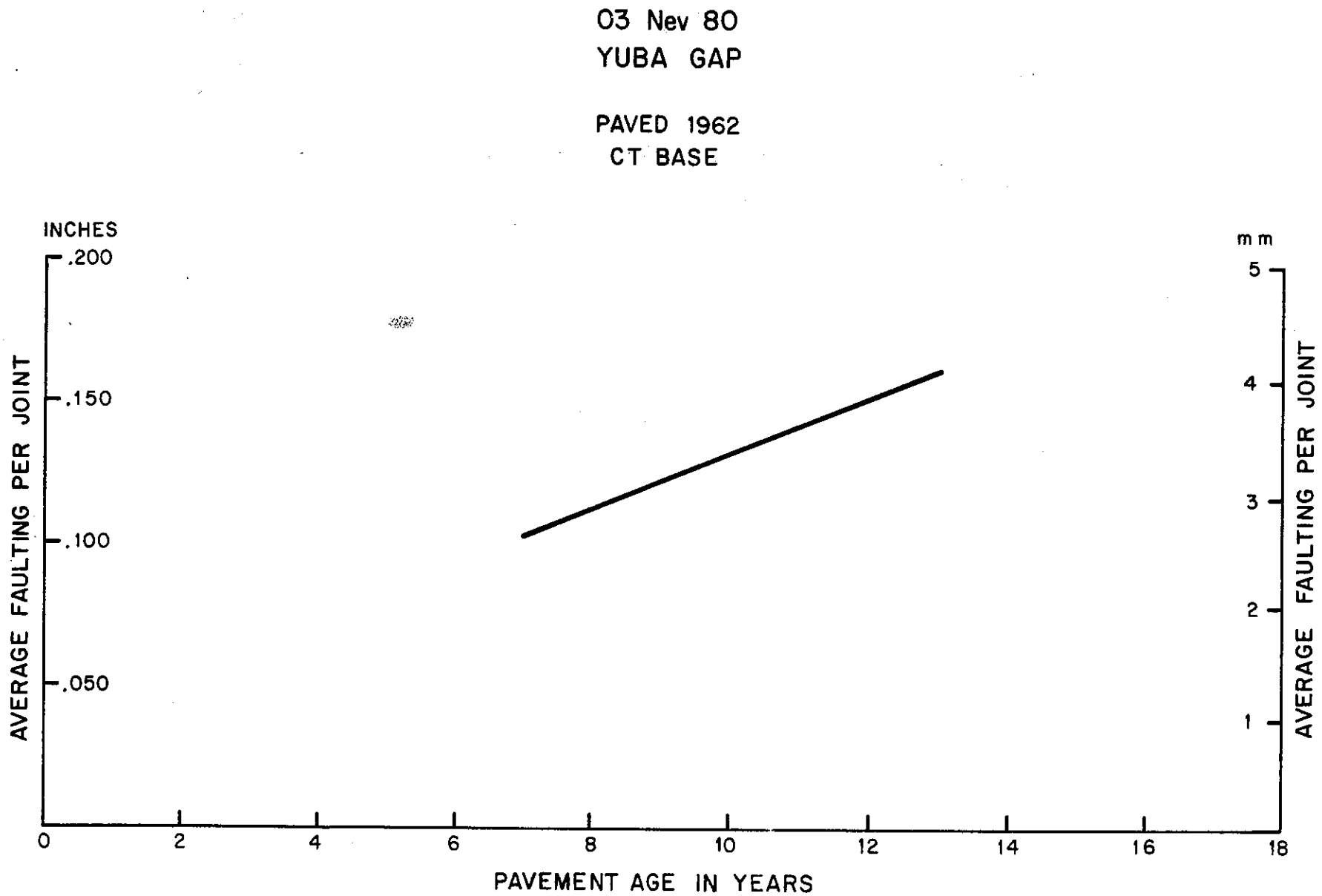

Figure B-12

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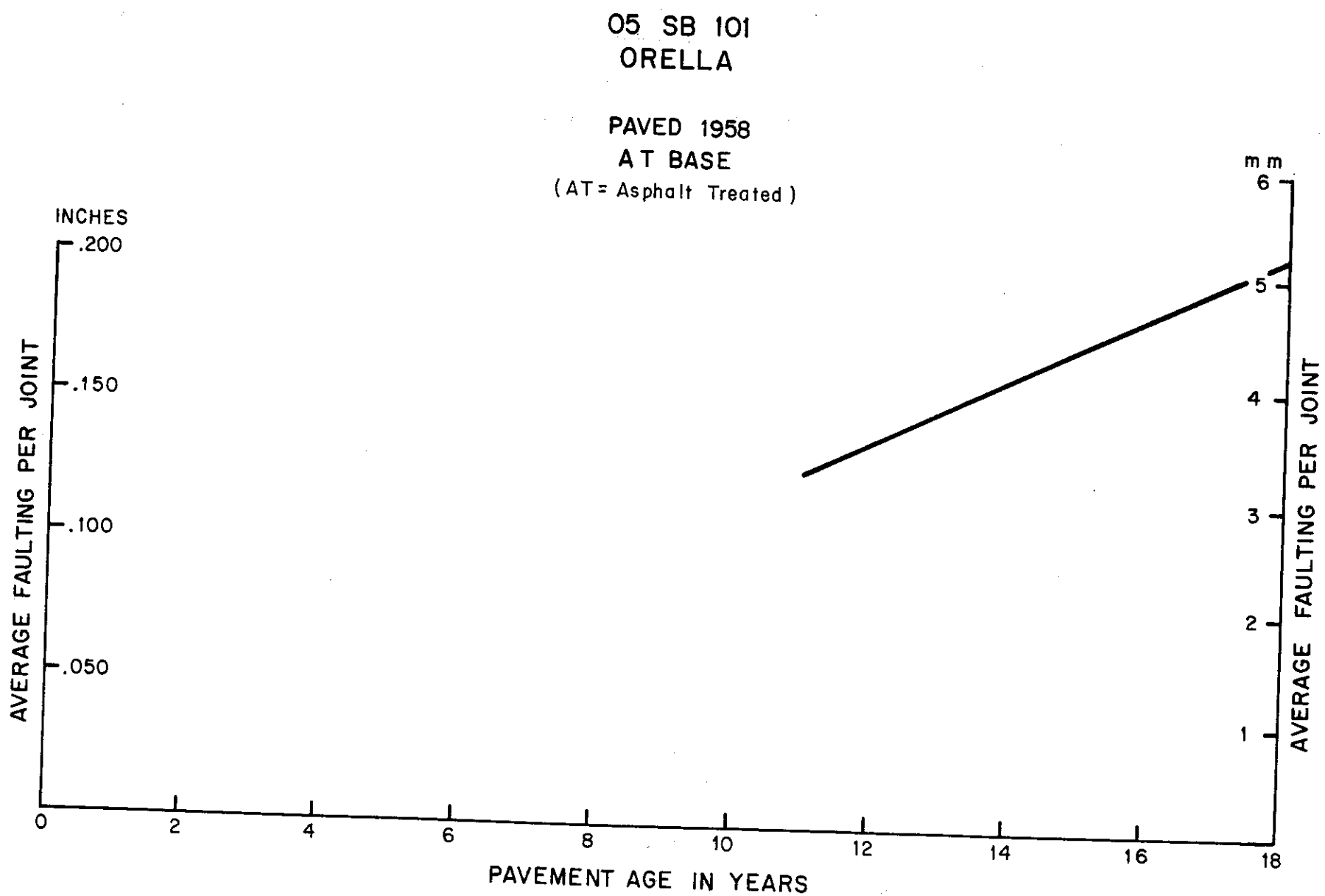

Figure B-13

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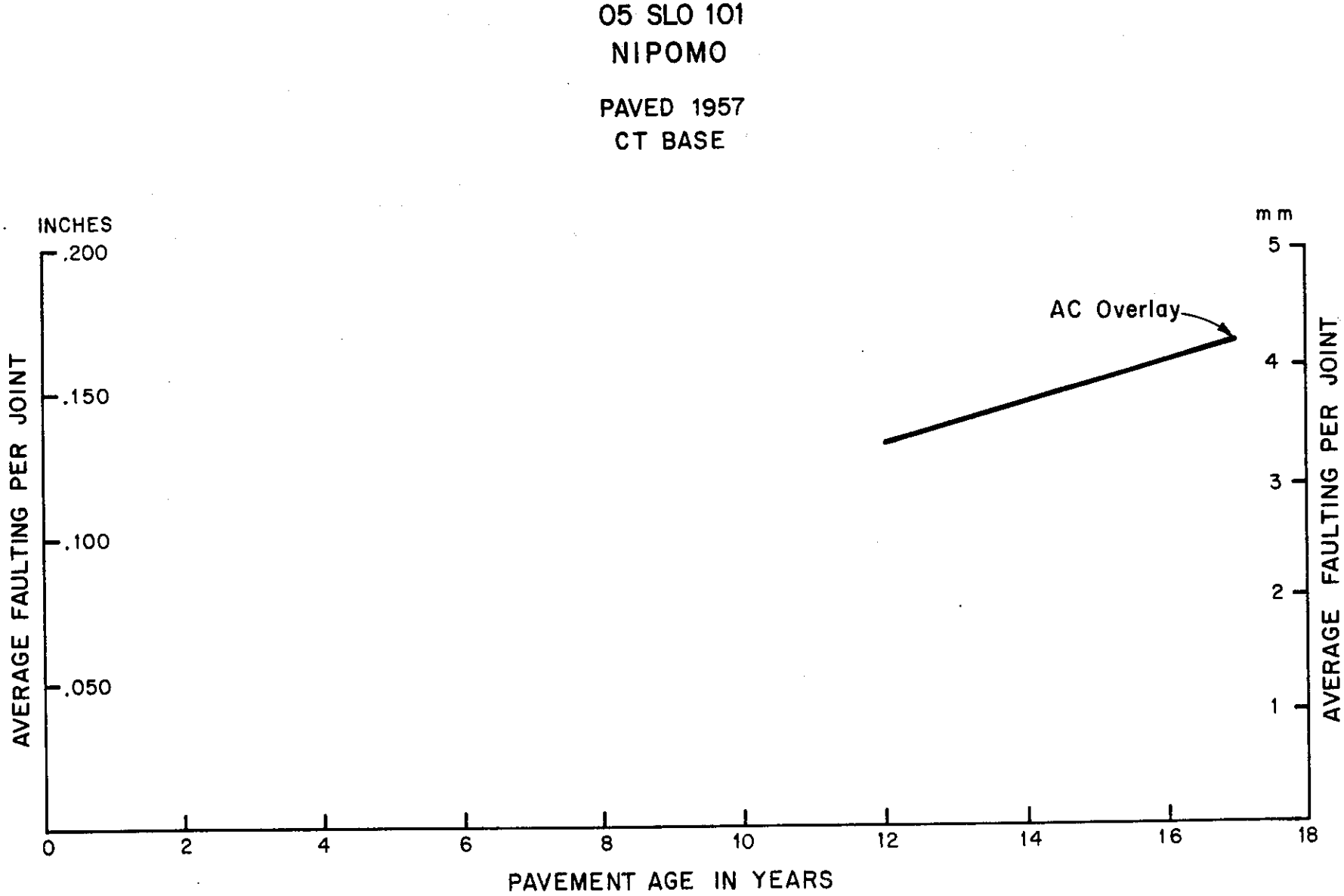


Figure B-14

ClibPDF - www.fastio.com

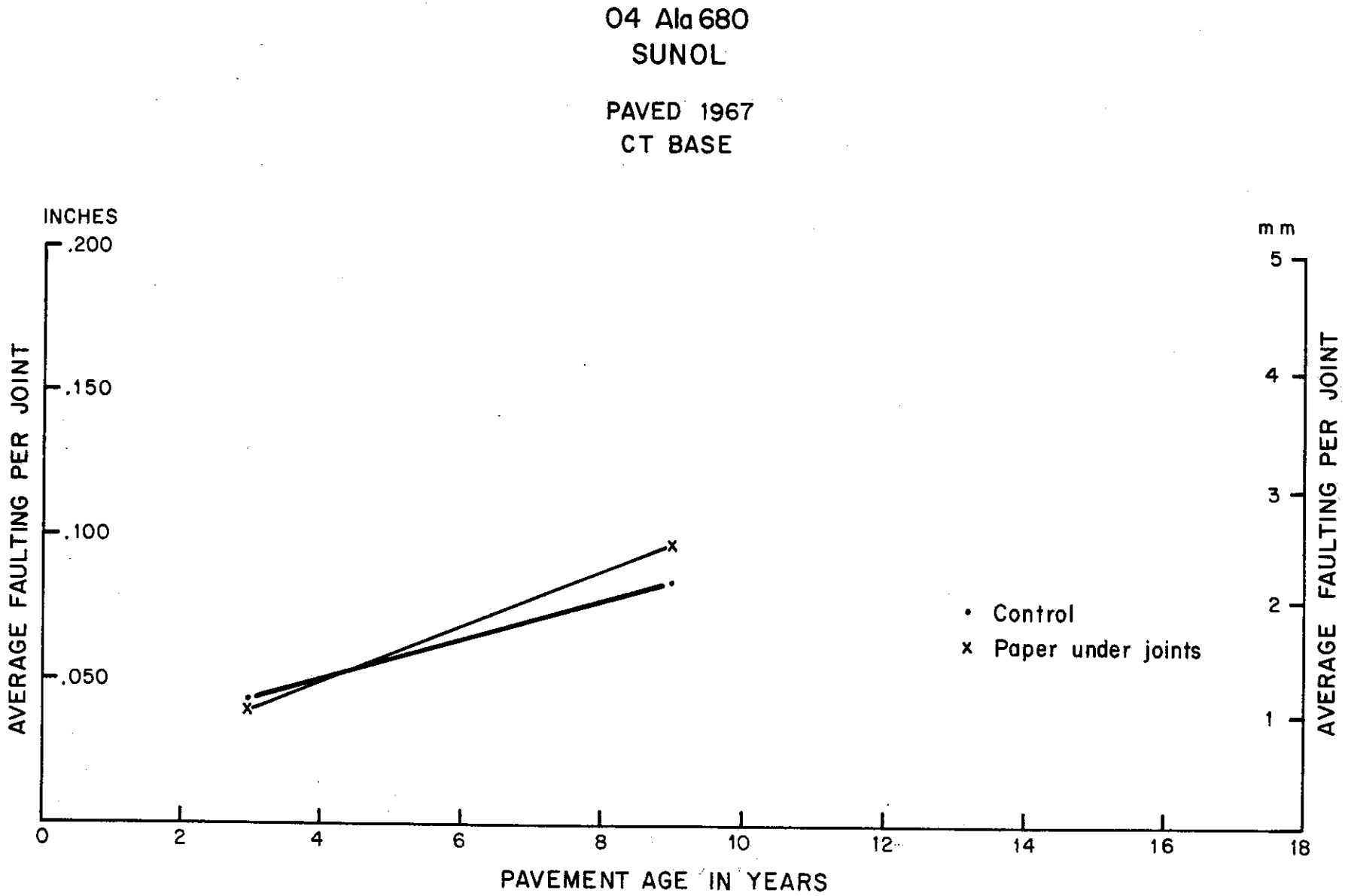


Figure B-15

ClibPDF - www.fastio.com

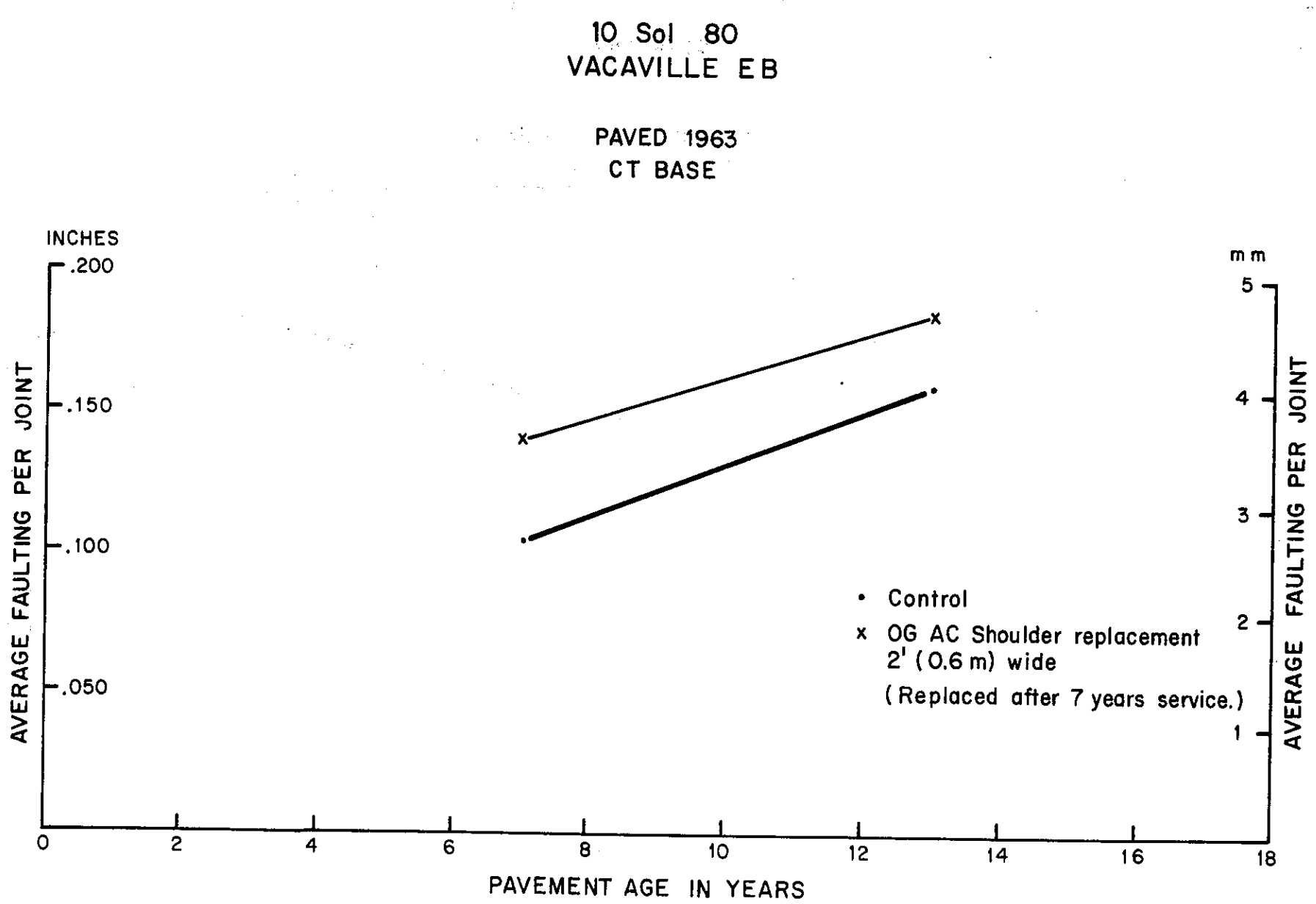


Figure B-16

ClibPDF - www.fastio.com

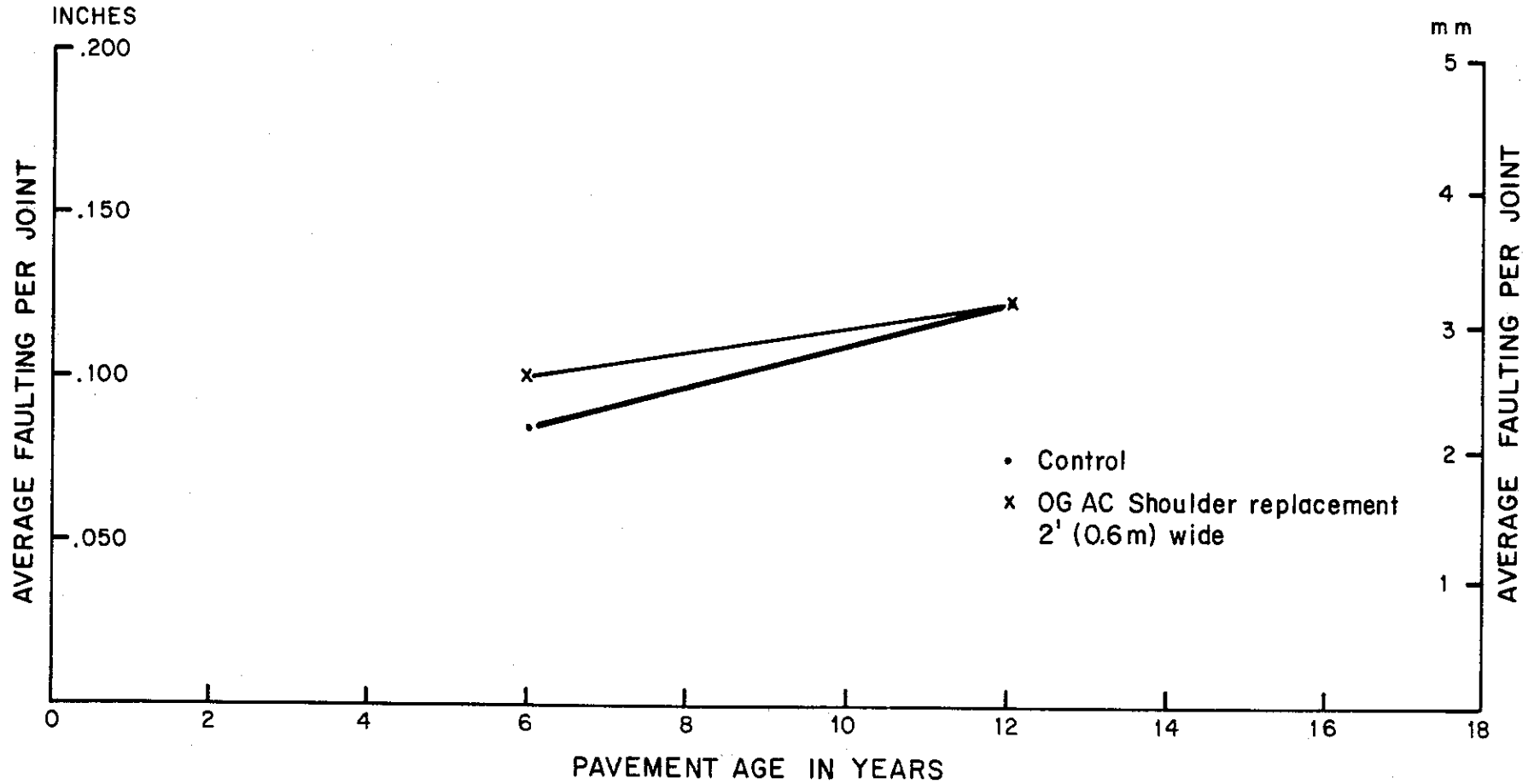


Figure B-17

ClibPDF - www.fastio.com

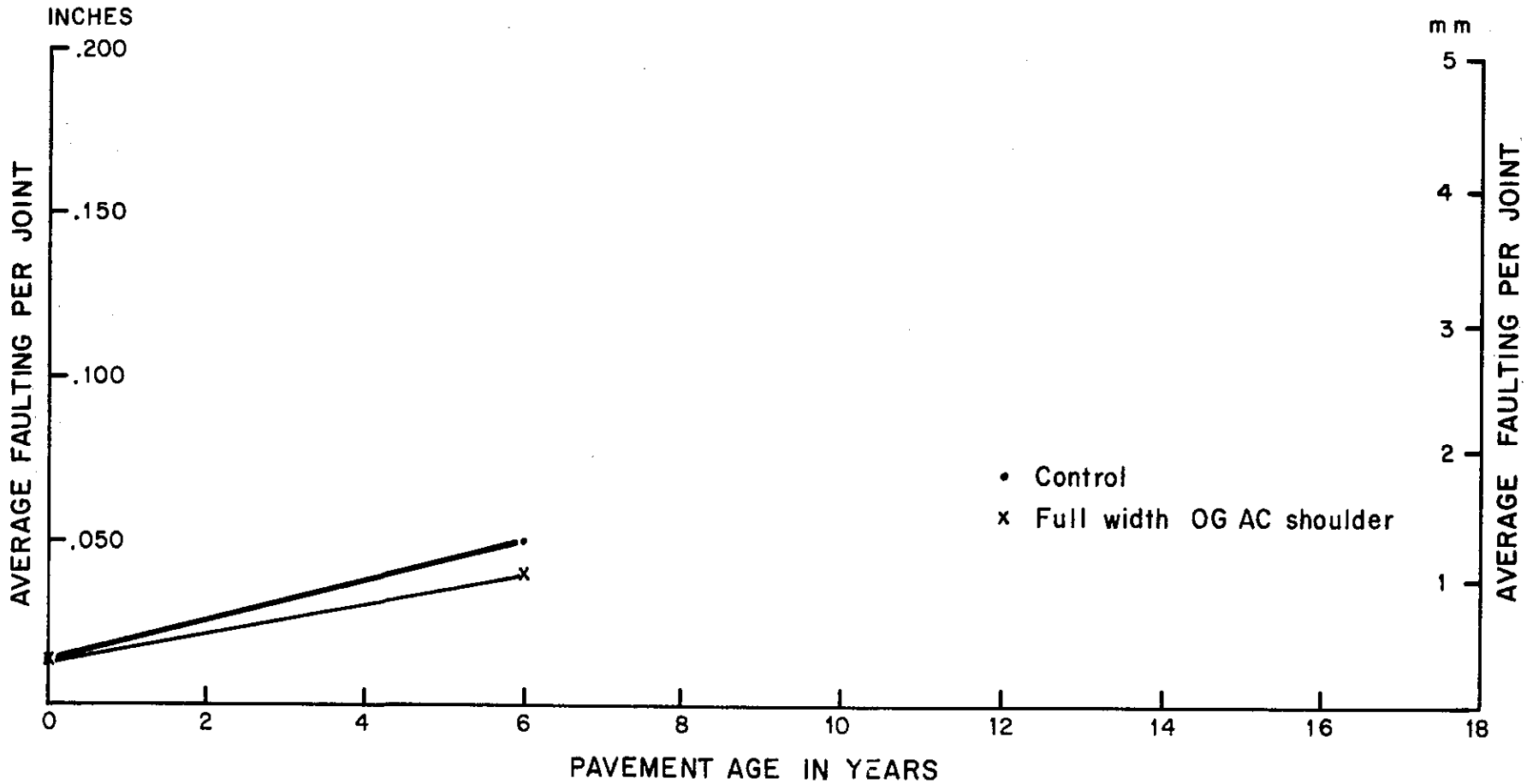


Figure B-18

ClibPDF - www.fastio.com

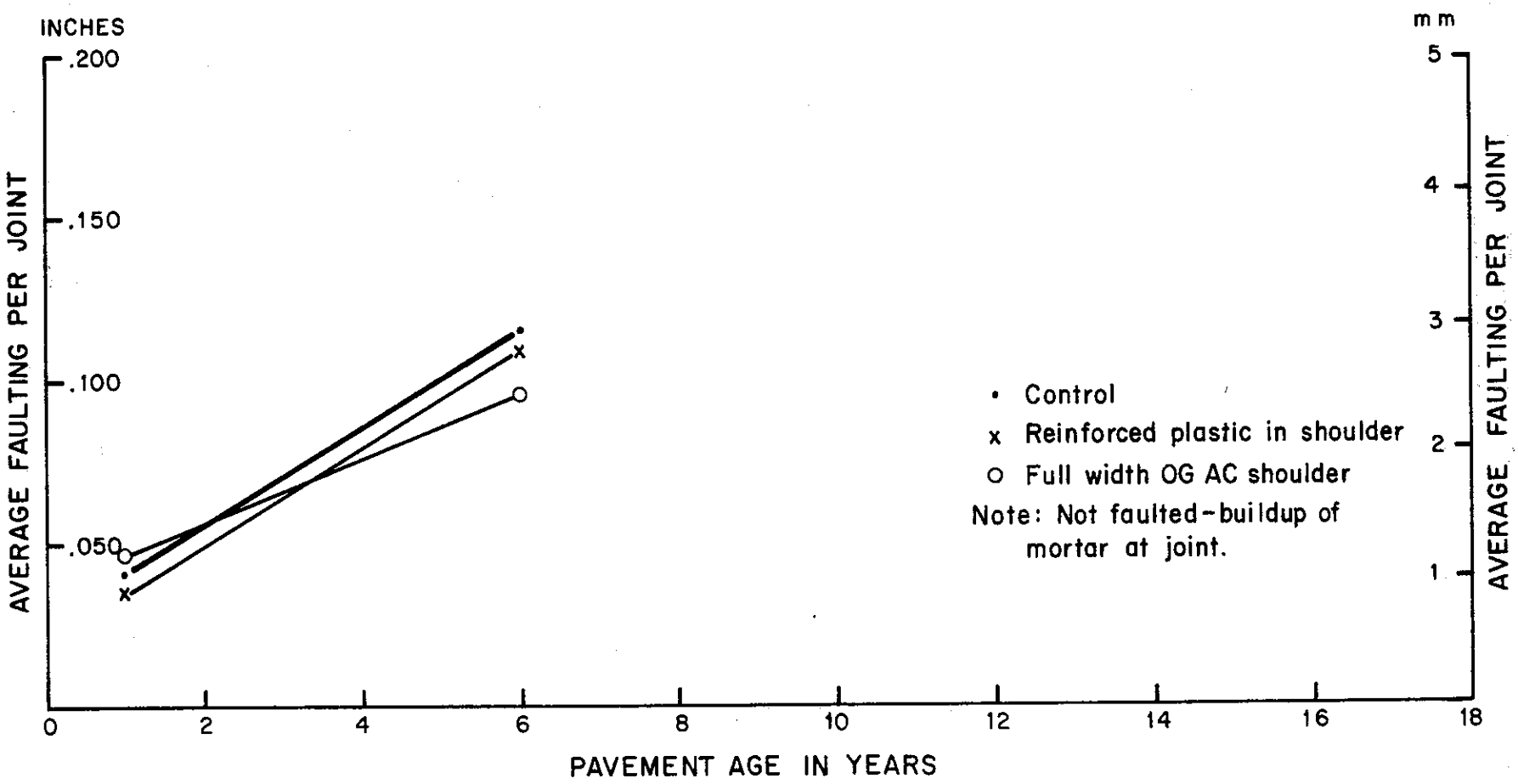


Figure B-19

ClibPDF - www.fastio.com

10 SJ 205
N. TRACY

PAVED 1970
CT BASE

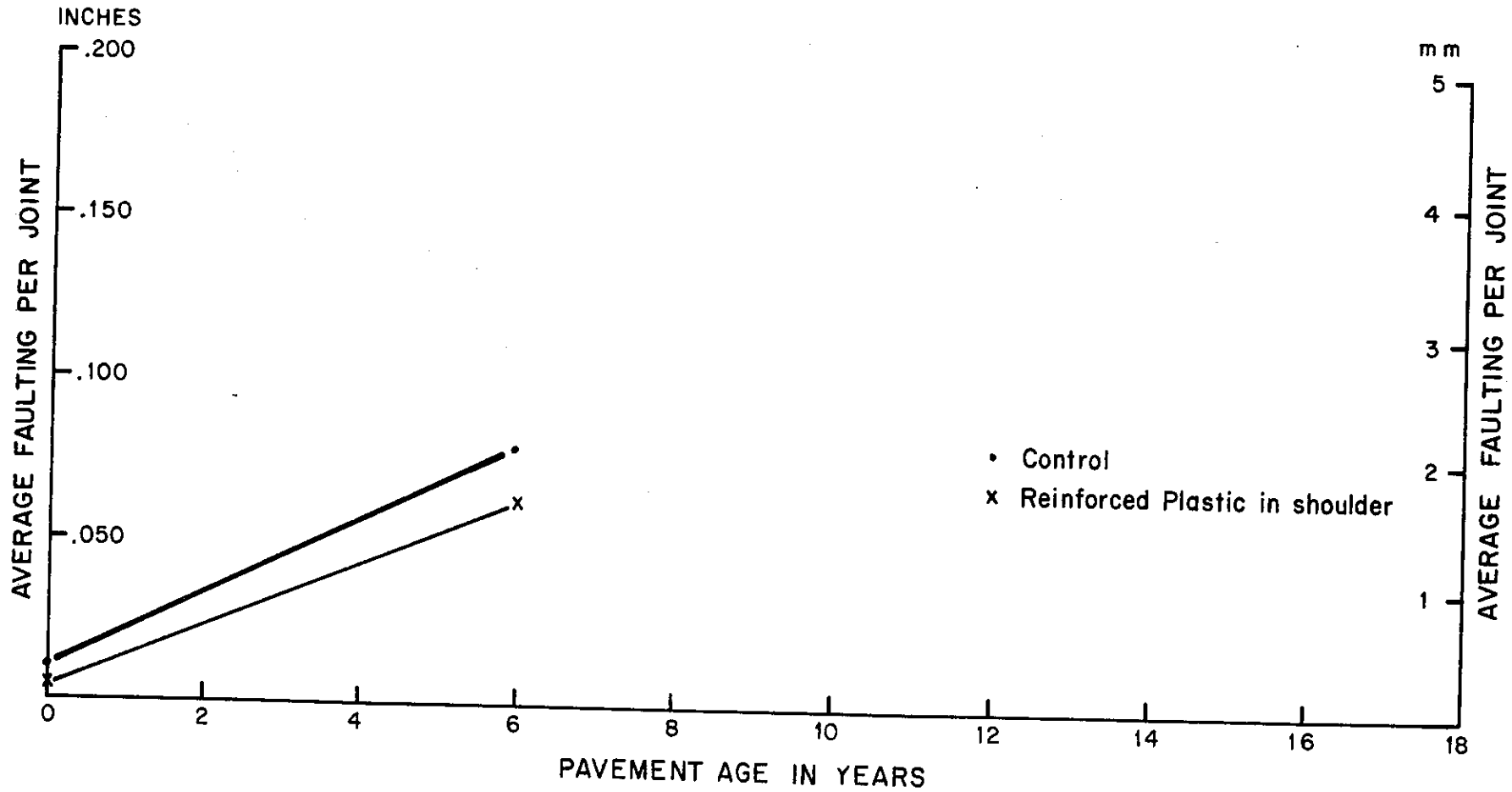


Figure B-20

ClibPDF - www.fastio.com

05 Mon 1
FORT ORD

PAVED 1972 & 1973

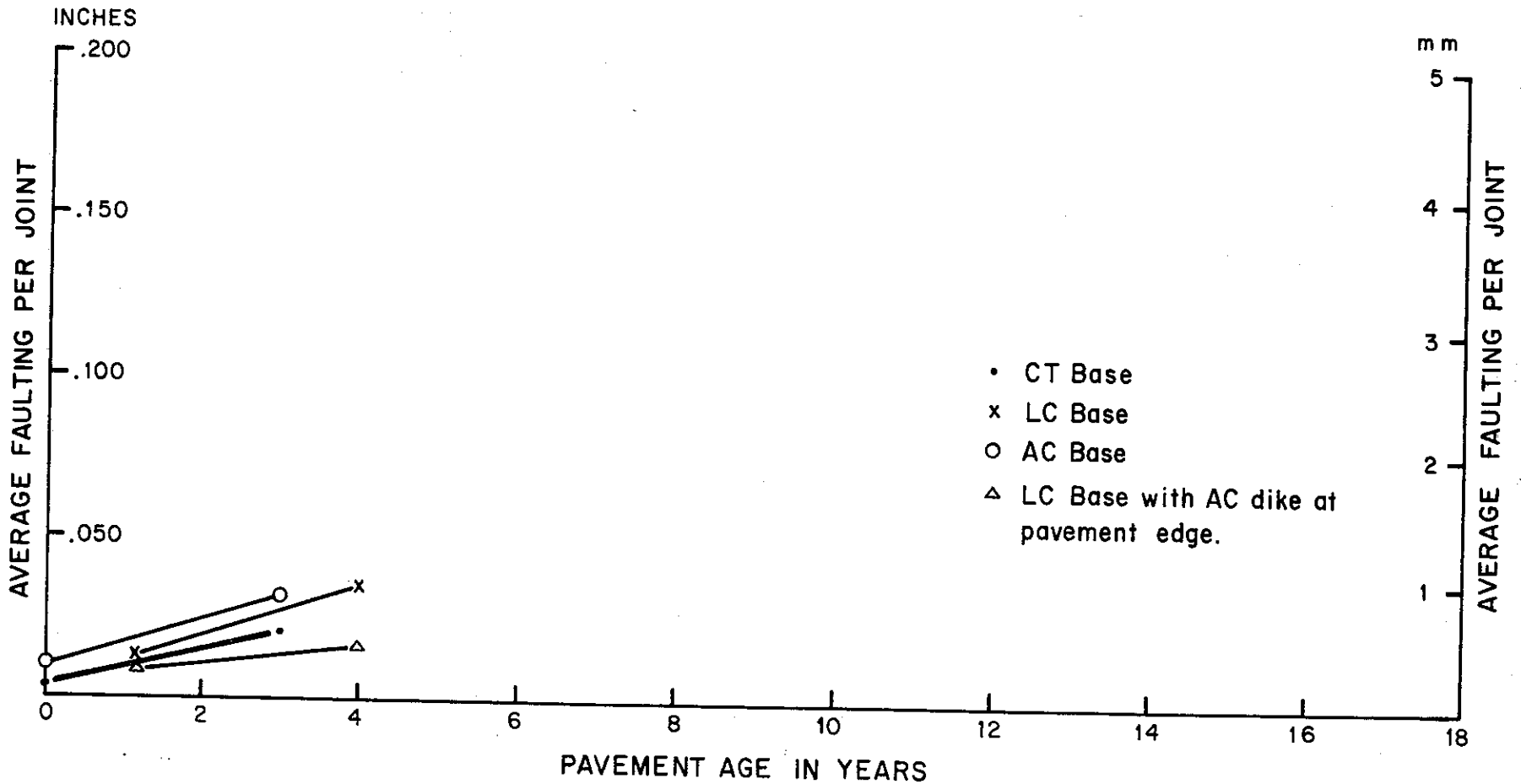


Figure B-21

ClibPDF - www.fastio.com

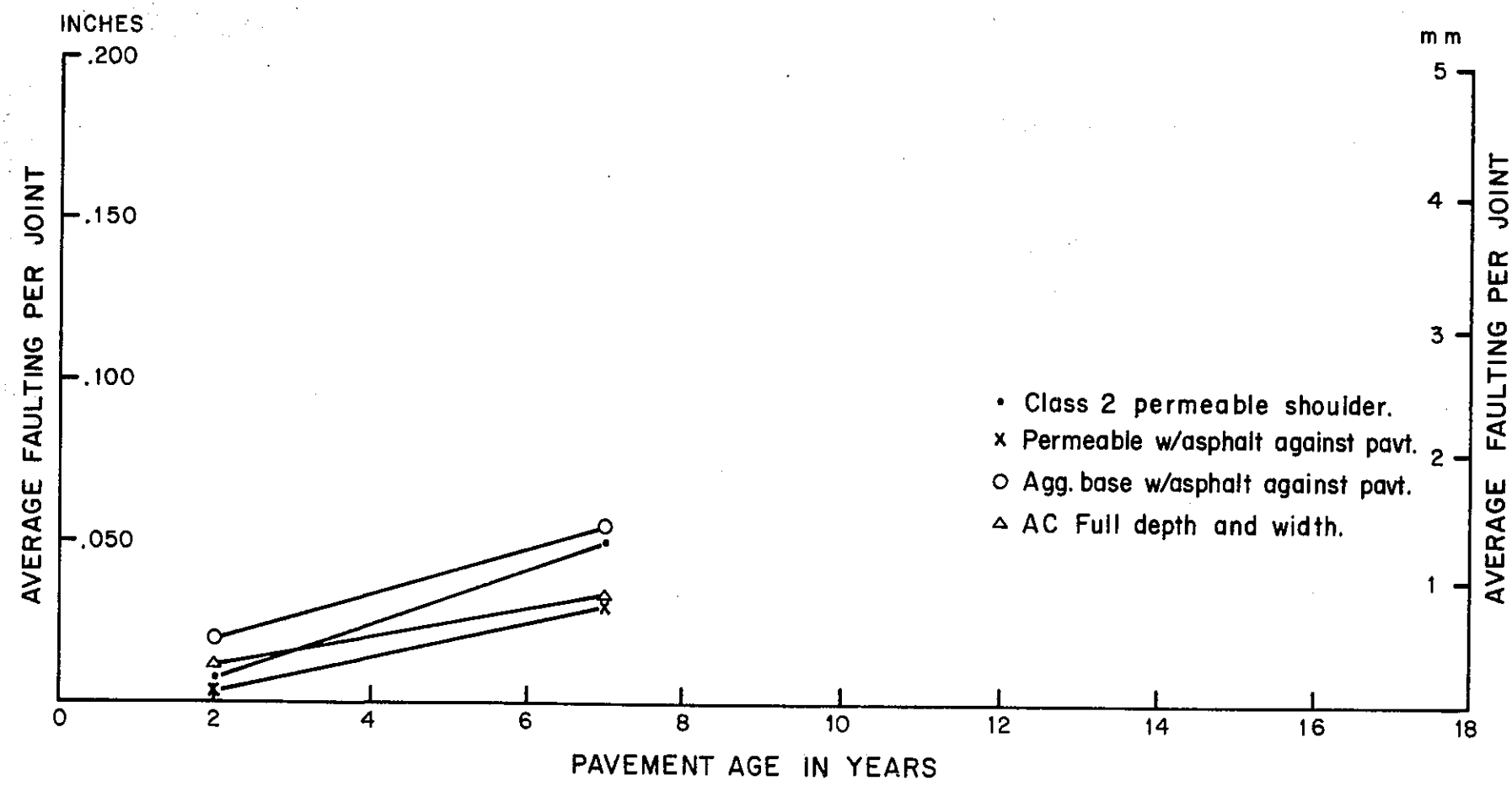


Figure B-22

ClibPDF - www.fastio.com

10 SJ 5
E. TRACY SB

PAVED 1971
CT BASE

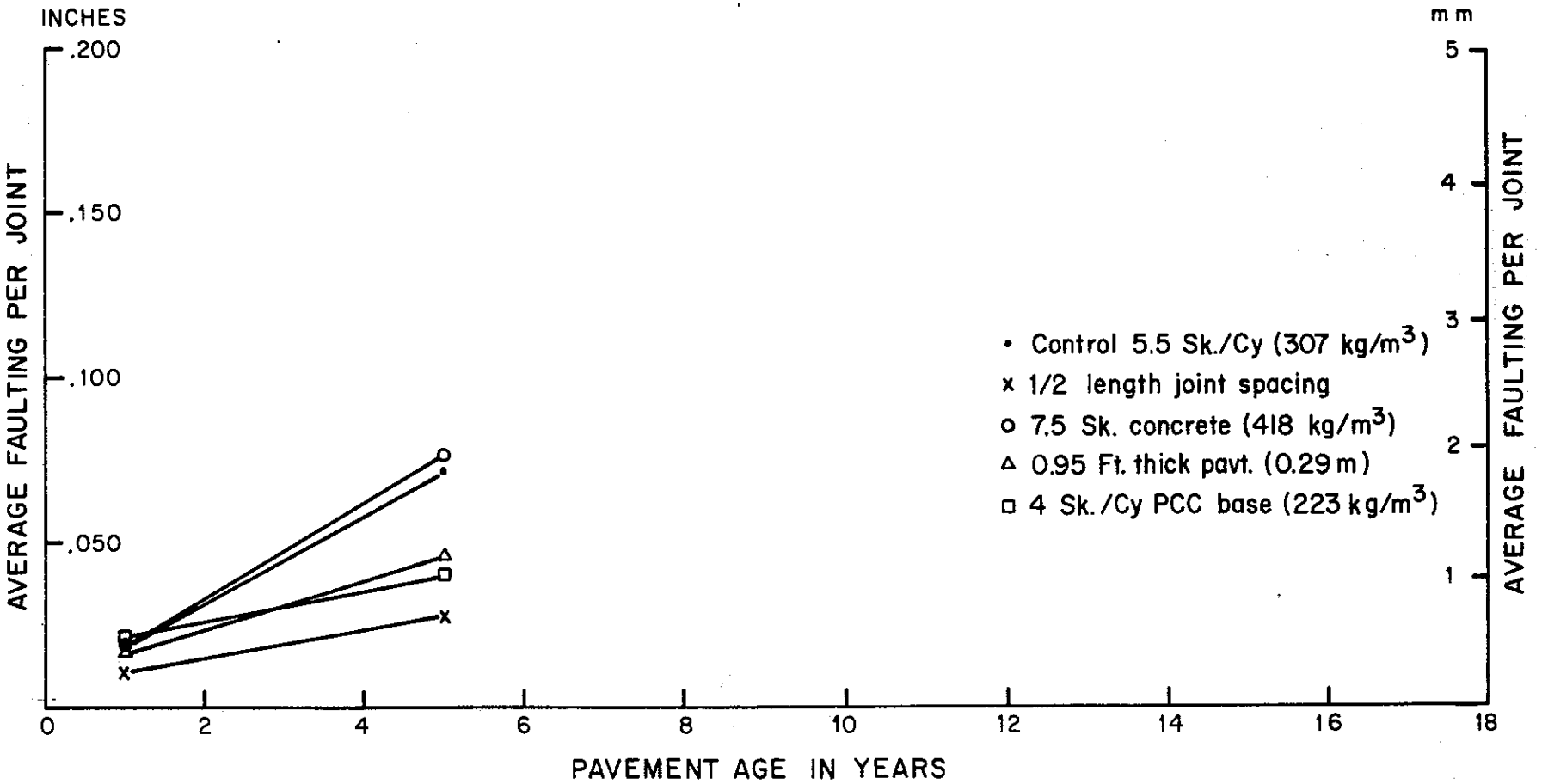


Figure B-23

ClibPDF - www.fastio.com

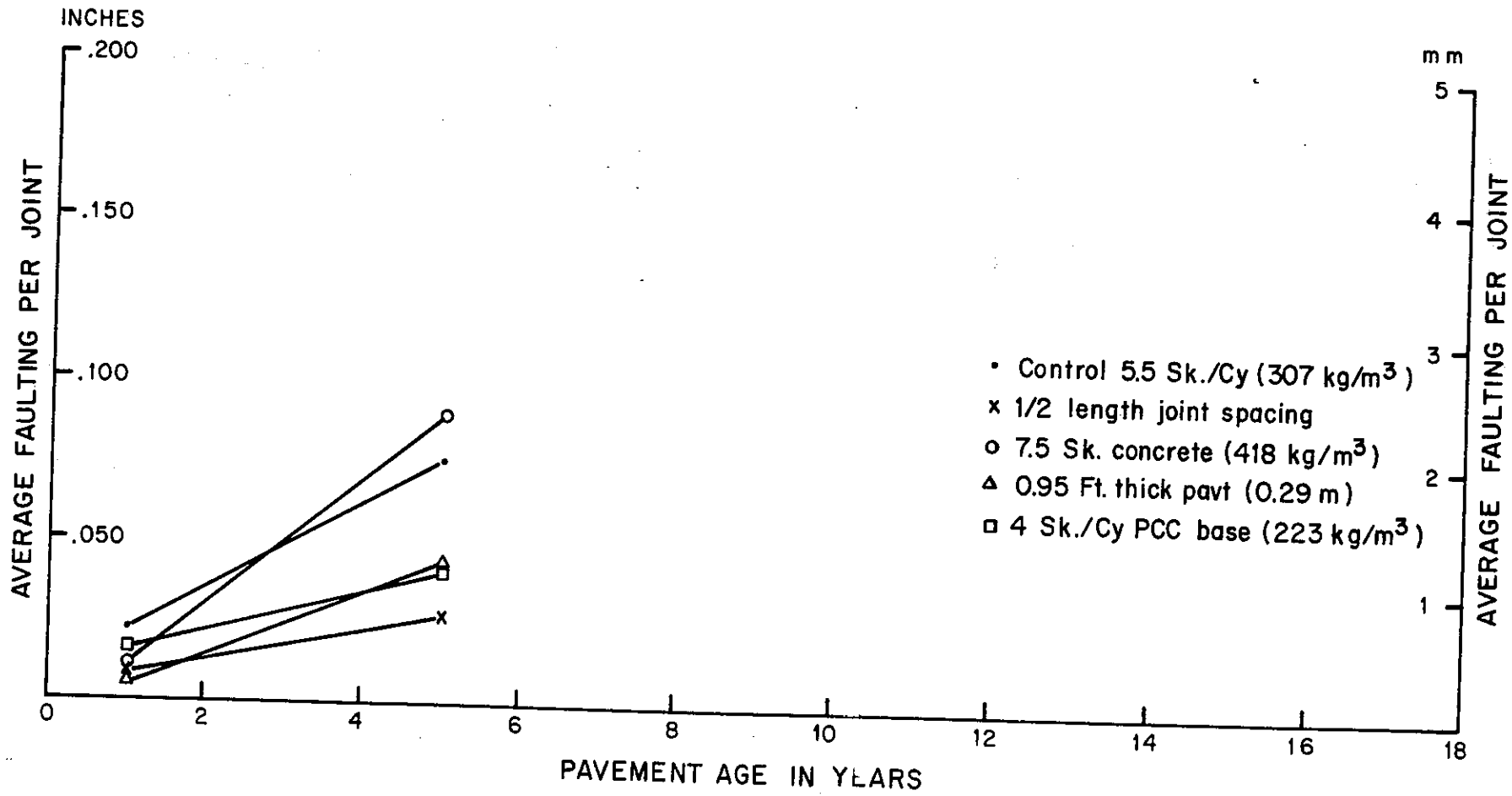


Figure B-24

ClibPDF - www.fastio.com

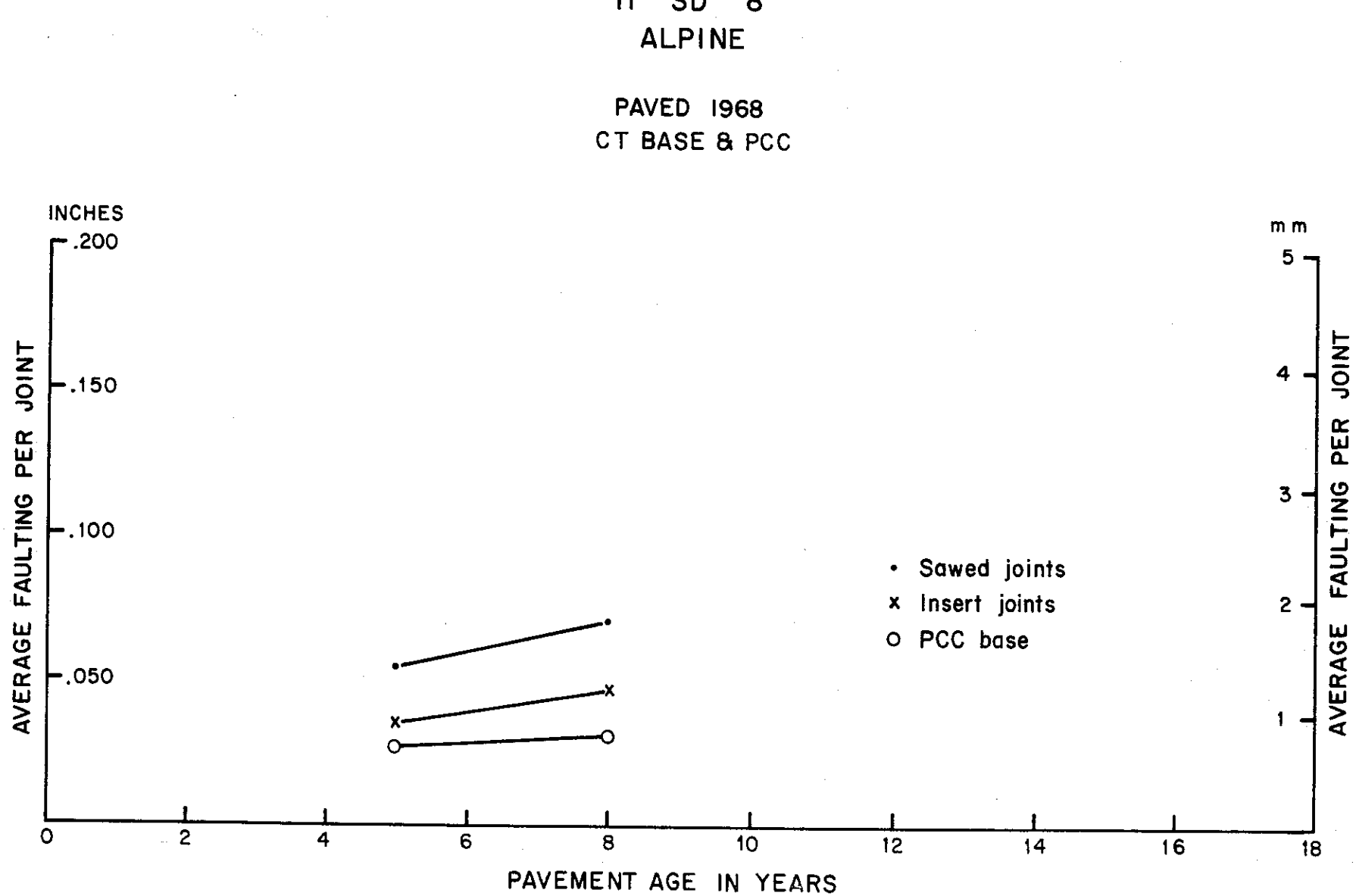


Figure B-25

ClibPDF - www.fastio.com

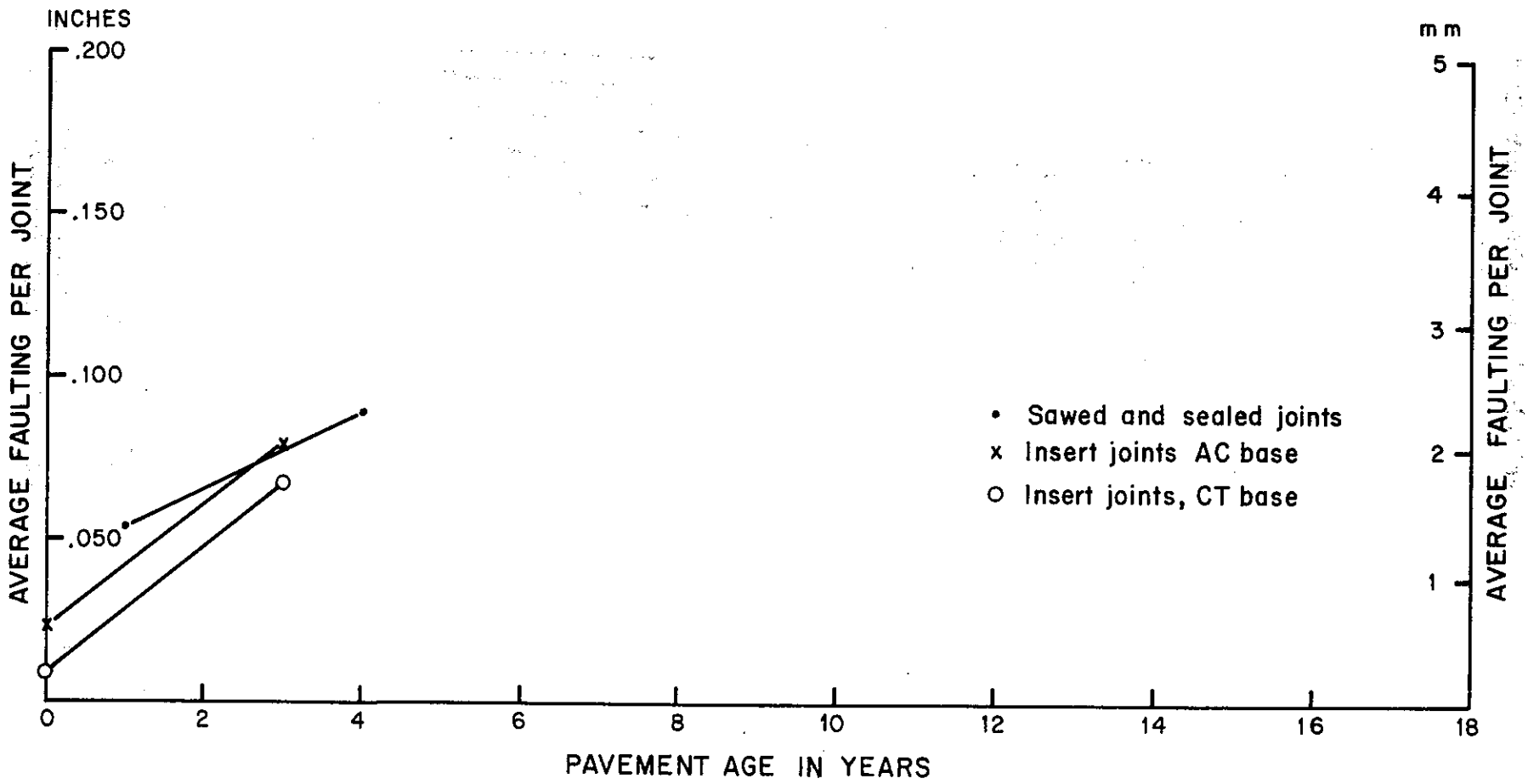


Figure B-26

ClibPDF - www.fastio.com

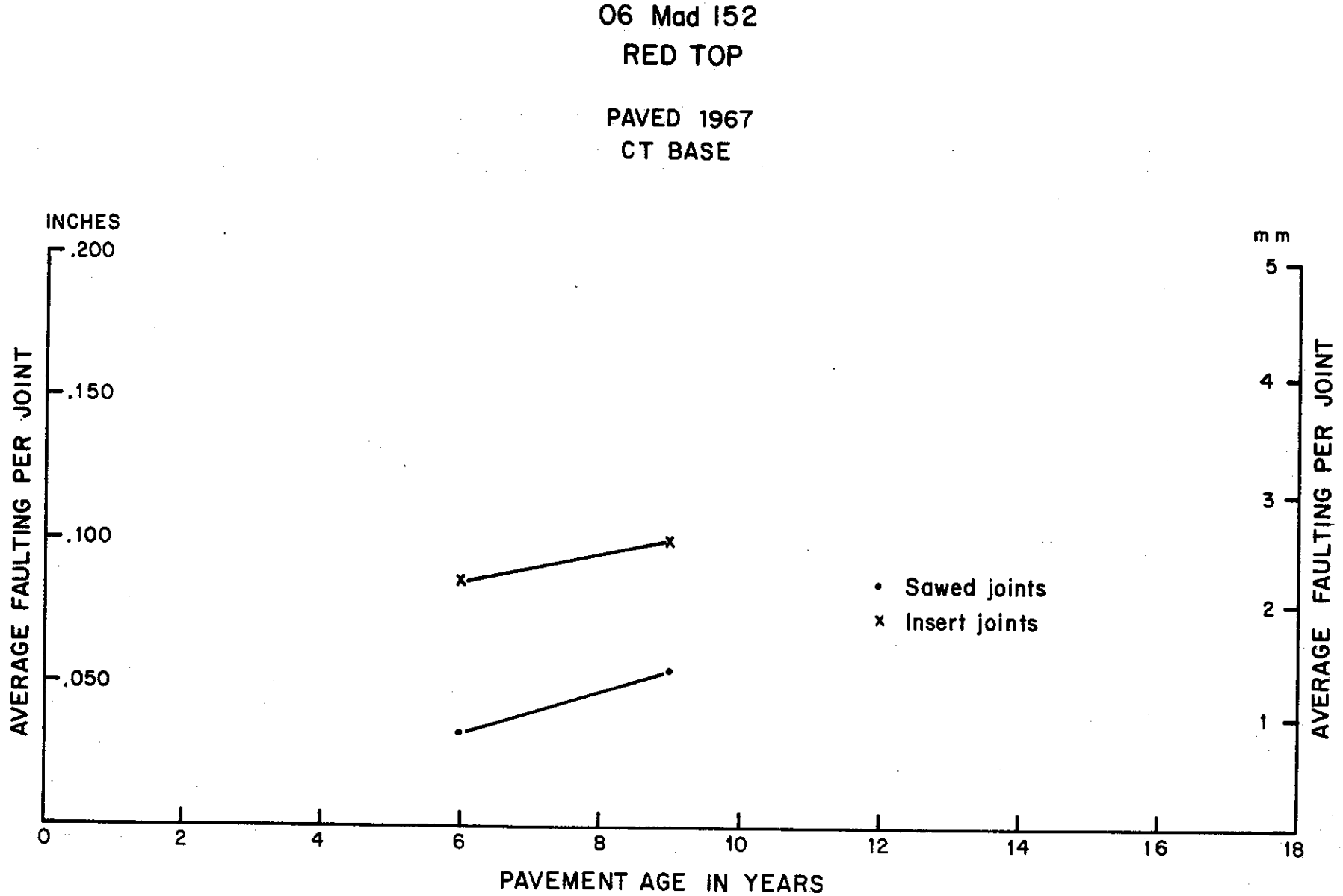


Figure B-27

ClibPDF - www.fastio.com

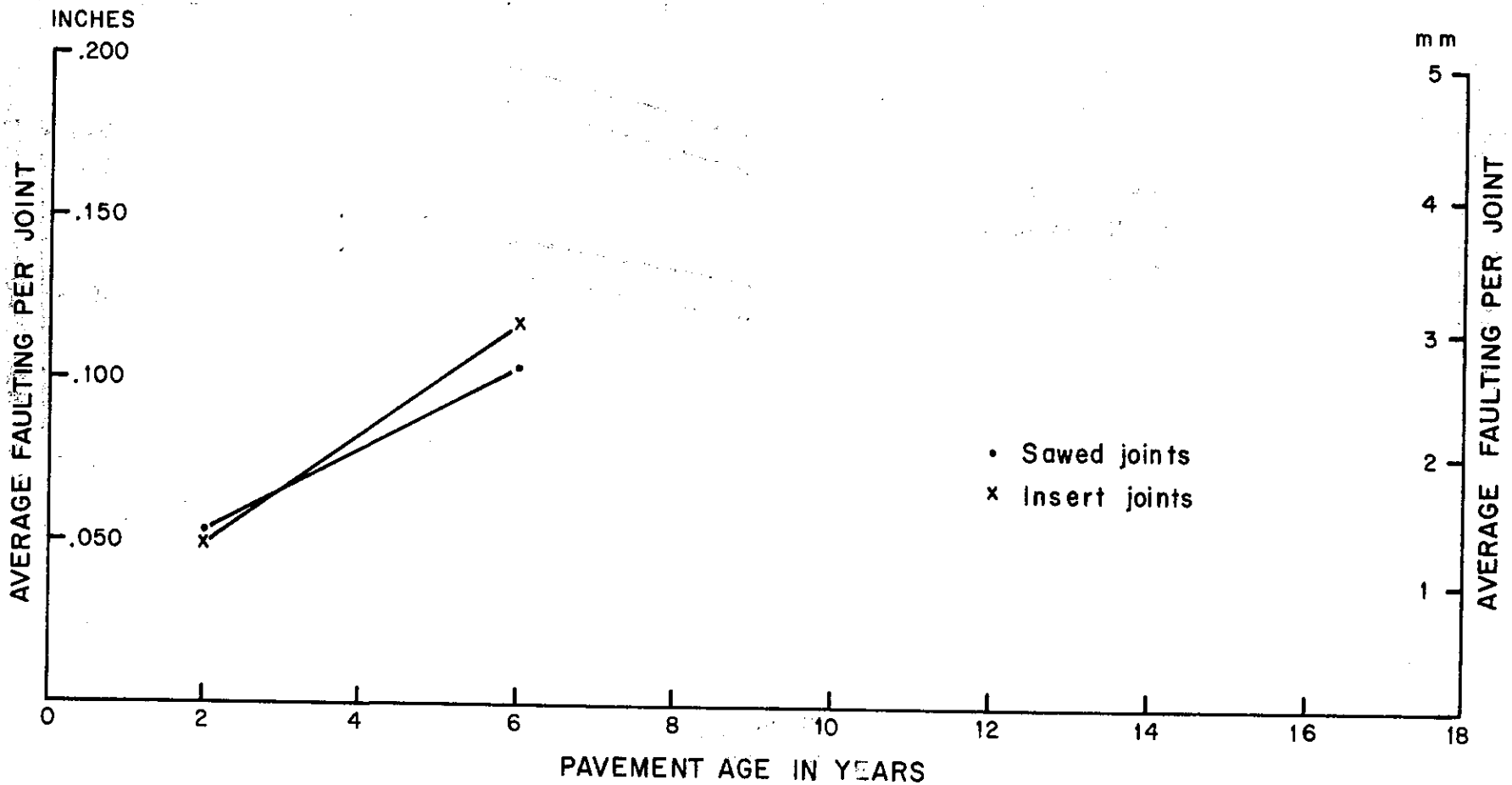


Figure B-28

ClibPDF - www.fastio.com

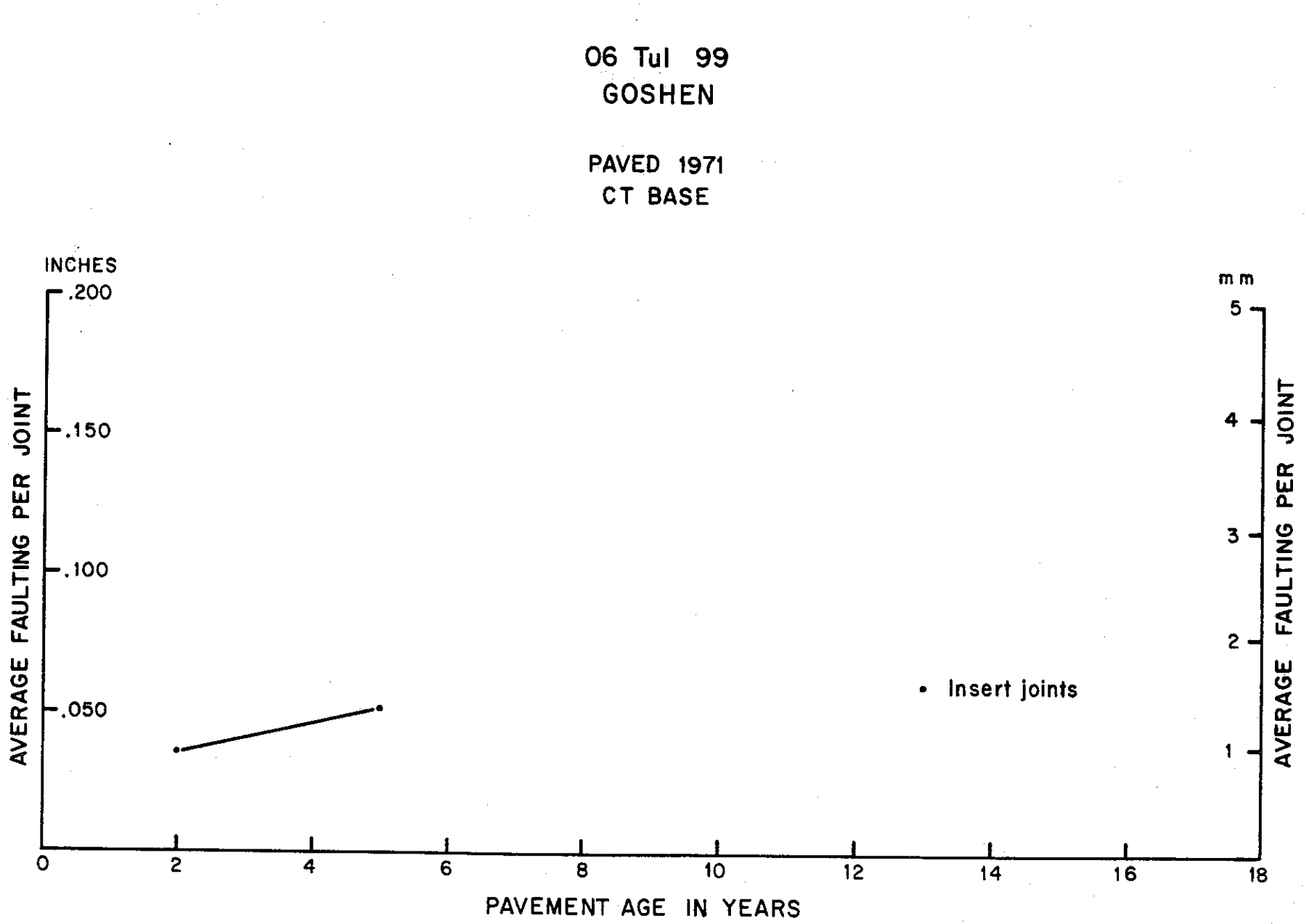


Figure B-29

ClibPDF - www.fastio.com

04 Son 101
GEYSERVILLE

PAVED 1975
CT BASE

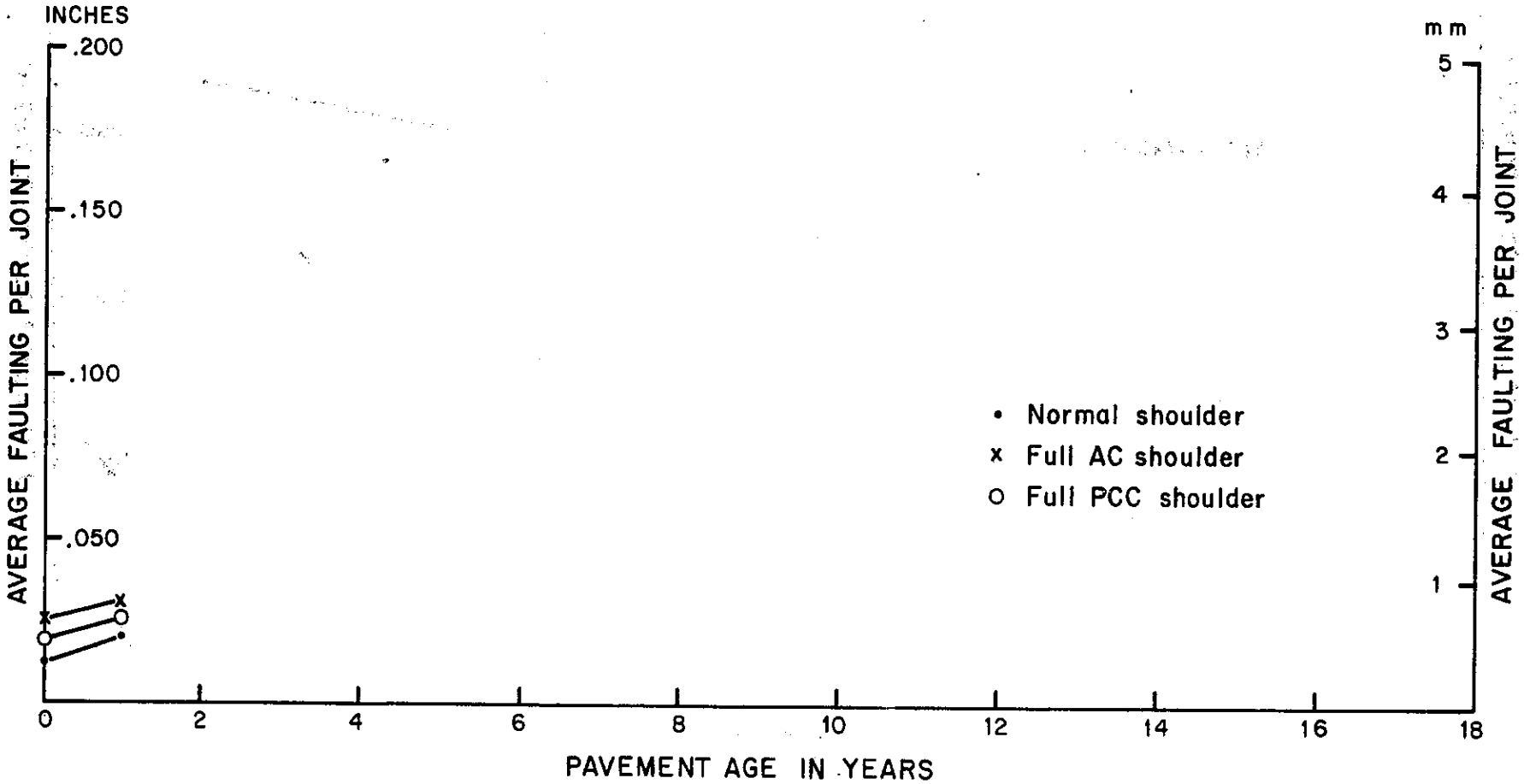
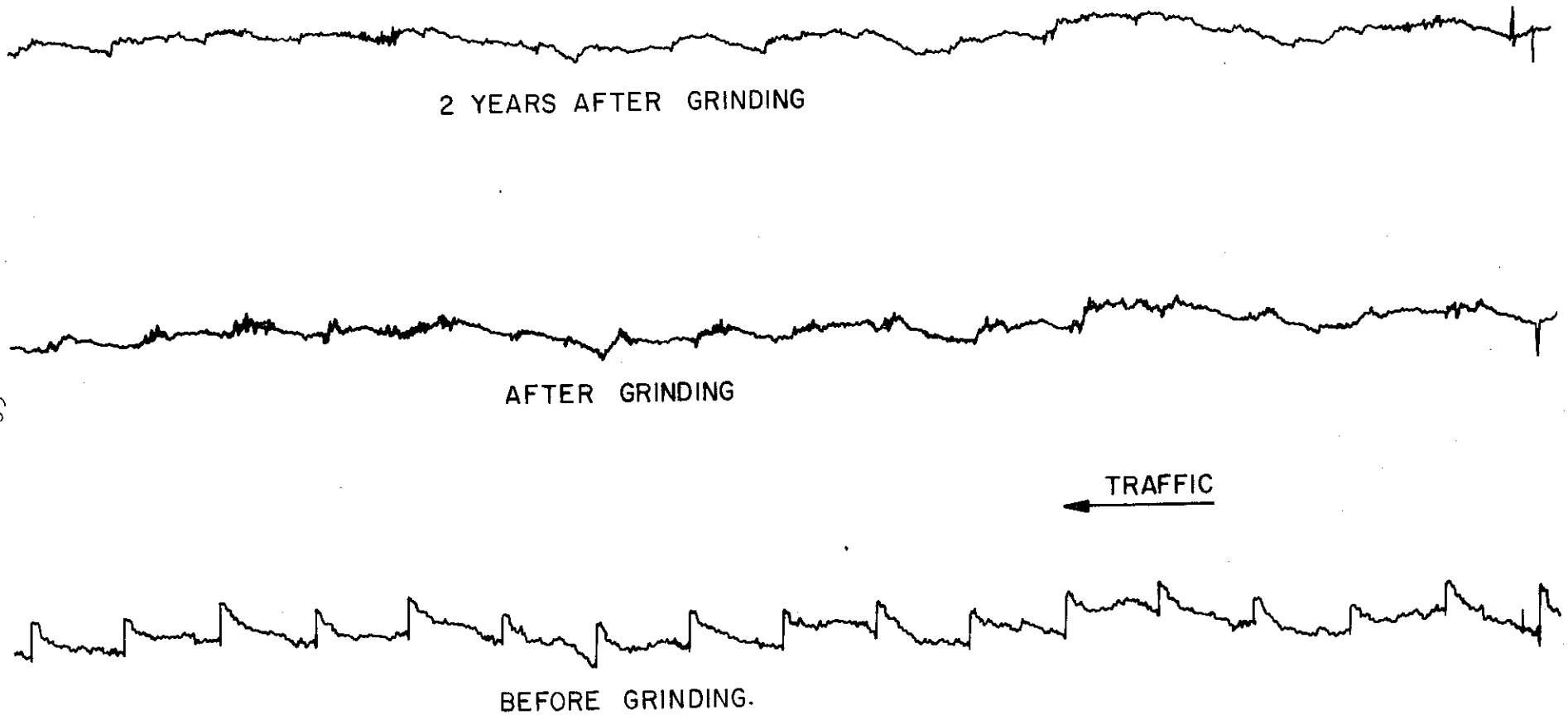


Figure B-30

ClibPDF - www.fastio.com



SCALE: Vert. 1 in. = 1 in
Horiz. 1 in = 25 ft.
NOTE: 1 in = 25.4 mm
1 ft. = 0.305 m

Figure B-31

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