TRRL Laboratory Report 886

TRANSPORT and ROAD RESEARCH LABORATORY

DEPARTMENT of the ENVIRONMENT DEPARTMENT of TRANSPORT

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Performance of sections of the Nairobi to Mombasa road in Kenya

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by

H. R. Smith, T. E. Jones and C. R. Jones

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Department of the Environment
Department of Transport

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PERFORMANCE OF SECTIONS OF THE NAIROBI TO MOMBASA ROAD IN KENYA

ABSTRACT

Details are given of the performance of sections of the Nairobi-Mombasa road in Kenya. Nine sections of road with cement-stabilised bases surfaced with multiple seals, and three sections with crushed rock bases and asphaltic concrete surfacings have been studied for seven years.

These road sections are located in a dry area, on strong subgrade soils.

It was found that the lightly constructed sections with cement-stabilised bases had suffered little structural damage after carrying 6 x 10^6 equivalent standard (80 kN) axles, considerably more than would be predicted by current methods of pavement design. The more heavily constructed sections with asphaltic concrete surfacings are performing broadly as would be expected.

For both types of pavement, deterioration has been mainly confined to the surfacings, and timely resealing has a powerful effect in limiting the amount of patching required and in maintaining an acceptable level of surface roughness. The lives of the better quality seals have been of the order of four to five years.

Deflection measurements clearly show how variations in overall pavement strength are affected by changes in annual rainfall, and the wide variation in strength which can occur on a nominally uniform pavement. Deflection measurements did not give early warning of pavement surfacing failures.

1. INTRODUCTION

This report describes a study of the performance of twelve one-kilometre sections of the Nairobi to Mombasa road in Kenya. This road is the principal trunk road in the country linking the capital city with the main port at Mombasa.

The twelve sections of the road were the subject of detailed investigations during the period 1971 to 1973, as part of a larger 'Road Transport Cost Study'[1,2] which was undertaken to provide relationships for use in a computer model capable of calculating total transport costs[3]. Monitoring of the performance of these road sections has continued on a regular basis during the period 1973-1979.

2. DETAILS OF THE SECTIONS INVESTIGATED

The locations and type of construction of each of the twelve sections of the road that were studied are summarised in Table 1. The one-kilometre sections were constructed normally and are representative of much longer lengths of the road. Geometric constraints imposed by the investigations for the Kenya 'Road Transport Cost Study'[1] governed the locations of the sections. Considerable variations in the crossfall and vertical alignment of the road occur within the length of certain sections, notably Sections 3, 5, 6 and 7. As a consequence the drainage conditions are not uniform within these sections. All of the sections have been resealed periodically with surface dressings. Slurry seals were also placed on Sections 5 to 8 in 1974.

3. CLIMATE

The sections are located in areas which experience low rainfall. Details of total annual rainfall recorded near to the sections are summarised in Table 2.

4. MATERIALS TESTING

In order to compare the performance of the road sections, a number of inspection holes were dug within each section and measurements were made of layer thicknesses, in-situ CBRs and moisture contents.

Selection of the points where inspection holes were dug has been described elsewhere[1]. The majority of these inspection holes were dug at the points where the largest deflection was measured. At these points it is likely that the overall strength of the pavement or the subgrade was weaker than elsewhere in the section.

The maximum size of aggregate used in the crushed stone road bases precluded the use of the in-situ CBR test on this layer. The results of measurements and tests of the pavement layers, together with Casagrande classifications of the subgrade soils are summarised in Tables 3 and 4.

The results of grading tests and aggregate strength tests made on samples taken from the crushed stone road bases are summarised in Tables 5 and 6.

5. TRAFFIC

The damage caused to a road pavement by vehicles is dependent upon the magnitude of the individual wheel loads and the number of times these loads pass over the pavement.

Many axle load surveys have been carried out on the Nairobi to Mombasa road, initially by the Overseas Unit and in recent years by the Kenya Ministry of Works. In these surveys vehicles were weighed on a portable weighbridge developed by the Overseas Unit of the Transport and Road Research Laboratory[4]. From the results of these surveys estimates of the distribution of the axle loads of commercial vehicles using the road have been made and are reported elsewhere[5]. Factors derived from the AASHO Road Test[6] have been used to express all axle loads in terms of an equivalent number of 'standard' (80 kN) axle loads[7].

The equivalence factors used were calculated from the following formula:

$$\text{Equivalence Factor} = (\text{axle load in kgf}/8160\text{ kgf})^{4.5}.$$

The estimated traffic loading histories for the sections are summarised in Table 7.

6. ROAD PERFORMANCE MEASUREMENTS

On each section test points were located in the four wheelpaths at eleven chainages spaced at one hundred metre intervals. Periodically roughness measurements were made over the length of each wheelpath, and the transient deflection, rut depth and cracking were measured at each test point. The total area of patching in each lane was also measured.

Section 7 was used to study the performance of a pavement that received no normal maintenance. Between September 1971 and August 1973 the repair work was restricted to the filling of potholes with soil.

6.1 Roughness measurements

Since August 1972 changes in the roughness of the sections have been monitored with a towed fifth-wheel bump integrator. Prior to this date measurements were made with a bump integrator unit mounted over the rear axle of a car. These early results were subsequently converted to equivalent towed bump integrator values[1]. The mean roughness for each lane is shown plotted against time in Figure 1.

6.2 Rut depths

The rut depth was measured at each test point under a 2m straight-edge, placed transversely to the centre line of the road.

6.3 Cracking and patching

Cracking at a point was measured within a one metre square frame placed over the test point with one edge of the frame parallel to the edge of the road. A tape measure was used to determine the length of cracking which was expressed in metres per square metre (m/m^2). Similarly the amount of patching was expressed in m^2/km.

The maintenance policy in Kenya is to patch areas in which the cracking is in excess of $5m/m^2$. A measure of the degree of failure of the surfacing has been obtained by summing the area of patching and the area of pavement with cracking in excess of $5m/m^2$ for each lane. The results have been related to the dates at which each successive seal was applied and are shown in Figure 2. In Figure 3 the mean cracking per square metre measured only in the verge side wheelpaths is plotted.

Table 8 lists the mean cracking, cracking plus patching and mean rut depths measured on the sections immediately before each resealing operation.

6.4 Deflection measurements

It is generally accepted that the magnitude of the surface deflections of flexible pavements can be correlated with the subsequent performance of the pavements under traffic[8,9]. Deflection tests can also be used for designing the thickness of bituminous overlays. From field studies it has been possible to relate the magnitude of the deflection before overlaying, the thickness of overlay and the subsequent performance of the overlaid pavement[10]. In the present study measurements of deflection were made on each test point using the Transport and Road Research Laboratory method of measuring transient deflections[11,12].

Typical deflection histories, for sites 2 and 6, are shown in Figures 4 and 5 where the mean deflection in each wheelpath has been plotted against time, traffic loading and total monthly rainfall.

To develop deflection criterion curves[8] for a given pavement, deflections should be measured from the time that the road is opened to traffic. This type of relationship could not be developed for the first nine sections because they were in service for a number of years before the study commenced.

It might be expected that the life of a particular seal could be related to the total traffic loading and the magnitude of deflections measured in a standard manner. To investigate relationships of this kind, deflection histories for individual test points were plotted, using the classification of road surface conditions shown in Table 9 and the symbols shown in Figure 6 to denote the degree of cracking (but not rut depth) in the verge-side wheelpaths. The data for the verge-side wheelpaths were used for this because the proximity of the off-side wheelpaths to each other means that in places the damaging effects of both wheelpaths are superimposed. It is not usually possible to identify the locations along the road where this regularly happens. Typical deflection histories of individual test points for Sections 2 and 6 for the period commencing just before the application of new seals in 1972-73 are shown in Figures 7 and 8.

Sections 10, 11 and 12 carried an appreciable amount of traffic during the few months between their formal opening to traffic and the start of the study. Whilst deflection values remained reasonably constant between September 1971 and March 1972, it is by no means certain that these values are representative of conditions before the study started. The 'early life' deflections may have been larger and influenced the subsequent performance of the surfacings.

Deterioration of the sections has been evident only in the verge-side wheelpaths. Figure 9 shows deflection histories for individual test points on Section 11, plotted against the cumulative traffic loading using the symbols indicating road surface condition shown in Figure 6. Sections 10, 11 and 12 were resurfaced with slurry seals in 1976.

7. DISCUSSION OF RESULTS

7.1 Deterioration of sealed roads with cement stabilised road bases

7.1.1 Surface roughness. Although there is considerable scatter in the roughness values obtained with a vehicle-mounted integrator unit during the period September 1971 to September 1972 (see Figure 1) a marked increase in roughness of the sections is evident during this period. This was particularly true for Section 7 on which no normal maintenance was carried out. Between September 1972 and June 1978 roughness values only increased on Sections 2 and 3, where failures in the surface dressing occurred and potholes formed.

It will be seen from Figure 1 that mean values of roughness measured in each lane on each section followed the same trend even though the rates of traffic loading towards Mombasa and towards Nairobi are very different. Also the difference in roughness measured in the verge-side wheelpaths of all sections remained virtually constant from August 1972 to June 1978 with the roughness in the Nairobi direction being between 100 and 380 mm/km greater than in the Mombasa direction. Therefore traffic loadings during the period 1972 to 1978 did not play a major part in changing roughness levels on the sections.

From observation of the surface condition of these sections, it has been evident that the most important factor affecting roughness has been the durability of the surface dressings and their ability to prevent the ingress of water which leads to separation of the surfacing and localised degradation of the top of the base. Where surfacing failures have occurred (invariably after periods of prolonged rainfall) the quality of finish achieved in the patching work has been of paramount importance in determining the subsequent surface roughness of the road. With the exception of Section 7 the level of roughness on all the sites is less than 3750 mm/km, regarded as the critical level of roughness at which remedial work is warranted[1]. The large increase in roughness of Section 7 can be attributed to the 'nil-maintenance' policy adopted during the period 1971-73, and the difficulty in obtaining a smooth finish to the numerous patches which had to be made at the end of the nil-maintenance period.

7.1.2 Rut depths. The results summarised in Table 8 show that rutting on the sections has been minimal and there has been little change in rut depths during the five year period to 1979.

7.1.3 Cracking and patching. There has been a tendency for the most serious cracking and potholing to occur along the centre of the road. The two offside wheelpaths overlap to varying degrees, depending upon road alignment, so that the opposing traffic flows both contribute to the cumulative traffic loading along the centre of the road. This would be expected to produce more rapid deterioration in the centre of the road than elsewhere. A contributory factor may be pavement weakness due to a construction joint on the centre line of the road, but no circumstantial evidence was found to substantiate this supposition.

Small differences in the amounts of cracking occurring in the verge-side wheelpaths are evident on some sections (see Figure 3). Between 1971 and the date of resealing more cracking occurred on Sections 1, 5 and 8 in the verge-side wheelpath in the direction towards Nairobi than in the other direction. However the difference in time for mean cracking in the two wheelpaths to reach 1 m/m^2 was only four months, hence the differences are not very significant. On Sections 2, 3, 4, 6 and 7 there was little or no difference in the amount of cracking in the two verge-side wheelpaths, whilst on Section 9 no significant cracking occurred. This is surprising since the cumulative equivalent axle loading in the Nairobi direction is approximately three times greater than in the Mombasa direction. The cracking may be the result of localised surfacing failure caused either by the number of vehicles using the road or by climatic conditions or a combination of these two factors. The overall structural integrity of the pavements has been little affected by the cumulative axle loads.

The data given in Table 7 and Figures 2 and 3 show that whilst, in general, each successive seal has been more durable than the previous one, resealing has not been carried out when the existing seals had deteriorated to a common condition.

It can also be seen that the slurry seals have been especially effective in preserving surface condition and that the nil maintenance policy adopted for Section 7 resulted in a very difficult maintenance problem, in 1979 the condition of the slurry seal on this section was poor compared with those on the other sections. It is noticeable that the slurry seals appear to be 'rich' in bitumen in the wheelpaths, which suggests that the bitumen content is sufficient to ensure a durable and flexible surfacing but is not so high as to cause instability in the relatively thin layer of surfacing. This durability may have been obtained at the cost of reduced skid resistance.

7.1.4 Deflections. It can be seen from Figures 4 and 5 that the deflections measured in the verge-side wheelpaths respond to changes in the seasonal pattern of rainfall. The process of resealing can significantly affect deflection values. Very marked reductions in deflection resulted from the application of slurry seals on Sections 5, 6, 7 and 8 in June 1974. It is possible that these seals have provided a more impervious surface than the surface dressings, allowing the top of the base to dry out. In particular, where slurry seals have been used, the long term reductions in deflections measured in the off-side wheelpaths, where most of the patching work was carried out, is very marked.

Section 4, which deflection measurements indicate is the strongest pavement, was least affected by changes in rainfall. The results of in-situ tests carried out on the sections indicate that the road base of

Section 4 contributes more to the strength of the pavement than do the road bases on the other sections. Trends in the mean deflections measured in the verge-side wheelpaths on each section are very similar despite the heavier traffic loading in the direction towards Nairobi.

The largest changes in deflection have been caused by variation in rainfall, although all the sections have been strong enough to carry the imposed traffic loadings without suffering appreciable damage below the surface layer. However if the marked increase in rainfall during 1977 and 1978, which is reflected in the increased deflections measured in the verge-side wheelpaths, continues through 1979, then serious weakening of the overall pavement structure could occur. It can be seen from Figures 7 and 8, that the magnitudes of deflections measured at the time of resealing did not give an indication of the 'life' of the new seal. The quality of the seal at a given point and any lack of bond between the various seals, patches and road base are important in determining the performance of the seals.

Whilst the data shows considerable scatter, the amount of cracking and patching that occurred in the 2nd seal on the sections after approximately 1.25 x 10^6 ESA tends to be inversely related to the mean subgrade CBR of the sections and directly related to the mean deflections measured in 1972/74.

7.1.5 Performance of sections 1 to 9. The range of mean layer thicknesses of the sections are compared in Table 10 with recommended layer thicknesses from the pavement design guides Road Notes 29[13] and 31[14]. Road Note 31 is applicable for roads in tropical and sub-tropical climates for traffic loadings up to 2.5 x 10^6 equivalent standard axles. Road Note 29 is applicable for roads in Britain, carrying a maximum of 1.5 x 10^6 equivalent standard axles for soil-cement road bases surfaced with premixed bituminous materials. Graded crushed rock road bases are appropriate for greater traffic loadings. For both design Notes the implication is that at the end of the 'design life' of the road, strengthening by overlaying and possibly partial reconstruction will be necessary to extend the life of the road.

Sections 1 to 9 are of similar total thickness to those recommended in Road Note 31 but their road bases are thinner. The sections have carried nearly three times the traffic loading suggested in the Road Note. This has been achieved at the cost of some patching work and two or three resealing operations. In addition the sections appear to be capable of sustaining present traffic loads for some time into the future provided that these maintenance practices are continued.

Whilst the *in-situ* CBR measurements shown in Table 4 indicate that Sections 4, 5 and 9 have very strong subgrades, which could explain their good performance, the other sections have strong, but not exceptionally strong, subgrades in comparison with most roads in East Africa.

Comparisons with the recommendations of Road Note 29 are not really valid because these pavements would have suffered far greater damage if they had been subject to frost and had weaker subgrades more typical of those found in the United Kingdom.

Since there is no obvious means of predicting the performance of these sections, the regular monitoring of surface deformation and cracking offers the best method of giving warning of the need for substantial patching work or resealing.

Attention should be given to the quality of patching since this is important in determining the roughness of these pavements.

Deflection surveys of representative lengths of pavement carried out initially on an annual basis or after periods of rain and thence biennially, would help in the design of overlays in the future. Whilst present knowledge does not permit such surveys to be used to predict failure, they would indicate variations in strength along the road, and the annual trends in deflections would assist in the design of overlays. In addition periodic measurements of roughness would indicate when an overlay is required to restore an acceptable level of riding quality.

7.2 Deterioration of sections with asphaltic concrete surfaces and crushed rock road bases

7.2.1 Surface roughness. There was no significant change in roughness on these sections before the application of slurry seals in 1976. It appears that the surface finish of the seals caused a small increase in roughness.

7.2.2 Rut depths. In all cases where critical or failure conditions occurred, cracking of the surfacing was the initial indication of deterioration. Rutting increased at a later date and was dependent upon the effect which water, having entered the structure through the cracks, had upon the pavements' strength. Where rutting occurred, further deterioration in the verge-side wheelpath in the Nairobi direction was rapid under the influence of the heavier traffic travelling in this direction.

7.2.3 Cracking. It has been found that cracking in the bituminous surfacings on other sites and on bituminous overlays in Kenya begins at the top of the layer. This means that there can be a considerable delay between the initial appearance of a crack and its propagation to the full depth of the asphalt. Climatic effects cause considerable hardening of the bitumen in asphalt layers and a consequent reduction in the ability of the surfacing material to resist fatigue failure. Cracking of the asphalt on these sites, without any associated deformation indicates that the surfacings have failed due to fatigue.

It is noticeable that the onset of cracking in the verge-side wheelpaths in both directions occurred at a similar time, despite the considerable difference in traffic loadings.

As stated previously, where structural deterioration occurred the heavier traffic travelling towards Nairobi caused additional rapid deterioration.

7.2.4 Deflections. Deflection measurements on these sections did not give an early indication of pavement failure.

On Section 10, one test point in each of the verge-side wheelpaths failed to the extent that patching was required. In both these areas cracking was followed by an increase in rut depth, and then by an increase in deflection.

In Section 11 one test point in each verge-side wheelpath showed marked increases in deflection of which only the point in the more lightly trafficked lane 'failed'.

Whilst Section 12 has a similar deflection history to Sections 10 and 11 in terms of magnitudes, this section has suffered far less cracking.

7.2.5 Performance of sections 10, 11 and 12. The total thicknesses suggested in Road Note 29 are comparable with those in Sections 10 to 12, although layer thicknesses were variable. Section 12 had a very variable but generally thicker sub-base layer, and a thicker road base than Sections 10 and 11.

The asphalt surfacings on the sections suffered fatigue failure and the seal applied in 1976 was needed to waterproof the pavements. This seal was applied before serious structural damage became apparent on Sections 11 and 12. Section 10 had suffered some serious damage in part of the verge-side wheelpath of the Nairobi-bound lane by 1976 and the application of the seal was ineffective in preventing further cracking and entry of water into the structure. Further deterioration has occurred and has spread along the wheelpath and now requires partial reconstruction and strengthening. Application of a seal at an earlier date would probably have prevented all of this deterioration.

Direct comparisons between these sections and the recommendations in Road Note 29 are not possible without bearing in mind the differences in thicknesses and types of the surfacing materials and the climatic conditions for which the Note is relevant. The performance of the sections is broadly in agreement with the recommendations in the Road Note. These sections have carried in excess of 6×10^6 equivalent standard axles in the Nairobi direction, but Sections 10 and 11 required resealing after carrying approximately 3.5×10^6 equivalent standard axles, and Section 12 required resealing after carrying more than 5×10^6 equivalent standard axles. It is likely that with additional resealing these sections, except for part of Section 10, will continue to provide good service for some years.

8. IMPLICATIONS OF THE RESULTS FOR THE RELATIONSHIPS USED IN THE ROAD TRANSPORT INVESTMENT MODEL[3]

The sections which are the subjects of this report (referred to as OBs 17 to 25 and P.8 to 10 in reference 1) formed only a part of the original investigation, but the pavement deterioration relationships in the model that were derived from Sections 1 to 9 will have to be modified.

In the model the pavement strength of each section is expressed in terms of a modified structural number[1] and pavement deterioration relationships are related to the cumulative equivalent standard axles carried by the sections. Different relationships have been developed for a range of modified structural members.

It has been shown that between 1973 and 1979 the sections have been strong enough to carry the imposed traffic loadings without suffering serious structural damage. Little change in rut depths has occurred and roughness only increased when potholes were allowed to develop or the surfaces of patches were not finished to the same level as the adjacent pavement.

Significant deterioration has been confined to the surfacings, but each successive seal has apparently been more durable than the preceding one. This could reflect variations in the qualities of the seals, but their performances may also have been affected by the drier weather between 1973 and 1977.

Before any amendments are made to the existing deterioration relationships additional measurements are required on the sections to determine the effects of the wetter weather which started in 1977 and the durability of the slurry seals.

9. CONCLUSIONS

9.1 Sections with soil-cement road bases and bituminous seals

i) Traffic loading at the rate of three-quarters of a million equivalent standard axles per year has had negligible effect on the condition of these lightly-constructed and normally maintained pavements built on strong subgrades in a 'dry' climate.

ii) It is likely that climatic effects have a much stronger influence than traffic loading on these pavements (climate clearly influences deflection), but it is too early to tell whether the recent wet weather will result in significantly accelerated pavement deterioration.

iii) The deterioration that has occurred, initially in the surfacing, is most prevalent in wet weather and can be remedied by simple patching, waterproofing and periodic resealing.

iv) Timely resealing has a powerful effect in limiting the amount of patching required and maintaining an acceptable level of roughness. Subsequent seals appear to have longer 'lives' than earlier seals.

v) The lives of the better quality seals have been of the order of four to five years, but the life of a seal is influenced by the quality of previous patching and the bond achieved between the seals.

vi) Deflection measurements clearly showed how changes in overall pavement strength can be affected by rainfall and the wide variation in strengths which can occur on a nominally uniform pavement. It is unlikely that deflection measurements can be used to predict pavement performance in these circumstances, where climate and the quality of the surfacings greatly affect pavement deterioration.

Deflection histories would however be of value for overlay thickness design.

vii) The pavement deterioration relationships used in the Road Transport Investment Model for surface-dressed roads with cement stabilised road bases need to be revised, but further evidence of the combined effects of climate and traffic on the deterioration of these pavements is required.

9.2 Sections with crushed rock road bases and asphaltic concrete surfacings

i) Two sections have carried some 7×10^6 equivalent standard axles and the third has carried 8×10^6 equivalent standard axles in the Nairobi direction by mid-1979.

ii) Measurable deterioration has been confined to the verge-side wheelpaths and has been consistent with fatigue failure of the surfacings.

iii) Similar values of mean linear cracking of the surfacings were recorded on the sections in both verge-side wheelpaths, despite the fact that the traffic loading in the Nairobi direction was three times greater than in the Mombasa direction. There is evidence that cracking propagates down through the surfacing more rapidly under the heavier traffic, resulting in accelerated deterioration in the form of rutting when water is able to enter the road base.

iv) As with the other sections studied the application of seals at the appropriate time has a great effect in preserving the structural strength of the pavement.

v) Measurement of surface deflection did not provide an indicator of subsequent pavement deterioration in the form of cracking.

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TABLE 1

Details of the road sections

Site Number	Location Kilometres from Mombasa	Date opened to traffic*	Type of construction
1 2 3 4	355.0–356.0 353.0–354.0 349.3–350.3 331.1–332.1	1967	Surface treatment on cement-stabilised base. Granular sub-base
5 6 7 8 9	269.0–270.0 262.1–263.1 261.1–262.1 254.4–255.4 210.6–211.6	1966	
10 11 12	53.0–54.0 47.0–48.0 30.0–31.0	1971	Asphaltic concrete on crushed stone road base. Stabilised granular sub-base

* Before 1970, when freight was transferred from rail to road transport, there was only light traffic on the road.

TABLE 2

Summary of annual rainfall recorded near to the sections

Sections	1–9		10,11	12
Year	Range (mm)	Mean (mm)	Mean (mm)	Mean (mm)
1971	490– 780	600	373	580
1972	490– 680	660	873	1519
1973	270– 560	410	492	982
1974	460– 580	500	521	804
1975	170– 340	250	511	901
1976	420– 560	500	626	902
1977	420– 820*	690	790	1447
1978	740–1250	980	–	–

* Incomplete data for 2 sections.

TABLE 3

Pavement layer thicknesses

Section No.	Mean and range of layer thicknesses measured (mm)							
	Surfacing		Base		Sub-base		Base + Sub-base	
1	29,	20–35	147,	120–160	131,	75–250	278,	210–400
2	21,	20–25	128,	120–140	115,	100–140	243,	250–260
3	26,	25–30	126,	105–140	100,	80–120	226,	185–240
4	29,	20–40	133,	110–150	103,	80–130	236,	210–260
5	32,	25–50	131,	115–140	95,	65–150	226,	180–290
6	34,	25–40	130,	110–160	116,	80–170	246,	210–280
7	34,	25–55	150,	130–160	105,	80–140	255,	210–300
8	27,	25–30	150,	130–180	112,	80–150	262	225–320
9	26,	20–30	139,	100–180	124,	90–180	263,	210–360
10	32,	20–40	130,	80–190	167,	120–270	297,	240–370
11	31,	30–35	155,	135–180	114,	70–140	269,	230–320
12	26,	20–40	279,	200–320	248,	70–380	527,	370–580

Note: The surfacings on Sections 1 to 9 comprise multiple seals.

The surfacings on Sections 10 to 12 were asphaltic concrete.

TABLE 4

In-situ materials test data

Section No.	Base					Sub-base						Subgrade						Casagrande classification
	CBR (Per cent)		Moisture content (Per cent)			CBR (Per cent)			Moisture content (Per cent)			CBR (Per cent)			Moisture content (Per cent)			
	Mean	Range	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	
1 (1971/2)	91+	70–>100	14.1	8–18	3.2	55	35–75	18.5	16	9–22	4	16	8–29	8	21	18–23	2	GC
1 (1975/6)	96+	65–>100	13.3	9–18	3.2	48	20–100	26.3	17	10–24	4	21	12–32	5	19	16–21	1	GC
2	>100	–	7.7	7– 8	0.5	65	50–80	11.1	16	14–18	2	13	10–17	3	20	19–22	1	GC
3	>100	–	7.3	4–10	2.0	50+	23–>100	–	7	3–15	4	39	21–50	9	20	15–24	3	GC
4	>100	–	8.8	8–10	0.9	45	19–80	24.8	8	4–11	2	65	40–95	24	9	5–11	2	GC
5	96+	80–>100	8.8	7–11	1.5	60	30–90	21.5	8	7–8	1	52	35–100	24	8	6–10	1	SF
6	96+	75–>100	10.7	8–14	2.0	30	12–50	16.0	11	7–14	3	27	15–50	12	9	6–12	2	SC
7	86+	75–>100	13.1	11–15	1.3	30	12–60	19.3	12	7–14	2	25	15–35	9	9	6–12	2	SC
8	84+	75–>100	12.1	11–13	0.9	28	15–30	13.3	12	10–14	1	26	15–40	10	10	9–13	1	SF
9	>100	–	10.8	8–12	1.3	60	20–95	26.5	9	5–12	3	65	19–100	28	5	3–6	1	SC
10	Not measured					85+	50–>100	–	6	2–13	4	62	25–70	28+	10	7–12	2	GC
11						95+	80–>100	–	5	3–7	2	80+	40–>100	27+	9	7–11	1	GC
12						77+	30–>100	–	3	2–4	1	25+	5–>100	38+	11	5–15	5	GF

SD = Standard deviation

TABLE 5

Percentage of material passing various sieve sizes for crushed stone road bases

Sieve size (mm)	63	50	37.5	28	20	14	10	5	2.36	2	0.6	0.425	0.212	0.075	0.063
Kenya MOW Specification	100		88–98	78–96	66–89	54–79	40–70	32–62		20–44	16–33	15–30	11–24		5–15
Road Note 31 Specification[14]	100	100	95–100		60–80		40–60	25–40	15–30		8–22			5–12	
Section 10	99		84	71	58	46	39	30	–	25	18	15	11		7
Section 11	100		88	81	72	64	58	48	–	43	32	27	17		6
Section 12	100		90	83	74	63	54	40	–	28	16	9	6		1

TABLE 6

Results of materials tests on crushed stone bases

Section No.	10	11	12	Kenya Ministry of Works Specification
Aggregate crushing value	35	35	36	35
Los Angeles value	43	41	45	50
P.I. of fines	Non plastic			<6

TABLE 7

Estimate of traffic carried by the sections

Section No.	Year of opening to traffic	Dates of sealing work			Traffic carried (ESA x 10^6)*				
		1st reseal	2nd reseal	3rd reseal	By first seal	By second seal	By third seal	By existing seal	Total to Jan. 1979
1	1967	1969	March 1974	Overlaid† February 1977	0.28 (0.10)	1.99 (0.68)	Overlaid	–	–
2	1967	1969	April 1973	June 1978	0.28 (0.10)	1.51 (0.54)	3.42 (1.21)	0.44 (0.20)	5.64 (2.05)
3	1967	1969	June 1978	–	0.28 (0.10)	4.92 (1.75)	–	0.44 (0.20)	5.64 (2.05)
4	1967	1969	March 1973	June 1978	0.28 (0.10)	1.47 (0.53)	3.46 (1.22)	0.44 (0.20)	5.64 (2.05)
5	1966	1970	August 1972	May 1974	0.45 (0.20)	1.12 (0.34)	0.96 (0.26)	3.28 (1.25)	5.81 (2.05)
6	1966	1970	August 1972	June 1974	0.45 (0.20)	1.12 (0.34)	1.00 (0.30)	3.24 (1.21)	5.81 (2.05)
7**	1966	1970	June 1974	–	0.45 (0.20)	2.12 (0.64)	–	3.24 (1.21)	5.81 (2.05)
8	1966	1970	September 1972	June 1974	0.45 (0.20)	1.17 (0.36)	0.95 (0.28)	3.24 (1.21)	5.81 (2.05)
9	1966	1968	October 1974	–	0.25 (0.10)	2.42 (0.76)	–	3.06 (1.19)	5.73 (2.05)
10	1971	June 1976	–	–	4.60 (1.27)	–	–	2.10 (0.89)	6.70 (2.16)
11	1971	June 1976	–	–	4.60 (1.27)	–	–	2.10 (0.89)	6.70 (2.16)
12	1971	June 1976	–	–	5.33 (1.70)	–	–	2.43 (1.09)	7.76 (2.79)

* No. of equivalent standard (80 kN) axle loads.

† Used for experimental overlays.

** Effect of nil maintenance studied. Section extensively patched in 1973.

Traffic towards Mombasa shown in brackets.

TABLE 8

Surface condition of the sections immediately before resealing

Section No.	Date of reseal	Mean cracking (m/m^2)		Cracking and patching (Per cent)		Mean rut depth (mm)	
		Towards Nairobi	Towards Mombasa	Towards Nairobi	Towards Mombasa	Towards Nairobi	Towards Mombasa
1	1974	6.9	4.6	38	35	4	4
	1977*	0	0	0	0	2	2
2	1973	4.4	3.5	26	18	4	5
	1978	1.6	1.6	20	8	3	3
3	1978	3.8	4.5	48	64	2	2
4	1973	0.9	0.1	3	0	4	3
	1978	0	0	1	1	2	1
5	1972	1.9	1.8	1	12	3	4
	1974	0.1	0.3	19	25	2	3
	(1979)	0	0.1	0	0	4	5
6	1972	2.5	3.4	14	27	4	4
	1974	0.1	0.7	6	10	3	3
	(1979)	0	0.2	0.4	0	5	3
7	1974	3.5	2.0	74	64	5	8
	(1979)	0.7	0.7	8	7	7	7
8	1972	1.9	1.7	25	32	6	4
	1974	0.1	0.1	16	10	5	3
	(1979)	0.1	0.1	0.3	0	6	3
9	1974	0.2	0.3	2	2	4	3
	1979†	0	0	0	0	7	4
10	1976	1.0	1.8	6.5	1.5	3 (1 reading of 21)	1
11	1976	0.8	0.7	0	0.1	1	0
12	1976	0.3	0.3	0	0	0	1

* Overlaid.

( ) Condition in 1979 of slurry seals applied in 1974.

† Condition in 1979 of surface dressing applied in 1974.

TABLE 9

Classification of road surface condition

Transverse deformation under a 2m long straightedge		Degree of cracking (visible cracks)	
Classification Index	Deformation	Classification Index	Crack length/unit area
D_1	Less than 10 mm	C_1	Nil
D_2	10 mm to 14 mm	C_2	Not greater than 1 m/m^2
D_3	15 mm to 19 mm	C_3	Greater than 1 m/m^2 but not greater than 2 m/m^2
D_4	20 mm to 25 mm	C_4	Greater than 2 m/m^2 but not greater than 5 m/m^2
D_5	Greater than 25 mm	C_5	Greater than 5 m/m^2 (ravelling and potholing imminent, immediate maintenance required)

TABLE 10

Comparison of actual and recommended layer thicknesses from design guides

Pavement layer	Range of mean layer thicknesses (mm)		Recommended layer thicknesses (mm) from design guides for total traffic loadings of:–					
			2.5 x 10^6 ESA				6 x 10^6 ESA	
	Sections 1–9	Sections 10–12	Road Note 31 for subgrade CBR (per cent) of:–		Road Note 29* for subgrade CBR (per cent) of:–		Road Note 29* for subgrade CBR (per cent) of:–	
			8–24	24+†	8–29	29+†	8–29	29+†
Surfacing	Surface dressings	26–32	Surface dressing		80	80	100	100
Road base	126–150	130–279	200	200	170	170	200	200
Sub-base	95–131	114–248	100	Nil	150	Nil	150	Nil
Total thickness (excluding surface dressings)	226–278	300–553	300	200	400	250	450	300

* Soil-cement road base acceptable for 1.5 x 10^6 ESA. Graded crushed rock road base acceptable for greater traffic loading.

† Applicable for Sections 4, 5 11 and parts of the other sections.

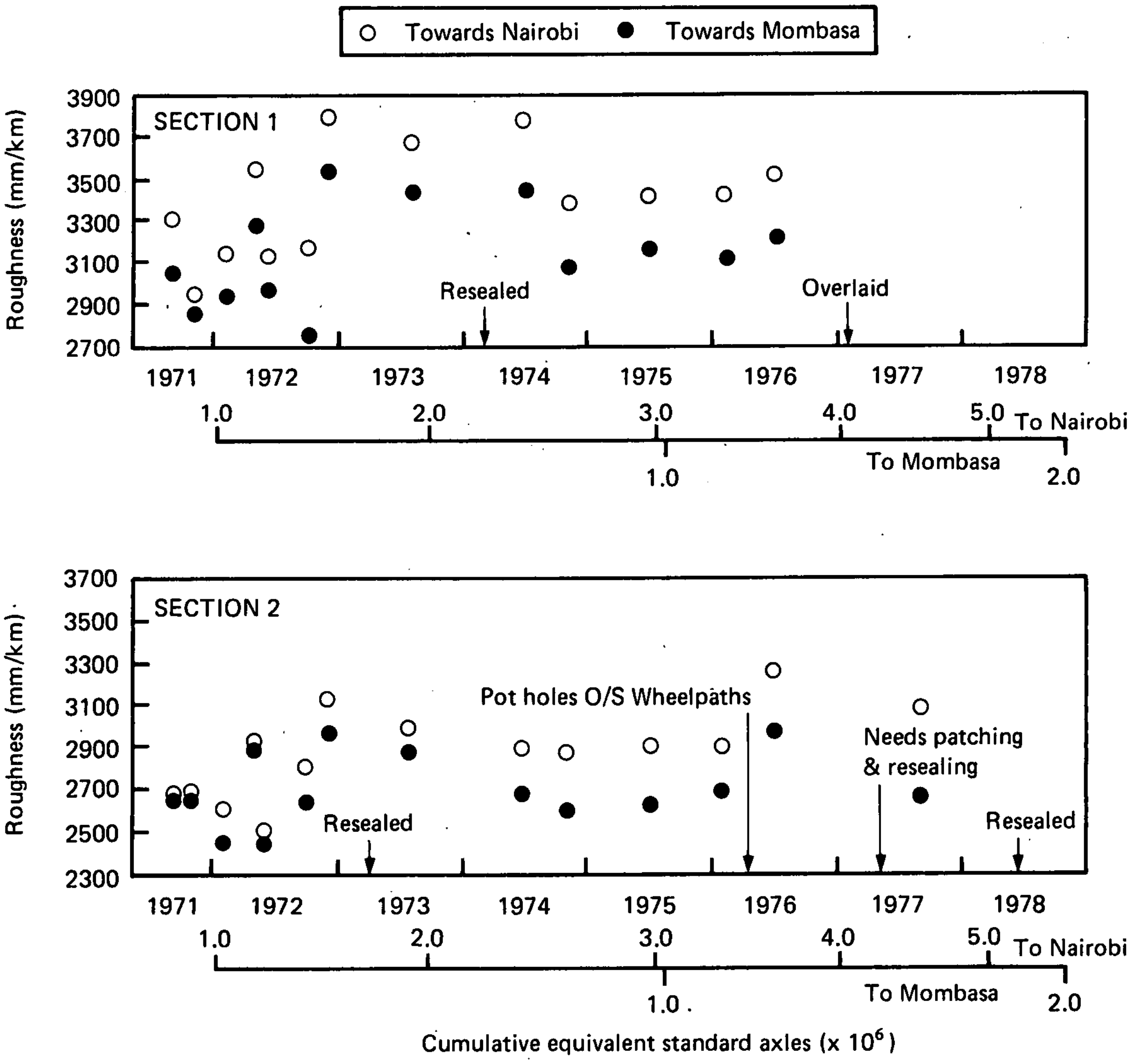

Fig. 1 ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING

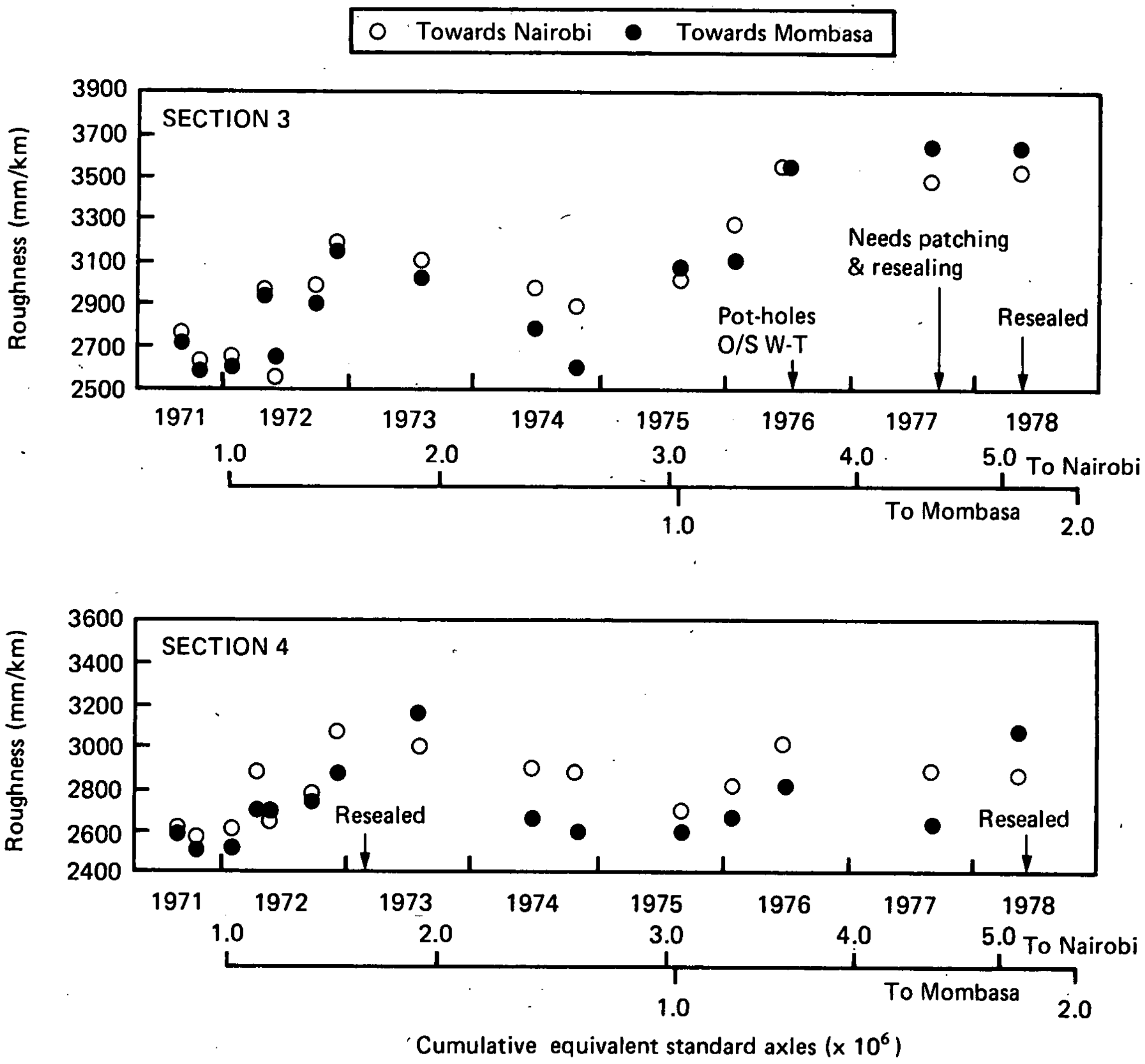

Fig. 1 (CONT.) ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING

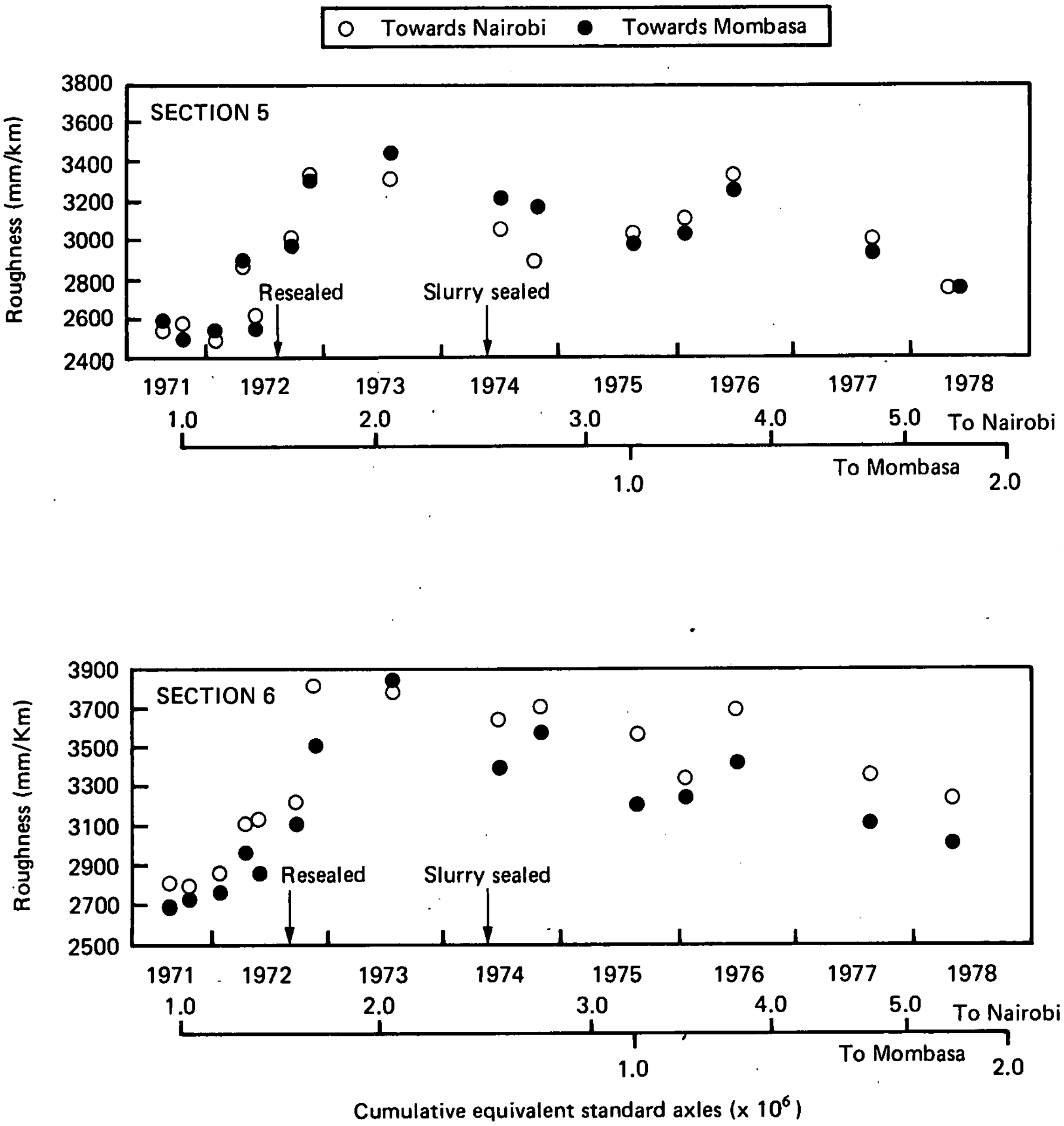

Fig. 1 (CONT.) ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING

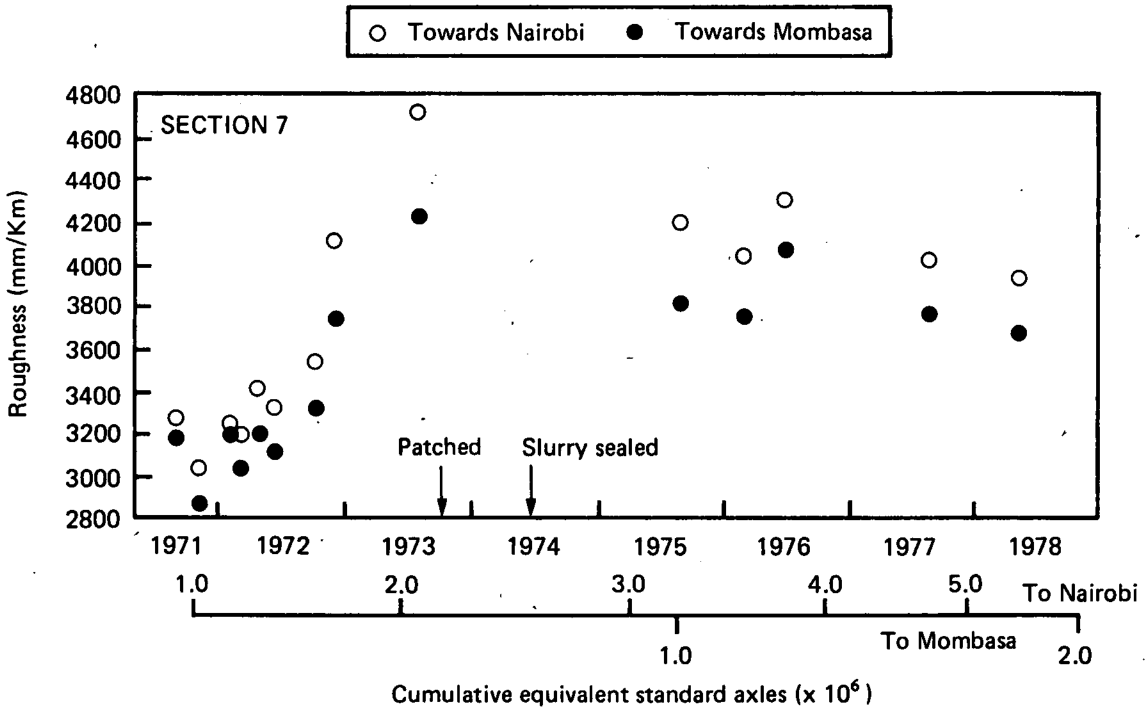

Fig. 1 (CONT.) ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING

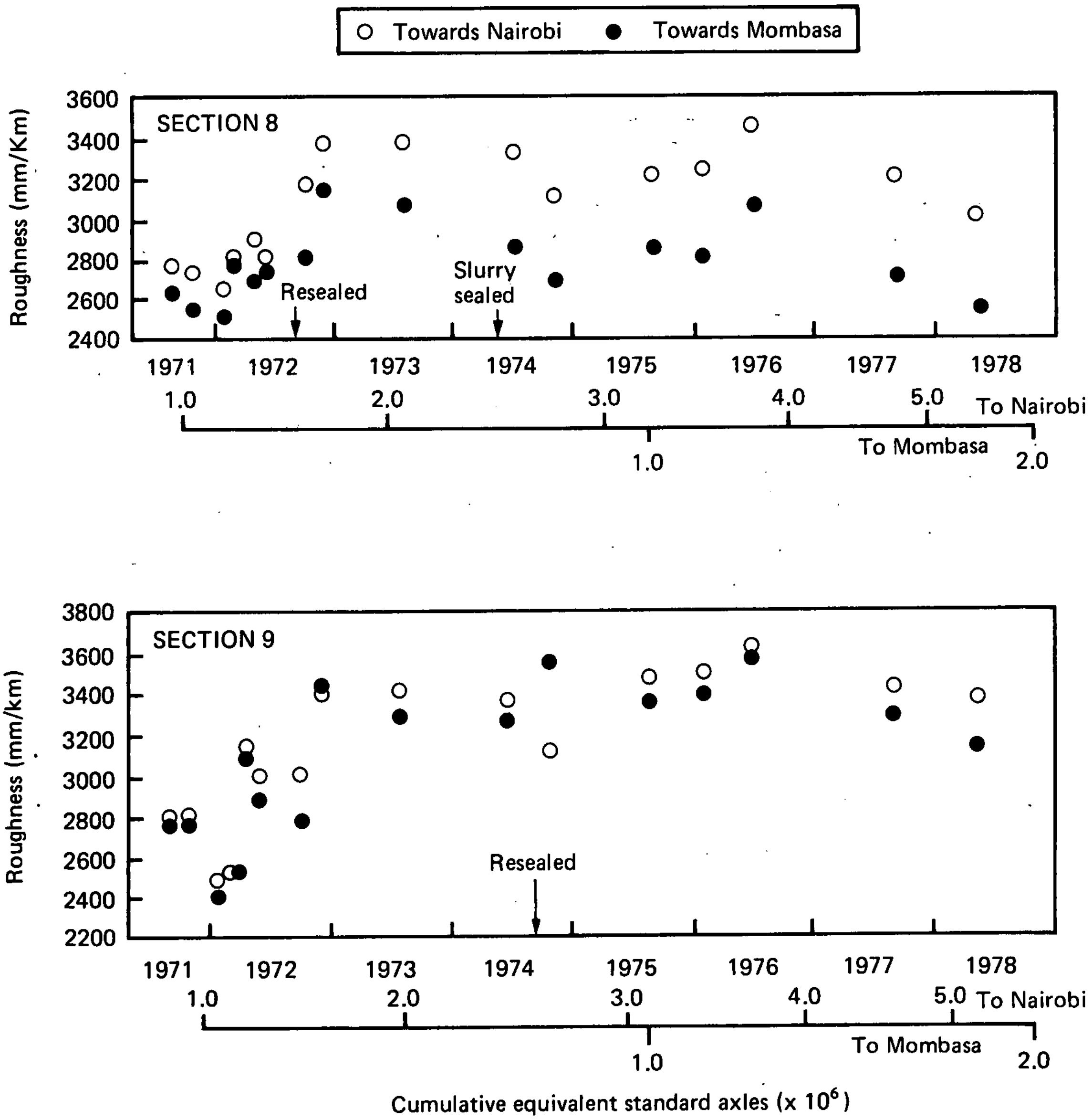

Fig. 1 (CONT.) ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING

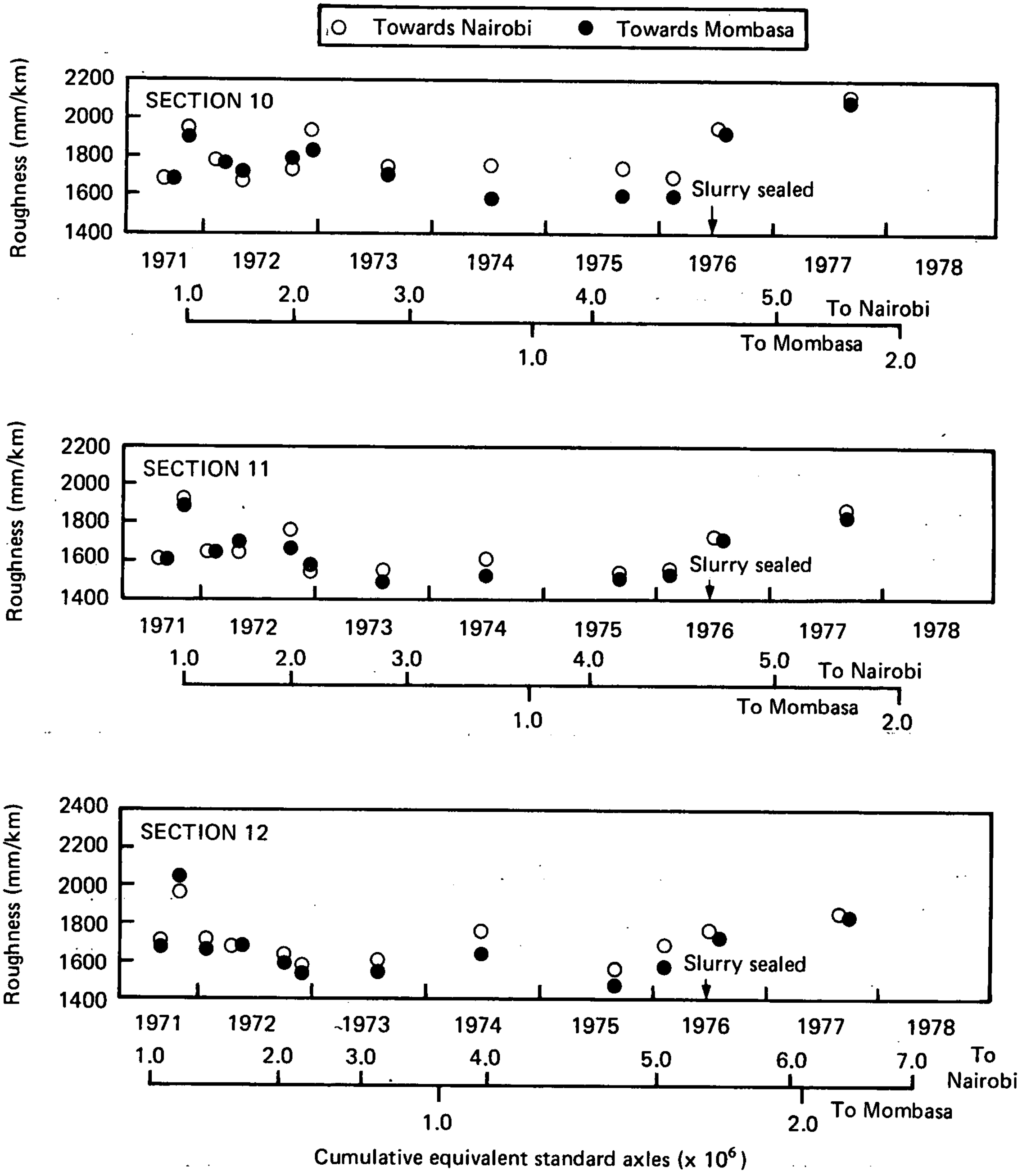

Fig. 1 **(CONT.) ROUGHNESS VERSUS CUMULATIVE TRAFFIC LOADING**

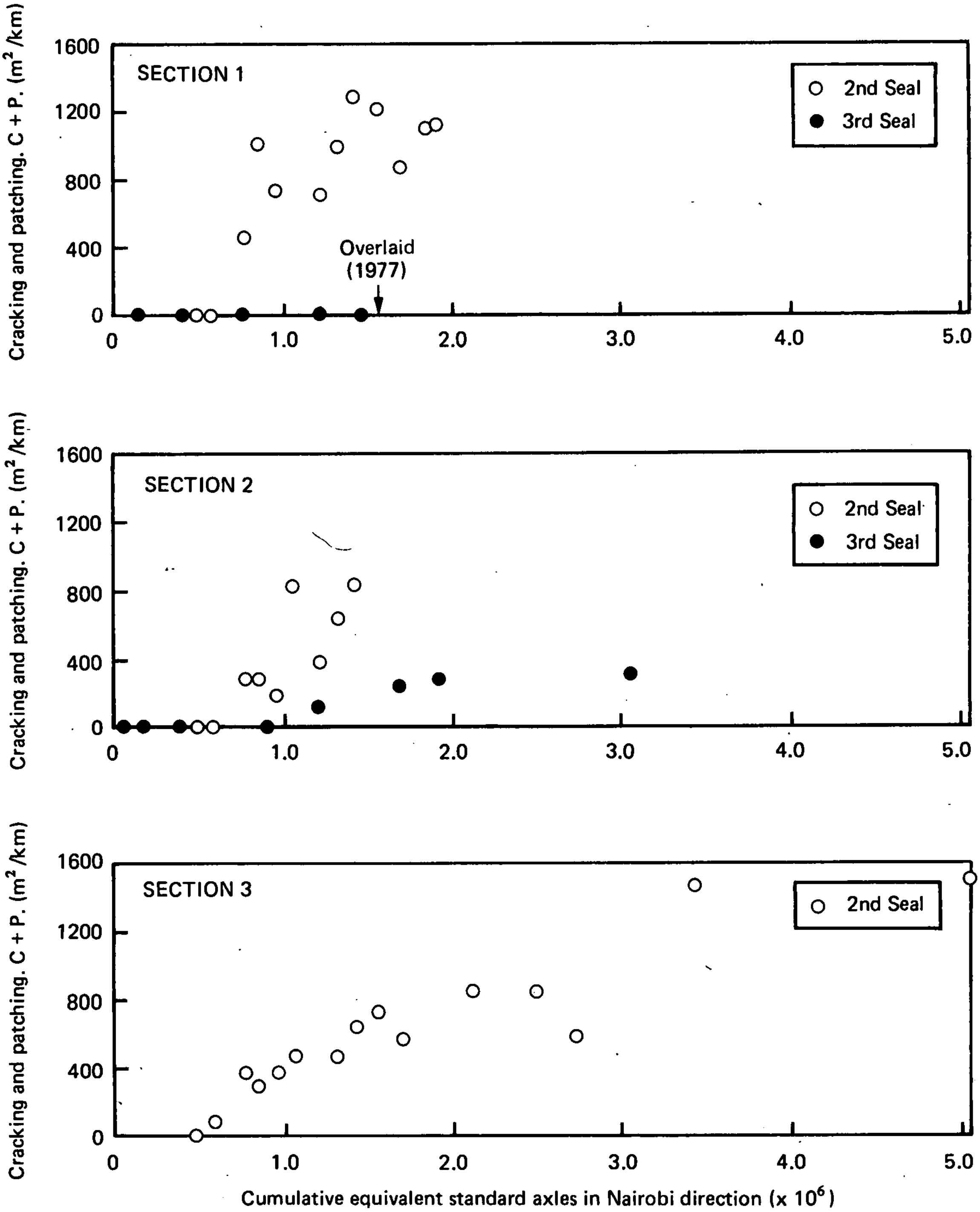

Fig. 2 CRACKING AND PATCHING VERSUS CUMULATIVE TRAFFIC LOADING CARRIED BY EACH SEAL.

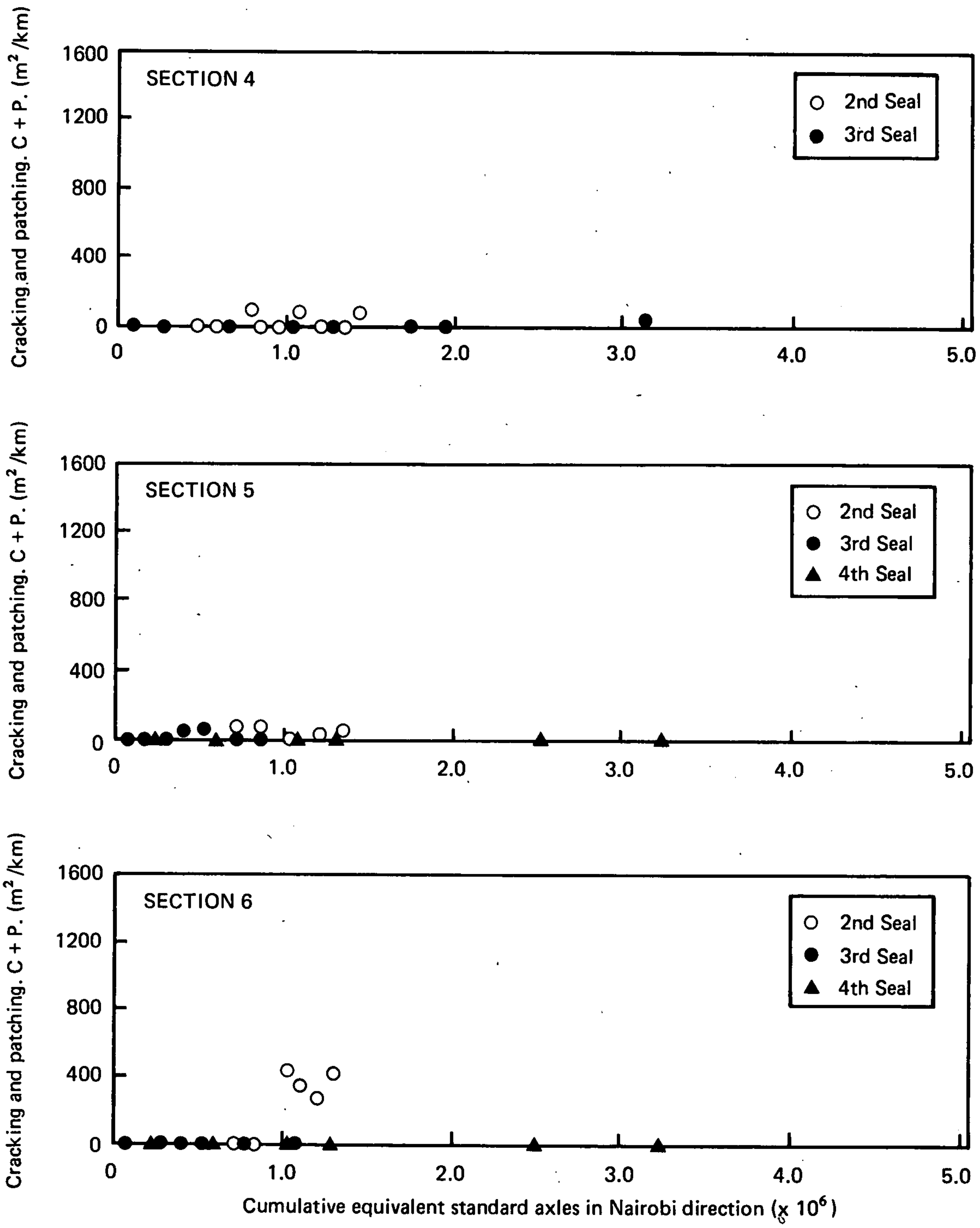

Fig. 2 (CONT.) CRACKING AND PATCHING VERSUS CUMULATIVE TRAFFIC LOADING CARRIED BY EACH SEAL.

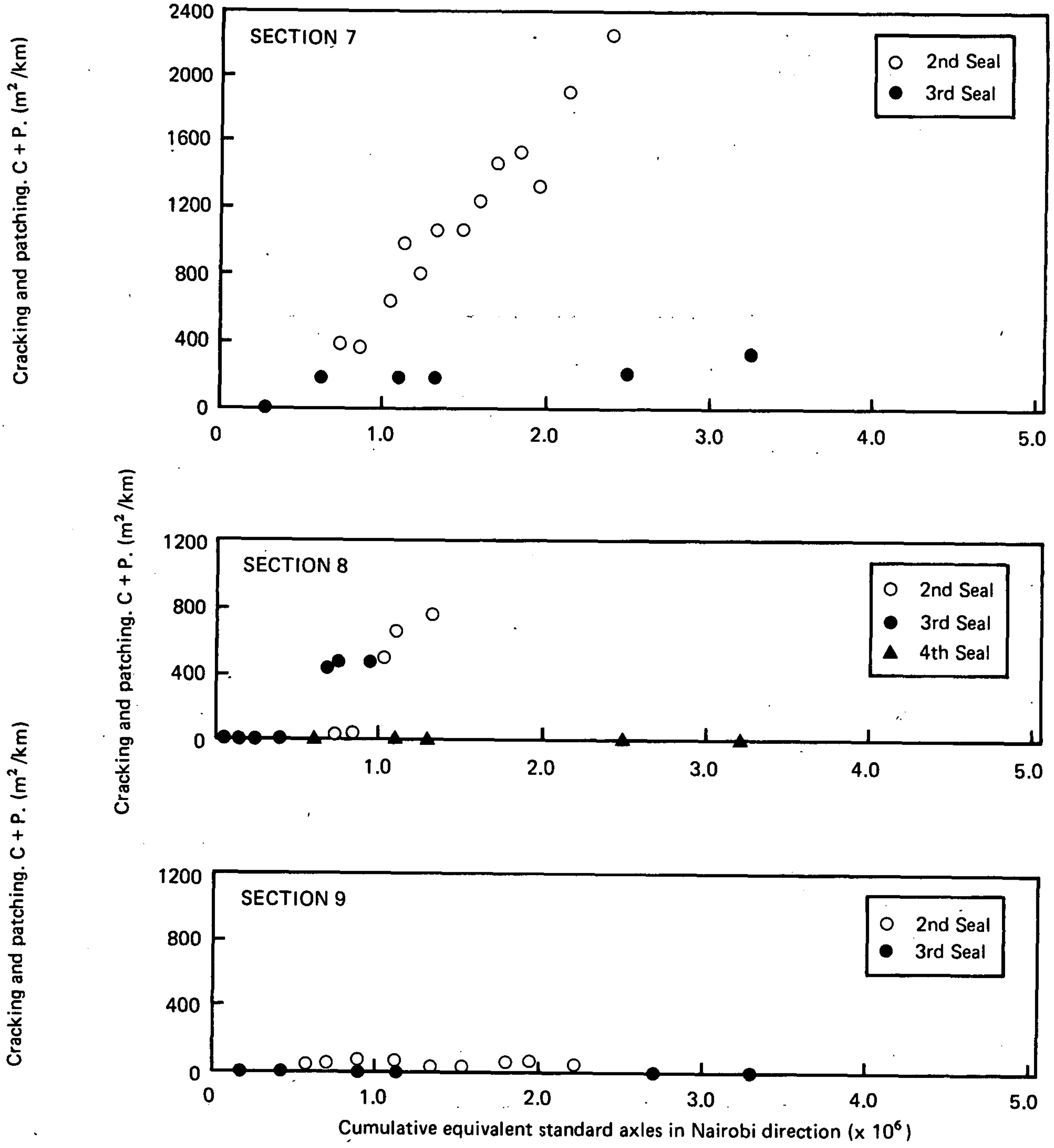

Fig. 2 (CONT.) CRACKING AND PATCHING VERSUS CUMULATIVE TRAFFIC LOADING CARRIED BY EACH SEAL.

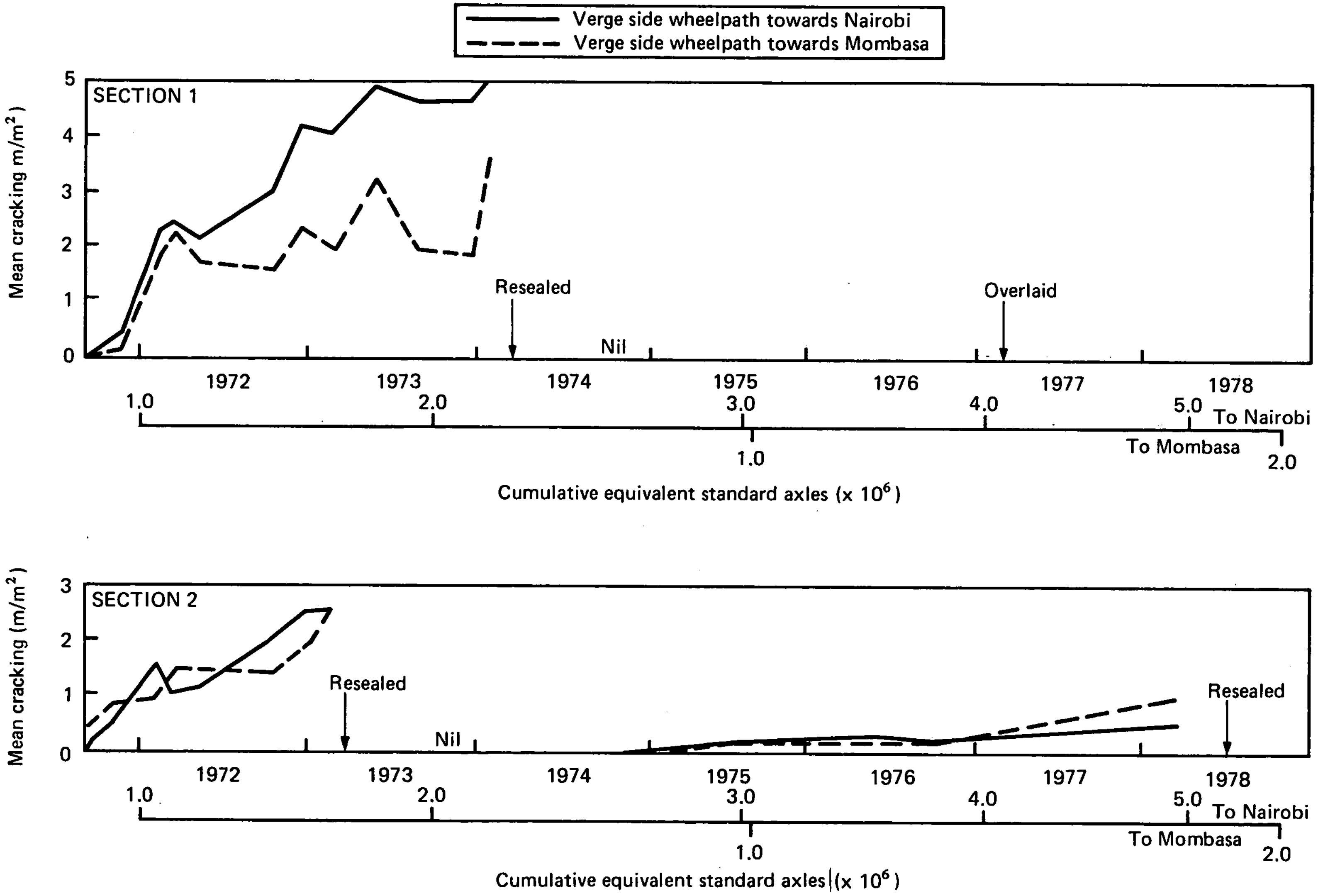

Fig. 3 MEAN CRACKING IN VERGE SIDE WHEELPATHS VERSUS CUMULATIVE TRAFFIC LOADING

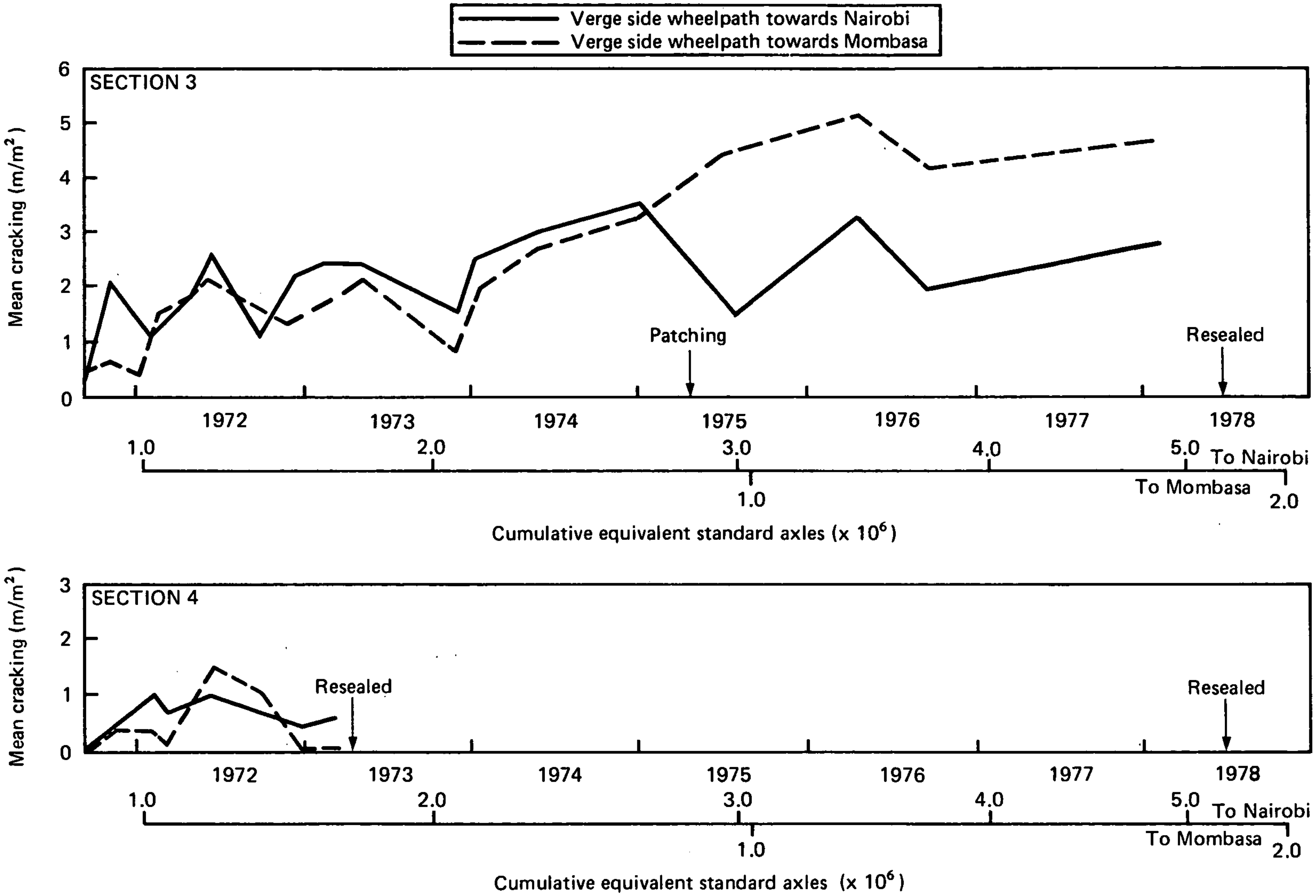

Fig. 3 (cont.) MEAN CRACKING IN VERGE SIDE WHEELPATHS VERSUS CUMULATIVE TRAFFIC LOADING

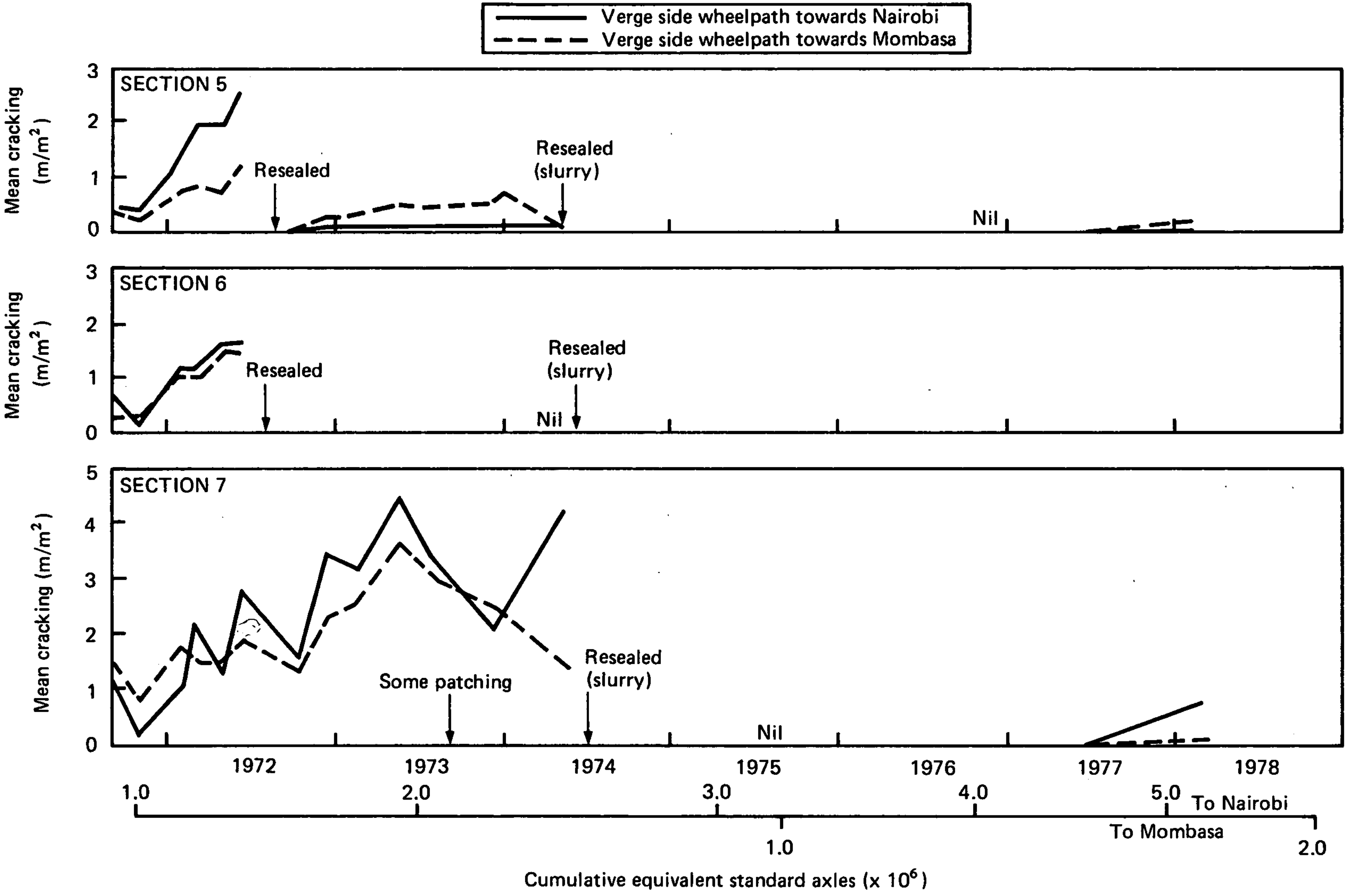

Fig. 3 (cont.) **MEAN CRACKING IN VERGE SIDE WHEELPATHS VERSUS CUMULATIVE TRAFFIC LOADING**

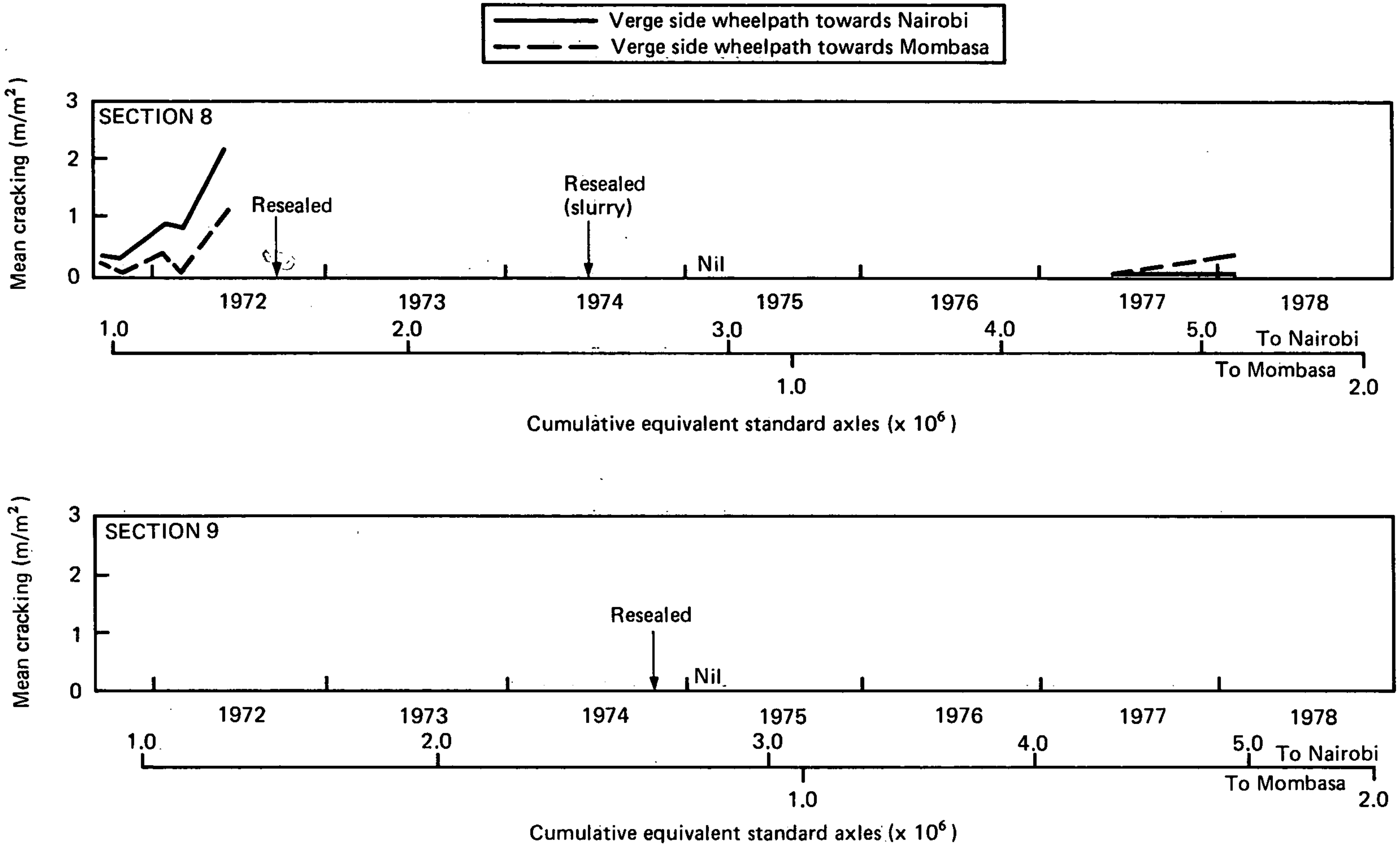

Fig. 3 (cont.) **MEAN CRACKING IN VERGE SIDE WHEELPATHS VERSUS CUMULATIVE TRAFFIC LOADING**

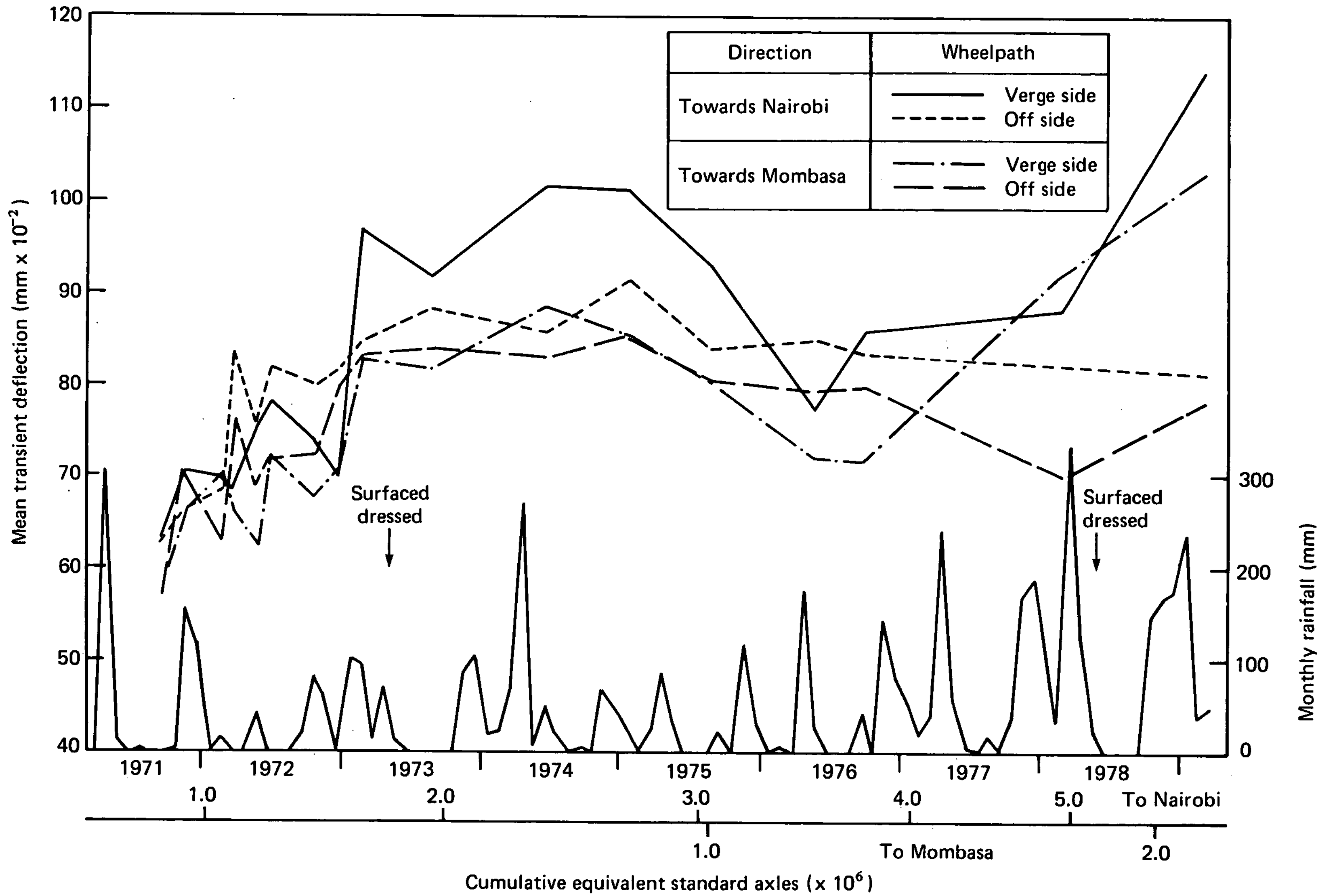

Fig. 4 DEFLECTION HISTORY FOR SECTION 2

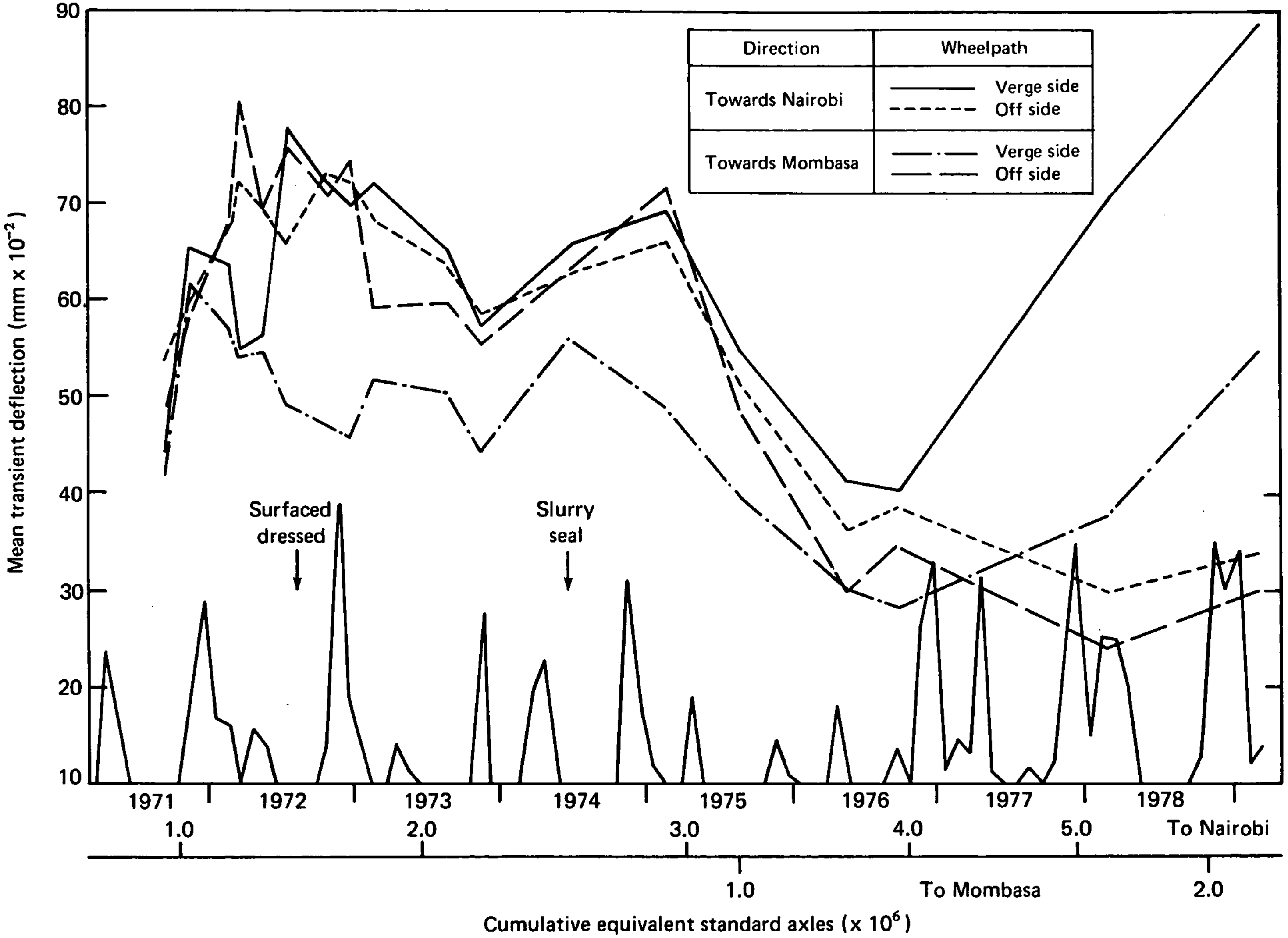

Fig. 5 DEFLECTION HISTORY FOR SECTION 6

C D	1	2	3	4	5	P
1	○	●	▲	◆	■	
2	○	●	▲	◆	■	
3	●	●	▲	◆	■	
4	▲	▲	▲	◆	■	
5	■	■	■	■	■	
P						■

C – Cracking
D – Deformation
P – Patching

Fig. 6 SYMBOLS USED FOR RECORDING PAVEMENT CONDITION ON DEFLECTION HISTORY CHARTS (Figs. 7 – 10)

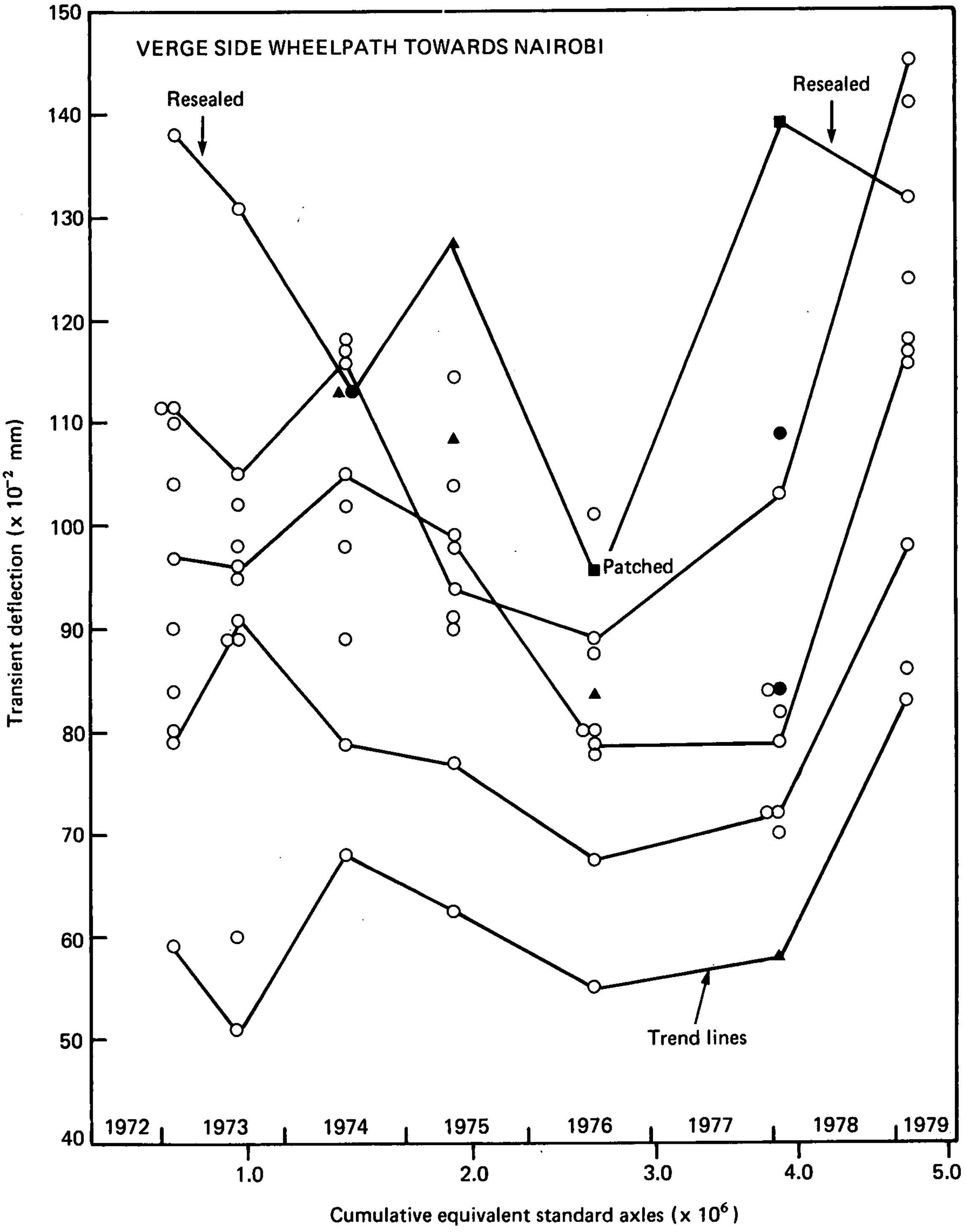

Fig. 7 DEFLECTION HISTORY FOR INDIVIDUAL TEST POINTS ON SECTION 2

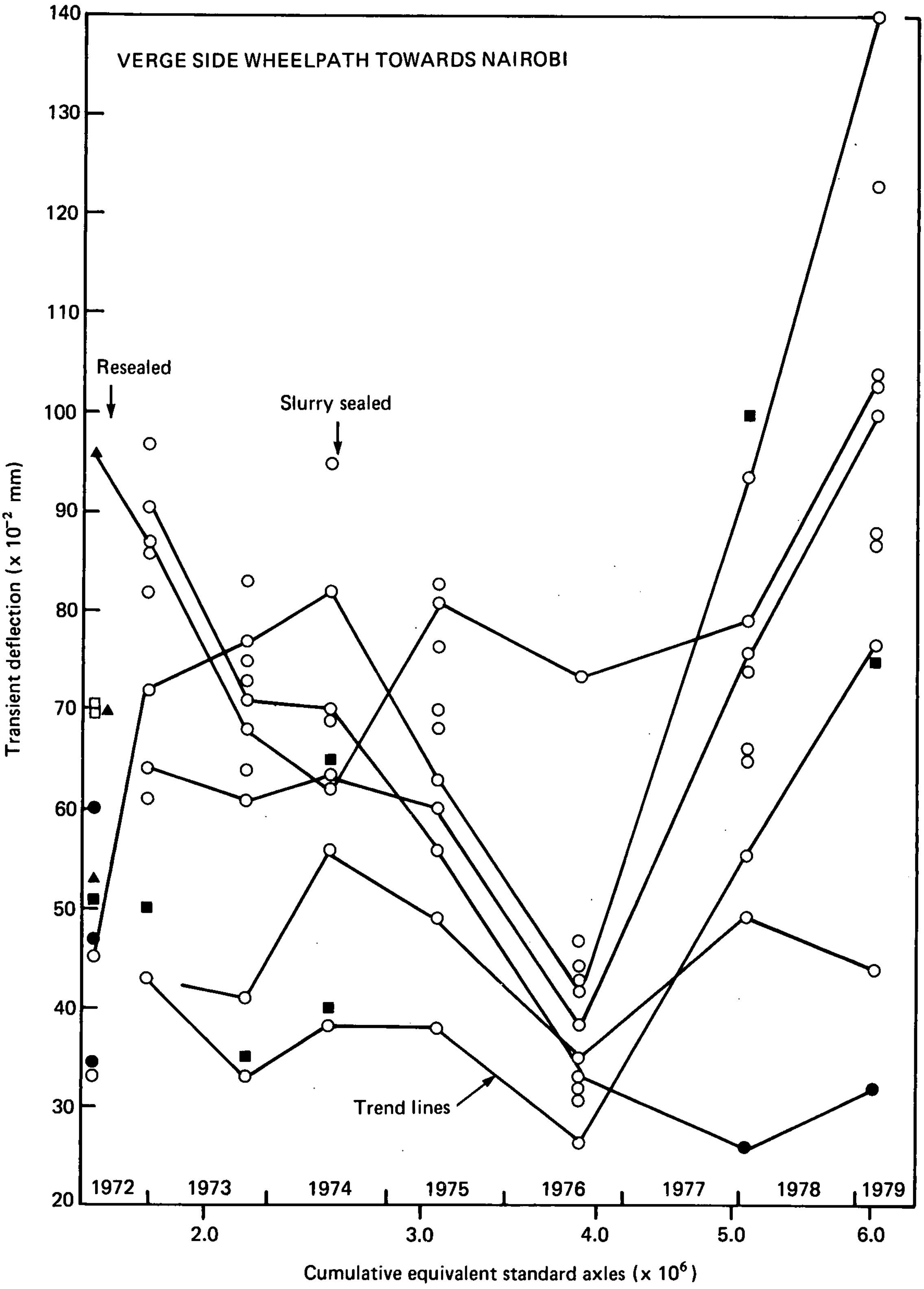

Fig. 8 DEFLECTION HISTORY FOR INDIVIDUAL TEST POINTS ON SECTION 6

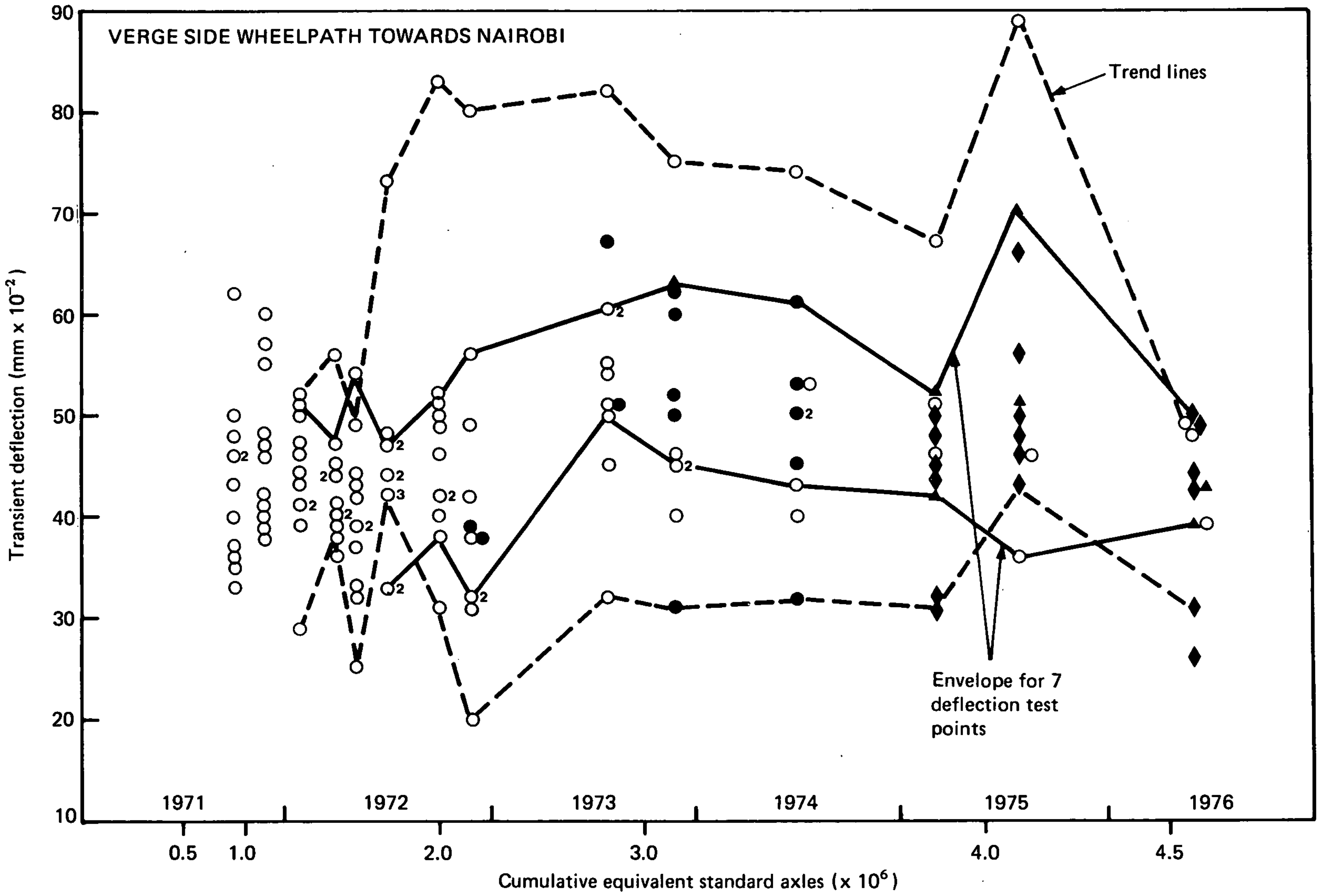

Fig. 9 DEFLECTION HISTORY FOR SITE 11

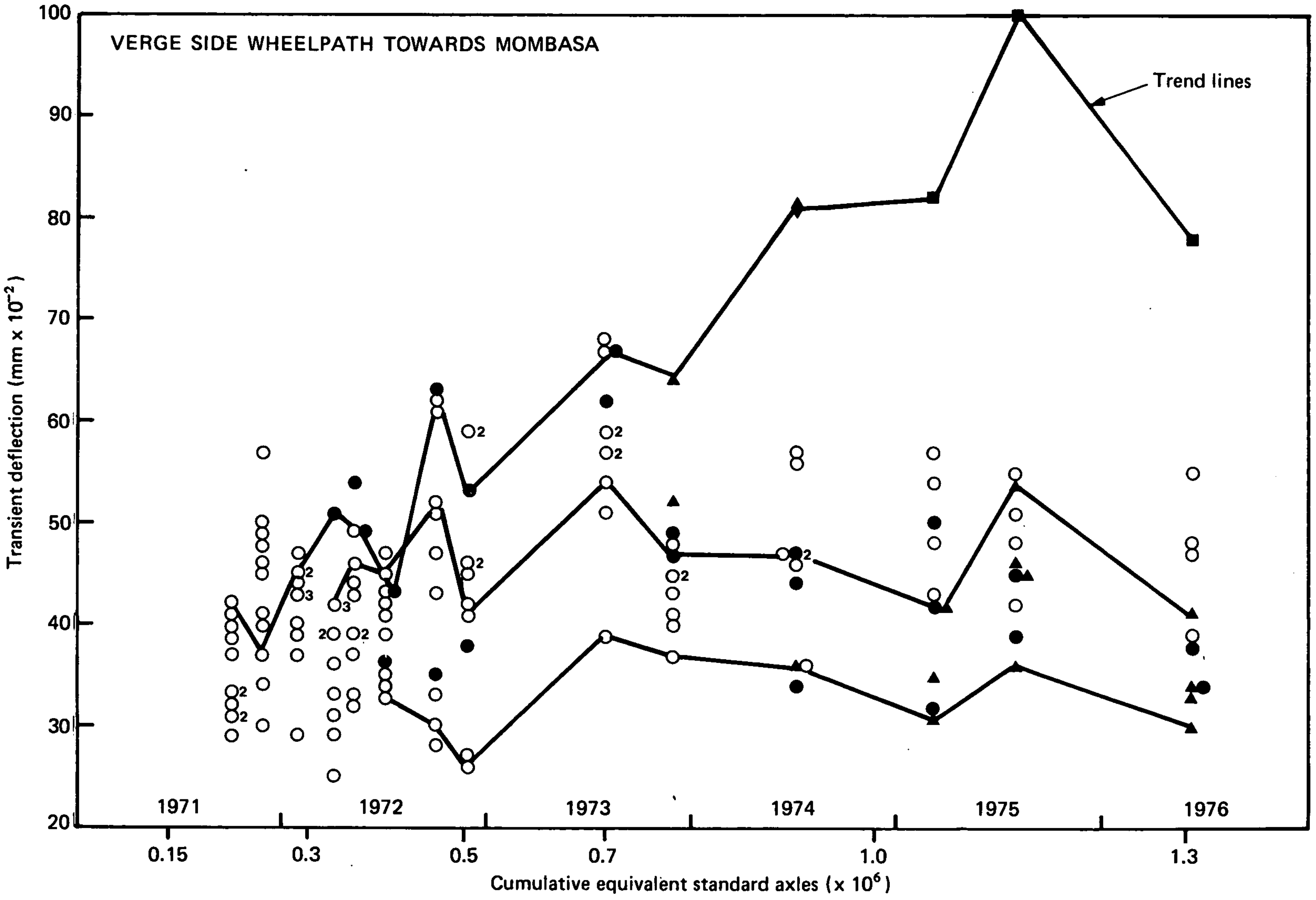

Fig. 10 DEFLECTION HISTORY FOR SITE 11

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ABSTRACT

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These road sections are located in a dry area, on strong subgrade soils.

It was found that the lightly constructed sections with cement-stabilised bases had suffered little structural damage after carrying 6 x 10^6 equivalent standard (80 kN) axles, considerably more than would be predicted by current methods of pavement design. The more heavily constructed sections with asphaltic concrete surfacings are performing broadly as would be expected.

For both types of pavement, deterioration has been mainly confined to the surfacings, and timely resealing has a powerful effect in limiting the amount of patching required and in maintaining an acceptable level of surface roughness. The lives of the better quality seals have been of the order of four to five years.

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