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Paper No. 208

# "TRAFFIC SURVEY IN AND AROUND CALCUTTA"

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CONTENTS



## SYNOPSIS

The Paper deals firstly with the study of external traffic on roads leading to Calcutta city. For this purpose, traffic counts were taken at eleven stations on the outskirts of the city in September 1957. A similar study was carried out earlier in 1950. The city was divided into various zones and the average daily traffic flow between the counting stations and the various zones was determined. Thus traffic flow diagrams for daily traffic were obtained from which hourly average could be deduced.

The traffic flow on various important roads in the city due to external traffic is then analysed and the effect of the proposed Greater Circular Road in relieving congestion on other busy roads is shown.

The Paper then describes the study of internal traffic for which traffic counts were taken at each important crossing within the city during rush hours. Both fast and slow traffic was counted and equivalent fast traffic worked out. The traffic capacities of carriageways and intersections of different internal roads are then analysed and various improvements are suggested to relieve congestion in the city.

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## 1. INTRODUCTION

1.1. Job Charnock who founded a small settlement on the banks of the River Hooghly for the limited Englishmen of the East India Company more than two centuries ago, could little imagine that one day this settlement would grow into one of the premier cities of the world. Unfortunately, from the unplanned haphazard growth spreading over two hundred years has resulted the inevitable chaos for the future planners in their efforts to improve the existing situation. The tremendous increase of vehicular traffic in Calcutta has, for quite some time, been a serious challenge to West Bengal's Highway Engineers and others who are trying to find a solution to this problem.

1.2. All cities have expanded at a terrific pace during the last few years. But unlike others, the expansion of the city of Calcutta has been restricted to only northern and southern sides due to the physical limitations on the east and the west, Table 1. The low lying salt lake areas on the eastern fringe of Calcutta make it practically impossible for human habitation there without substantial improvements at a huge cost, whereas the Ganges forms its boundary on the western side of the city. The sudden growth of the city and more specially its surroundings since the second Great War, was due to various industrial and commercial activities and to a large extent due to the heavy influx of refugees after the partition of Bengal. The suburban areas of Calcutta are now developing faster than usual due to the settlement of displaced persons from East Pakistan all round the city. Each and every problem associated with the urban life of the city is becoming more and more complex every day. Inadequate water supply, bad drainage, creation of slums and blighted areas, scanty accommodation for residence, and the ever increasing traffic congestion and accidents are the results experienced from this fast growth. The real solution of these problems lies in the decentralisation of commerce and industries for which preparation of a Metropolitan Regional Plan of Calcutta is essential. As regards the solution of traffic problem which brooks no delay, traffic census was taken in 1950 and 1957 by the Development (Roads) Department in collaboration with the Police (Traffic) Department.

1.3. The Police Department of the Government of West Bengal are quite aware of the situation which is bound to crop up in the near future if the traffic goes on increasing at the present rate and the creation of traffic branch is timely. Within a very short time, they have shown remarkable achievements in the reduction of street accidents and easing the congestion to some extent by imposing certain restrictions on



the slow moving traffic, introducing "one way" traffic in some important streets in the commercial areas, providing traffic islands at some important junctions and crossings, enforcing traffic laws rigorously, installing automatic traffic signals at all important junctions and crossings and also by way of educational drive and propaganda campaigns. These improvements have controlled the figures of street accidents since 1950 although the traffic volume has considerably increased since then, Table 2.

1.4. To determine the extent of congestion and also other factors relating to the flow of traffic, census work was first taken up in 1950. The volume of traffic flowing in some of the most important streets of Calcutta was counted and the impact of external traffic coming in or going out of the city, which was through in character, on the internal flow was also gauged. Enumeration work was again taken up in 1957 (August & September) exactly on the same lines as before with a view to compare the previous data with the present one and also to ascertain the present trend so as to project these data into the future planning programme with some amount of confidence and accuracy.

**Growth of Traffic**

The Table below shows the total number of each category of vehicle registered in Calcutta only upto December, 1957.

| S. No. | Category of Vehicles | Number | |
|---|---|---|---|
| 1. | Private Cars | 43,745 | FAST MOVING VEHICLES—67,000 Nos. |
| 2. | Lorries | 10,994 | |
| 3. | Contract Carriages | 963 | |
| 4. | Trailers | 1,073 | |
| 5. | Tractors | 137 | |
| 6. | Big Taxies | 668 | |
| 7. | Baby Taxies | 1,220 | |
| 8. | Private Buses | 883 | |
| 9. | State Buses | 640 | |
| 10. | Motor Cycles | 5,332 | |
| 11. | Delivery Vans | 995 | |
| 12. | Tram Cars | 422 | |

| S. No. | Category of Vehicles | Number | |
|---|---|---|---|
| 13. | Rickshaw (Pull Type) | 5,996 | SLOW MOVING VEHICLES— 17,016 Nos. |
| 14. | Hackney Carriages | 350 | |
| 15. | Animal Drawn Vehicles | 625 | |
| 16. | Hand Carts | 10,045 | |

From the graphical chart, Fig. 1, showing the growth of traffic it becomes evident that with the increase of population to

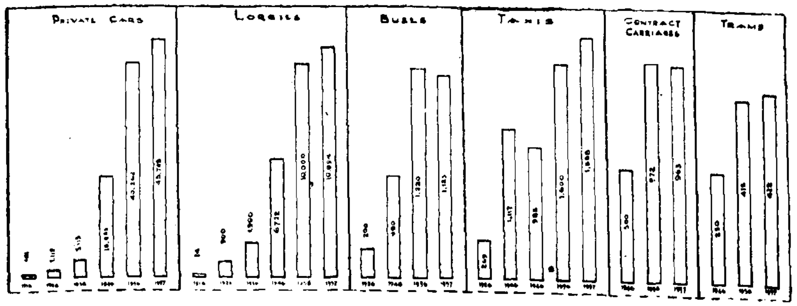


Fig. 1.

**Growth of fast moving traffic in Calcutta during 1916-1957**

the extent of 15 times during the last 40 years or so, the vehicular traffic has increased no less than 130 times.

It is, however, interesting to note that there has been a considerable drop in the number of animal drawn carts (Fig. 2) due to the introduction of lorries which have the advantage of quick transportation, increased handling capacity, greater number of turn-over as well as economy. The animal drawn carts will gradually disappear from the city with probable outlook for better prospects. The rise in the number of lorries from 6,772 in 1946 to 11,000 in 1957 amply proves the utility of fast traffic. The pull rickshaws have local importance and the replacement of these by auto-rickshaws has already started in other cities and it may not be long before the pull rickshaws will be off the road in Calcutta.

For short haulage and less bulky commodities in congested areas, the hand cart will still continue its stay for some more time. Although hand carts are a menace to fast traffic, dealers and sub-dealers prefer to transport their commodities by hand



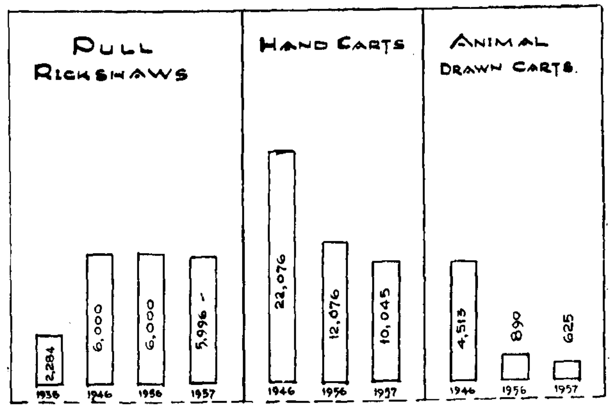


Fig. 2.

**Growth of slow moving traffic in Calcutta during 1936-1957**

carts as lorries and contract carriages cannot gain easy access to narrow lanes and by-lanes. In any case, their withdrawal from the streets will be facilitated if alternative employment is provided for the operators.

## 2. EXTERNAL TRAFFIC STUDY

2.1. External traffic enters Calcutta through the following routes: See Plate I.

(1) Barrackpur Trunk Road ($X_2$), Surya Sen Road ($X_1$) from north and Jessore Road ($X_3$) from north-east. All the traffic of these three streets has got to enter the city through Shyambazar Rotary ($A_1$), the main northern entrance of the city.

(2) Gariahata Road ($X_4$) and Russa Road ($X_5$) from the south-east and Diamond Harbour Road ($X_6$) and Budge Budge Road ($X_7$) from the south-west. All these roads have got independent entrances to the city and thus less congestion is found in the southern region in comparison with the north in spite of the abnormal increase in traffic.

(3) Grand Trunk Road ($X_{11}$), Old Banaras Road ($X_{10}$), Amta Road ($X_9$) and Andul Road ($X_8$) from the western or Howrah side. The traffic of these roads enters the city proper through the Howrah Bridge.

2.2. Traffic entering through the Howrah Bridge cannot be diverted and it enters the commercial centre directly. The improvement required for dealing with the traffic at this point is a matter of independent investigation which is being left out from the present study. Traffic statistics for Howrah Bridge were taken and discussed in Madhava's Paper No. 127 of Indian Roads Congress, Vol. XII (1948).

2.3. Traffic counts in the eleven stations on the outskirts of the city were made simultaneously for seven days from the 13th to the 20th September 1957, vide Table 3.

2.4. For determining the origin and destination of traffic within the city and probable travel routes, the city was divided into various zones as shown in Table 4 and Plate I and traffic census recorded accordingly. From the countings, results have been compiled and an abstract worked out giving the average daily traffic flows (both up and down traffic) between the counting stations and the various zones of the city. These are given in Table 5. The local traffic such as horse drawn carriages, hand-carts, rickshaws, and cycles, for which origins and destinations were not noted, are not included in the figures compiled here.

2.5. As the main roads run north and south, there are obligatory crossings through which traffic must pass to reach the various zones. For facility of consideration, zones have, therefore, been counted together depending on common travel routes, Table 6.

2.6. For drawing the existing average daily traffic flow diagram, due to the external traffic only, first of all the common routes which the traffic would in general take to travel between a particular part of the city and a counting station or another part of the city have been ascertained. The existing travel routes for the traffic of all the stations are given in Table 7. For facility of indicating the flow diagrammatically the different parts of the city have conveniently been represented in the diagram by the centres or vital junctions as given in Table 4.

2.7. Traffic flow diagrams for the northern stations (viz. $X_1$, $X_2$ & $X_3$), southern stations ($X_4$, $X_5$, $X_6$ & $X_7$) and western or Howrah side stations ($X_8$, $X_9$, $X_{10}$ & $X_{11}$) have been drawn separately and then combined together to obtain the required existing daily average traffic flow diagrams (for external traffic only) between the city and the outside. The diagram may be seen in Plate II.



2.8. It may be seen here that out of 2,534 Nos. of vehicles passing through the census station $X_{11}$ situated at Uttarpara on the G. T. Road, on an average 869 are crossing the Vivekananda Bridge at Bally and the remaining 1,665 Nos. take the G. T. Road route through Bally, Belur, Salkia and Howrah. Since these 869 Nos. of traffic from the Grand Trunk Road after crossing the Vivekananda Bridge have got to enter the city either through the Surya Sen Road ($X_1$) or Barrackpur Trunk Road ($X_2$), they must have been enumerated either at $X_1$ or at $X_2$. As such, the intensities of flow due to this have not been taken into consideration to avoid duplication.

2.9. From the study of diagram and Tables, it is evident that out of 22,649 Nos. of total external traffic (Table 6), 10,952 i.e., about 47.2 per cent pass through the three northern stations ($X_1$, $X_2$ & $X_3$), of which the traffic on the B. T. Road itself contributes 6,247, i.e., about 55 per cent. Only 7,118 Nos., i.e., 31.3 per cent of the total traffic relates to the four southern stations ($X_4$, $X_5$, $X_6$ & $X_7$) and only 4,579 Nos., i.e., 21.5 per cent of the total traffic enters the city through the Howrah Bridge.

When these figures are compared with the 1950 figures, Plate III, it becomes evident that the traffic entering the city through the northern and southern approach roads has hardly fallen but the intensity of flow through the western approaches has increased considerably and, to be precise, the increase is from 9 per cent to 21.5 per cent. The important factors contributing to such an increase are the intense road development activities on the western fringes of the city and the construction of a large number of local through roads.

2.10. All the external traffic from the north enters the city mainly through Shyambazar Crossing ($A_1$) by Surya Sen Road, Barrackpur Trunk Road and Jessore Road. The bulk of the south bound traffic from the northern side of the city is carried by the three city roads, viz., Chittaranjan Avenue, Cornwallis Street and Circular Road.

2.11. The Cornwallis Street is narrow in comparison with the other two roads mentioned above, having a carriageway of only 43 ft-0 in. with two tram lines running in the centre, leaving only one traffic lane on either side. The recent census figures also show that the traffic on this road has neither increased much in comparison with 1950 figures nor does it vary much during rush hours, indicating that only short local traffic generally uses this road. The Circular Road is broad and 68 ft-0 in. wide and although two tram lines run on this road, we are still left with at least four lanes of traffic. The volume using this road is only 11.2 per cent of the total volume of the crossing ($A_1$). The volume using the Chittaranjan Avenue is 30.2 per cent and a comparative idea of traffic in the three roads may be obtained from the graphs in Plates IV, V & VI which will evidently indicate that most of the external traffic reaching Shyambazar Rotary ($A_1$) uses the Chittaranjan Avenue.

2.12. In order to find out the impact of external traffic on the internal traffic flow, the daily average figures in the case of external traffic counts are to be reduced to hourly average. It is seen that the external traffic remains appreciable from 9.00 to 18.00 hrs., i.e., for about 9 hours, which also corresponds with the rush hours in the city areas. As such, to convert daily average of external traffic into hourly average with reasonable approximation, the figures are divided by 9. The internal counts of traffic taken on Chittaranjan Avenue give a peak average hourly traffic of 741 Nos. of vehicles at Shyambazar Crossing (Plate VI). The average of external traffic reaching Shyambazar Crossing (both towards the city and away from the city) comes to $\frac{679 + 6,247 + 4,026}{9} = 1,222$ vehicles per hour, Plate II.

2.13. The intensity of external traffic beyond the crossing is $\frac{876 + 5,956}{9} = 759$ Nos. of vehicles (Plate II) leaving the business, commercial and industrial areas in zones $B$, $C$, $D$ & $E$. The remaining is consequently for the northern industrial and Goods Shed areas ($A$ & $Ax$). Apart from the traffic going direct to zones $B$ & $D$ and also to $H_1$, $H_2$, $H_3$ & $H_x$, i.e., on Howrah side, the traffic for south-western industrial areas ($F_2$, $F_3$ & $F_4$) and the residential areas on the southern side as well as for the Kidderpore Docks, Behala and other areas ($F_1$ & $G$) takes its course through the Chittaranjan Avenue and the business areas of $B$ & $D$ $\frac{876}{9} = 97$ Nos. of vehicles on an average per hour are for western areas of Park Circus (zones $C$ & $E$ – Jn. III) and beyond. Chittaranjan Avenue is also the main traffic route for the internal traffic. The results show that in its most congested portion near Mission Row Crossing the hourly peak average is 1,720 Nos. of motor vehicles (Table 10) out of which $\frac{5,956}{9} = 662$ Nos. is the traffic of external character, i.e., out of the total traffic flow through Chittaranjan Avenue 38.5 per cent constitutes external traffic. Out of this, through traffic to and from the southern areas of the city is 204 Nos. per hour as detailed below (See Table 6):



| | | |
|---|---|---|
| From $X_1$ to zone IV | $= \frac{6}{9}$ | $= 0$ |
| From $X_2$ to zones IV, V & VI | $= \frac{467+177+141}{9}$ | $= 87$ |
| From $X_3$ to zones IV, V & VI | $= \frac{378+108+90}{9}$ | $= 64$ |
| From $X_5$ to zone I | $= \frac{18}{9}$ | $= 2$ |
| From $X_6$ to zone I | $= \frac{369}{9}$ | $= 41$ |
| From $X_7$ to zone I | $= \frac{91}{9}$ | $= 10$ |
| | | 204 |

2.14. Figures for Shyambazar Rotary ($A_1$) from internal census give (Plate VI & Table 10) $\frac{639+741+766}{2} = 1,073$ motor vehicles per hour (peak average) and $\frac{1,577+1,501+2,422}{2} =$ 2,750 Nos. equivalent fast traffic per hour (peak average). It is a junction of five streets, viz., Chittaranjan Avenue, Cornwallis Street, Upper Circular Road, R. G. Kar Road and Barrackpur Trunk Road. Tram lines run on four of the roads excepting on the Chittaranjan Avenue. A busy market is also situated there, just on the north-east corner of the crossing which renders control of traffic more difficult. It is most desirable to reduce the congestion on the Chittaranjan Avenue as well as of the crossing thereby by providing a second entry into the city from Barrackpur Trunk Road and Jessore Road which will conveniently be used by the south and east bound external through traffic (zones III, IV & V) as well as the traffic to the central part of the city (zone II) from Jessore Road. The present census figures give more support to the findings of the 1950 census and it is imperative for a second entrance to be constructed immediately as indicated in the proposal made earlier.

2.15. The Calcutta Improvement Trust has already undertaken development schemes known as New Manicktolla Schemes which are almost complete. The road alignments have been marked in Plate VII in dotted lines. It is also gathered that there is a proposal for development of Paikpara area between Dum Dum and Jessore Road by the Trust authorities. The alignment II in the Manicktolla scheme running north and south is proposed to be 120 ft - 0 in. wide and if no tram lines are allowed, which seems to be reasonable and wise, this alignment can be conveniently utilised for an outer circular road. It would have been better, however, if the road were made 200 ft wide at the outset which, though costly in the beginning, would be economical in the long run and would provide enough scope to cope with future traffic requirements as in that case service roads on either sides could easily be accommodated, making the road truly "through" in character. If this road is extended and linked with the Barrackpur Trunk Road and Jessore Road as indicated in the Plate by ABCDEFGH, it will provide several entries to the city through the recently improved streets of Manicktolla, Narkeldanga and Beliaghata as marked 1, 2, 3, 4, 5, 6 in the Plate. For the traffic going through the Park Circus area (zone III), the Beliaghata Road can be very conveniently joined to the newly constructed Calcutta Improvement Trust Road from Park Circus to Entally as indicated in the Plate. Consequently the traffic from Jessore Road will find it easier to approach the city by the Greater Circular Road, as suggested, except for the particular traffic destined to zone $A_x$ and $A$, while the traffic from Surya Sen Road and Barrackpur Trunk Road towards Park Circus and southern zones will naturally avail of this road. Thus in those circumstances, the Shyambazar Rotary ($A_1$) will be relieved of at least 384 Nos. of vehicles per hour as indicated below, Table 6:

| | | | |
|---|---|---|---|
| From station $X_1$ | to zone III – | 14 | = 23 |
| | to zone IV – | 6 | |
| | to zone V – | 3 | |
| From station $X_2$ | to zone III – | 506 | = 1,150 |
| | to zone IV – | 467 | |
| | to zone V – | 177 | |
| From station $X_3$ | to zone II – | 1,402 | = 2,279 |
| | to zone III – | 301 | |
| | to zone IV – | 378 | |
| | to zone V – | 108 | |
| | to zone VI – | 90 | |
| | | Total | 3,452 Nos. |

i.e. 384 Nos. of vehicles per hour.



Similarly, Chittaranjan Avenue will also be relieved of 360 Nos. of vehicles per hour as detailed below:

Through traffic (external) as given in para. 2.13 = 204 Nos. per hr.

From station $X_3$ to zone II $= \frac{1402}{9}$ = 156 ,, ,, ,,

360 Nos. of vehicles per hour.

2.16. The population of the southern areas beyond the Corporation units has risen to more than 3½ lakhs as indicated on the 1951 General Census given in Table 1. But as a matter of fact this figure will have grown still higher since then, as we find every day the tremendous rate of building up of lands. Consequently, the traffic census figures taken in 1950 for the census stations $X_4$, $X_5$, $X_6$ & $X_7$ show a total of 539 number of motor vehicles per hour whereas the present figure stands at $\frac{2{,}404 + 946 + 2{,}724 + 1{,}044}{9} = 791$, i.e., an overall increase of nearly 47 per cent of traffic since 1950. This clearly indicates how rapidly the traffic is increasing in these areas with rapid refugee rehabilitation going on with such a vigorous pace. From this we can now guess without fear of going far out the future increase of the volume of traffic. All the traffic having its destination to and beyond the central area (zone II) is now passing through the already congested Chittaranjan Avenue and other roads. In view of the very rapid anticipated growth, it is necessary to extend the Greater Circular Road all round the city right now as already recommended in an earlier report. This idea of constructing a Greater Circular Road will be almost futile if the work is not immediately started before the entire area is fully built up when it will involve a tremendous initial expenditure. A possible alignment is indicated in Plate VII by ABCDEIJKLM with several entries by cross roads to the city as marked by 6, 7, 8, 9, 10. It is also necessary to extend this alignment further to the north for facilities of air traffic as indicated in Plate VII by dotted lines EN, in view of the fact that air traffic in this country is developing very rapidly.

2.17. The scheme for construction of the Greater Circular Road will also be of great importance if it is considered from the point of view of development of the eastern part of the city. The authorities are now seriously contemplating to develop the low lying areas of the eastern part of Calcutta for rehabilitating the low income group people and for the displaced persons from the abolished bustees and slumps of Calcutta. Planning for the development of the areas mentioned here will be not only enhanced but can effectively be co-ordinated with other aspects of life.

2.18. Of the southern entry roads, the Gariahata Road ($X_4$) has a traffic intensity of $\frac{2404}{9}$ = 267 Nos. of motor vehicles per hour, the corresponding figure of 1950 Census being 172, thus indicating an increase of traffic to the extent of 50 per cent approximately. The metalled width of the road is only 20 ft-0 in. with 10 ft wide unpaved footways on either sides of the carriageway. The metalled width of the road being only 20 ft, vehicles from opposite direction cannot cross without reduction of speed and travelling on the unpaved flanks. Moreover, there exists a very serious obstacle just at the point of entry of the road to the city proper. It has to cross the railway lines by a level-crossing which acts as a serious bottleneck to the free flow of traffic. The railway line is also very busy with four tracks leading to Budge Budge industrial areas. As we see it to-day, the road is gaining importance every day due to development of Jadavpur area and even for the present traffic of 267 Nos. of vehicles per hour, it should have a minimum metal width of 24 ft-0 in. for utilisation of the two lanes properly. Arrangement of grade-separation by way of constructing an over-bridge at the railway crossing is an immediate necessity and is long overdue.

2.19. For Russa Road ($X_5$) the traffic intensity is $\frac{946}{9}$ = 105 Nos. of vehicles per hour and the road is quite capable of taking this traffic and does not yet call for any immediate improvement.

2.20. In the Diamond Harbour ($X_6$) and Budge Budge ($X_7$) roads, the hourly intensities are 303 and 116 vehicles respectively and these roads do not require any serious improvements just now.

## 3. INTERNAL TRAFFIC STUDY

3.1. The census work with regard to the flow of internal traffic within the city was carried out at each important crossings during rush hours both in the morning from 9.00 hrs. to 12.00 hrs. and in the evening from 16.00 hrs. to 19.00 hrs. The results of each crossing were tabulated as per specimen given in Table 11 in which the average traffic of peak periods as indicated above has only been taken into consideration.

3.2. It has been indicated in connection with the external study, that all traffic coming from the north, which is the heaviest, finds its way through the Shyambazar Rotary. The traffic from the crossing can enter the city only through three roads, viz., Circular Road, Cornwallis Street and Chittaranjan Avenue. Graphical representations of the intensities of traffic along these roads have been drawn and given in Plates IV, V, & VI. Traffic on the cross roads has also been indicated therein by vertical lines. In drawing the above graphs, showing the hourly peak average traffic, the fast or motor vehicle traffic has been drawn separately by firm continuous lines, while trams, and slow traffic has been converted into equivalent volumes of fast traffic to obtain the total equivalent fast traffic curve. The conversion factors have been fixed on the basis indicated below.



Average speed of tram cars in the city does not exceed 10 miles per hour and the trams follow each other every two minutes on an average. The effective capacity of the lane occupied by the trams can be considered as only 50 per cent as the average speed of motor vehicles within the city streets is 20 miles per hour. The conversion factor for working out equivalent fast traffic may, therefore, be taken as "2". As regards slow traffic such as hand-carts, bullock-carts, rickshaws, etc., the factor has been taken as "4" without much error, and that for cycles is taken as "2" in consideration of the small width of lane occupied by it and its relative quick movements. The volumes of equivalent fast traffic on these three roads have thus been worked out and given in Tables 8, 9 & 10 and the graphical representations of the same have been made in Plates IV, V & VI by means of dotted lines. For the sake of convenience, figures of 1950 and 1957 have been superimposed on the same graph.

### 3.3. Traffic Capacity

The capacity of a road depends on the distances within which drivers of cars can come to a stop without collision, stopping distance of a car thus becoming important. This depends largely upon the speed. The car moved forward at the operating speed a certain distance before the driver applies brakes. There is then the added distance before the brakes action destroys the energy of the car's motion. On a level grade, this brake-action, or braking distance ($d$) in ft is given by the equation :

$$d = \frac{V^2}{30\,f}$$

where $V$ is the speed in miles per hour, $f$ is the assumed uniform frictional force for the period of deceleration or the so-called co-efficient of rolling friction between the tyres and the roadway. The value of '$f$' can be taken as 0.4 (reference American Highway Practice by Hewes) considering boundary conditions, such as tyre pressure, pavement moisture, comfort to the occupants of the vehicles, etc. Therefore, for the car speed of 20 miles per hour in the city area,

$$d = \frac{20 \times 20}{30 \times 0.4} = 33.3 \text{ ft} \ldots\ldots\ldots\ldots\ldots\ldots\text{(a)}$$

The time interval that is made up of the perception and brake reaction time is usually assumed as 3 seconds. Thus on a level tangent at 10 miles per hour, the car covers 88 ft, before the brake is applied. Considering the length of a car to be 16 ft, the safe distance between the centres of the two cars moving at 20 miles per hour is

$$33.3 + 88 + 16 = 137.3 \text{ ft say } 140 \text{ ft.}$$

Corresponding time in travel @ 20 m.p.h. $= \frac{140}{88/3} = 4.8$ sec.

Therefore, capacity per lane per hour $= \frac{60 \times 60}{4.8} = 750$ Nos.

A thoroughfare uninterrupted by cross-roads has a very high traffic capacity which reaches its maximum when there is a uniform flow of vehicles at a certain uniform speed. Tests made indicate that a speed between 17 and 27 m.p.h. (probably at 23) is the most favourable, being the highest at which vehicles can conveniently and safely run in close succession. At higher speed the interval must, for reasons of safety, be increased, and the number of vehicles passing the point of enumeration is thus reduced. It is computed in fact that, at double the most favourable speed, the number of vehicles is reduced by 30 per cent. At slower speed, the lessening of the distance between succeeding vehicles does not affect the reduction due to a smaller number of vehicles passing the point in a given time.

A rough idea of the number of vehicles which theoretically, given perfect conditions, could pass a given point in one hour is shown in the Table on next page. This number will obviously vary according to the distance between the vehicles which can only be given as an approximation.



| Speed of vehicles in m.p.h. | Distance apart in yards | Number of vehicles passed in 1 hour |
|---|---|---|
| 5 | 1 | 1,467 |
| 10 | 2 | 2,514 |
| 12 | 3 | 2,640 |
| 15 | 4 | 2,933 |
| 20 | 4 | 3,911 |
| 25 | 5 | 4,400 |
| 30 | 8 | 4,061 |
| 35 | 12 | 3,634 |

Given ideal conditions, therefore, it can be computed that each traffic lane on a road could accommodate over 4,000 vehicles per hour. In practice, however, ideal conditions do not obtain, vehicles do not run at uniform speed, performance and braking efficiency vary, the capability of drivers differ, and in all urban areas there are very considerable interruptions by reasons of cross-roads, junctions, standing vehicles, horse-drawn or slow moving traffic, pedestrians etc. All these factors should, therefore, be taken into account.

Where intersections are frequent, the capacity of the roads is governed by the capacity of intersections. Take for example a straight road in a modern city where the layout is rectangular. Let us assume that each lane in the road (having regard to the disparity of vehicle speed, etc.) has a maximum accommodation of 2,500 vehicles per lane per hour, and that the time of stoppage at each cross-road is standardised by means of traffic signals at each intersection which allow the following periods:

| | | |
|---|---|---|
| (a) For main streets | ... | 35 seconds |
| (b) For the cross-streets | ... | 25 ,, |
| (c) a period of 3 seconds of amber at each change viz. | ... | 6 ,, |
| | | 66 seconds |

In such circumstances the traffic in the main street is running only 25 seconds out of every 66 seconds; the traffic capacity is thereby reduced by 47 per cent, and it is usual to allow a further 10 per cent for the loss of speed incurred through stopping and starting. On that basis the total reduction works out to 57 per cent, thus yielding a computed capacity of approximately 1,075 vehicles per lane per hour—capacity which applies only to lanes unencumbered by standing vehicles. If there are standing vehicles, a still further reduction will occur. In a six-lane main street which has a continuous row of standing vehicles on each side, the average capacity of each lane of the street as a whole must be reduced theoretically by 33 per cent, but in practice the reduction is much greater on account of the delays due to weaving of three lanes of traffic into two. In addition, if vehicles are delayed by promiscuous crossing on the part of the pedestrians, the capacity is reduced still further. The ultimate figure might, therefore, be brought down very much lower, even indeed to the neighbourhood of 700 to 800 vehicles per lane per hour.

3.4. For Chittaranjan Avenue, Chowringhee Road, Ashutosh Mukherjee Road and Russa Road, the figures are tabulated in Table 10 (also see Plate VI). It is seen from these figures that only 741 Nos. of motor vehicles per hour are entering the Chittaranjan Avenue from Shyambazar Rotary ($A_1$). This traffic being fed by the cross-roads gradually increases up to Mission Row where the traffic reaches its peak value of 1,720 motor vehicles per hour. At the intermediate crossing of Vivekananda Road, the increase is 293 motor vehicles per hour, whereas at the Harrison Road crossing the increase is 128 motor vehicles per hour. At the Bowbazar crossing the value is slightly decreased by 127 Nos. of motor vehicles per hour which clearly indicates that the traffic from northern parts of the city takes the convenient route through Bowbazar Street (West) to reach the commercial and business areas of Calcutta. The main traffic on Chittaranjan Avenue bound for the commercial areas of the central part of Calcutta is again diverted through the Mission Row where the peak value of 1,720 falls to 1,559 Nos. of motor vehicles per hour and finally the number drops to 927 at the Esplanade Junction. Further on along the Chowringhee Road, which is a continuation of the Chittaranjan Avenue, the traffic jumps to 1,569 per hour at S. N. Bannerjee Road crossing and the value remains practically unaltered upto the Park Street crossing. The traffic from the Park Street as well as on the Chowringhee Road is channelled through the Mayo Road leading to Dalhousie Square areas and the traffic figures are further reduced from 1,639 to 1,116 Nos. of vehicles per hour. The traffic at Hazra Road is again increased from 530 to 708 per hour and flows upto Rashbehari Avenue and falls again to 521 Nos. as one proceeds towards Tollygunge Circular Road where the value stands at 284.

3.5. The Chittaranjan Avenue has a carriageway of 56 ft along with 22 ft wide footways on either side. Eight feet wide carriageways on both sides are being used by



standing vehicles leaving an effective carriageway of 40 ft i.e., 4 lanes for the traffic. The capacity of the road assuming a uniform speed of 20 m.p.h. comes to 3,000 motor vehicles per hour. If this speed can be maintained uninterrupted, the existing volume of vehicular traffic can easily be accommodated. But the speed can be interrupted at the crossings where it is reduced on account of controlling signals. The effect of the signals may be assumed to reduce the capacity by 25 per cent which is corroborated by actual experiment. Therefore, the ultimate capacity of Chittaranjan Avenue reduces to 2,250 Nos. of fast vehicles per hour. But the capacity is greatly affected by mixed traffic of slow vehicles such as hand-carts, rickshaws, bullock-carts, cycles, etc. This has, however, been considered and provided for by the conversion factors suggested in Para. 3.2. for different types of slow moving vehicles. The total equivalent fast traffic figures as represented in the graphs (Plates IV, V & VI) have, therefore, to be considered.

3.6. The graph in Plate VI clearly reveals that there is already traffic congestion in the section between Vivekananda Road and Mission Row crossing and also between Esplanade Junction and Park Street crossing. As a result, the traffic continuing to pass these sections is necessarily doing so with greatly restricted speed and actual experience shows that the average speed in the section from Vivekananda Road to Esplanade Junction varies from 10 m.p.h. to 26 m.p.h., the average being 13 m.p.h. compared to 10 m.p.h. as earlier recorded in the 1950 census. This improvement is due to certain effective measures taken by the Police Department since then. However, the efficiency is not up to the mark and there is immediate need for improving these sections of the road. The traffic in the section between S. N. Bannerjee Road and Park Street crossing has also grown considerably and improvement of this section should also be considered, although the priority may not be so high as compared to the former one.

3.7. The object in view is to ensure a clear and rapid run of traffic, while at the same time secure a higher safety factor. To that end, the aim must always be to keep the vehicular traffic on the main roads. In dealing with major town roads, there must be some definite conception of a general traffic system of the city as a whole. In the centre of busy cities and towns, it is very necessary to have free circulation of traffic. For this purpose, no less than safety, the existing main traffic routes require some immediate improvement. The possible improvements and remedial measures are:

3.7.1. **Complete Separation of Fast & Slow Traffic**: To get immediate relief, it may be possible to close down the road to slow traffic at least during the rush hours, say, between 9.00 hrs. to 12 00 hrs. and again from 16.00 hrs. to 19.00 hrs. for the most congested parts of the roads. Some main traffic roads may, if possible, be made 'out of bounds' to slow moving traffic. Material improvements can then be achieved in traffic flow by incurring very little or no expenditure.

3.7.2. **Automatic Signals**: When the slow and fast moving traffic are completely segregated, we can expect better results by installation of automatic signals. Automatic signals on a flexible progressive system can, with great advantage, be used to platoon the traffic and to afford the pedestrians safe crossing at regular intervals of time and place. In a flexible progressive system, the signals are so timed that the driver of a vehicle proceeding along the main avenue at a predetermined speed will, after being released by the green signal at the first installation, find that every signal on his approach will change from red to green, thus allowing him to travel the whole distance without stoppage or appreciable restriction of speed.

3.7.3. **Orderly Movement of Vehicles**: In order to obtain more orderly movement, it is necessary that all vehicles must be made to work on a common principle and anything that may induce drivers to impinge upon space provided for the traffic coming from opposite direction must be removed. Tram cars offend in both respects (a) they are not flexible in movement and (b) when stationary for loading and unloading, they obstruct the whole of the near side of the road, thus creating a direct temptation to other vehicles to proceed on the offside. Wherever possible, it is always desirable to remove the tram cars in order to increase the efficiency and capacity of the road effectively. Although the Chittaranjan Avenue is free from tram cars, the continual stopping and starting of commercial transport vehicles in the congested portions is a main factor in throttling the flow of traffic. Embayed stopping places created by means of local arcading or encroaching on the footway, if necessary, will be found to increase the average travel speed of motor vehicles, thereby increasing the traffic capacity of the road as a whole.

3.7.4. **Widening of Road**: The general section of the road is shown in Fig. 3 wherein the 22 ft wide footways can conveniently be reduced to 15 ft or so without much sacrificing the efficient flow of pedestrian traffic, thereby making the carriageway 70 ft wide. But this width is not sufficient enough for providing a parking strip and a lane for slow moving traffic on either sides. The minimum width required for this purpose is 80 ft as shown in Fig. 3 when only 10 ft wide footways on either side are left for the use of pedestrians which is really not



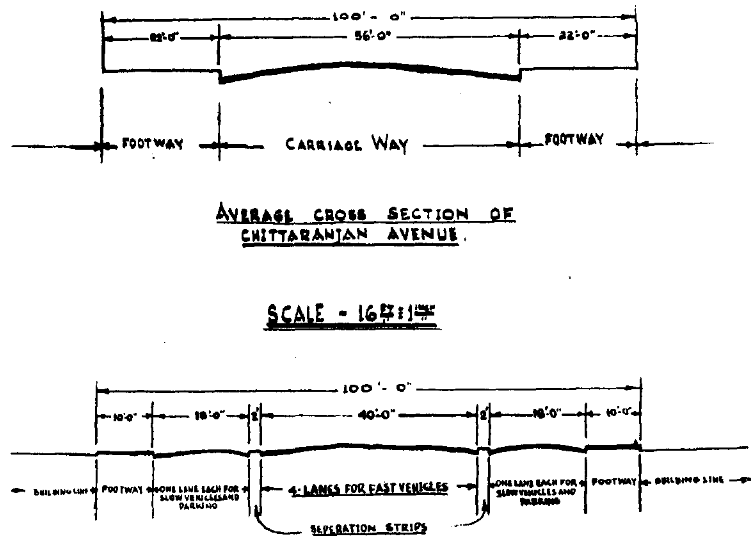


Fig. 3.

**Proposed arrangement of lanes in Chittaranjan Avenue**

sufficient. Even so, this improvement is desirable from the traffic point of view.

3.7.5. **Diversion of Traffic Through Other Roads**: This is not possible for traffic originating from the internal part of the city around the roads. There is, however, approximately 38.4 per cent of the traffic coming from the external suburbs of Calcutta and using these roads. This has, however, been discussed in detail in the external traffic study and a by-pass road has been recommended which will naturally give relief to the Chittaranjan Avenue and other roads.

3.7.6. **Improvement of Crossings**: The Chittaranjan Avenue will remain the main thoroughfare of Calcutta even if the Greater Circular Road is constructed around Calcutta on the eastern fringe as has been recommended in the external traffic study. Although the carriageway is fairly wide and can be made wider as recommended above, still fluidity of traffic flow cannot be obtained unless the obstructions and bottlenecks at its junctions with numerous cross roads are materially improved. Provision of grade crossings would have been the ideal solution, but as the areas abutting the streets are so heavily built up, it is almost impossible to provide even a roundabout. From the architectural point of view, grade crossings will not probably fit in in such a congested city as Calcutta. As such, it is necessary to study the traffic position again after the improvements like complete segregation of slow and fast movingtraffic, widening of roads where possible, installation of automatic traffic signals timed on the principle of flexible and progressive system with vehicular speed fixed at 20 m.p.h., thereby ensuring orderly movement of traffic and increased speed, have been incorporated.

3.7.7. **Pavement Hawkers:** The indiscriminate use of pavement, particularly near busy streets and parts as hawkers' stalls meant for displaced persons, is causing serious impediment to traffic. As a result of the pavement being fully occupied by hawkers and their prospective buyers, pedestrians have naturally to encroach upon the roads.

This overflow of pedestrians on to the roads and streets causes traffic bottleneck in as much as certain important roads, otherwise wide enough to take three lanes of traffic, are practically reduced to a single lane. The chances of accidents are also increased by the road space being occupied by unmindful sightseers and passers-by. It is, therefore, very much necessary that these hawkers' stalls are removed from the main streets and put in open spaces or by-lanes at least. Strict laws may have to be enforced for this purpose.

3.7.8. **Mobile Courts:** If mobile courts are in operation, the violators of traffic rules are caught then and there and warnings or token fines on the spot will naturally have more impression on the minds of offending drivers. With the lag of time, which is usual for traffic violation cases, there is least chance of reduction in violation offences. The court functioning immediately after occurrence of an offence has a greater chance of using discretion if the pedestrian is found at fault. Educating the public including children in elementary principles of how and where to cross will have beneficial effects. Introduction of 'Hore Belisha' beacon pedestrian while line crossings has been made in right time. But the use of these by the public has to be enforced more rigidly until such time as the public are self-conscious. After sometime, i.e., when the experimental period has been given a liberal trial, it will be necessary to prosecute pedestrians if they are found to disobey traffic rules which are intended for their own safety.



3.8. In the case of Park Street crossing with Chowringhee Road, the necessity of automatic traffic signals can be avoided if a suitable island or properly designed roundabout is provided. There is ample space and scope for doing this.

3.9. **Circular Road:** The hourly peak average fast traffic at the Shyambazar Rotary is only 254 Nos. per hour (See Plate IV) and the total equivalent fast traffic is 622 per hour. The average fast traffic through the length of the road upto Chowringhee Road crossing remains practically unaltered and uniform. The volume of slow traffic between Keshab Sen Street and Park Street has increased markedly and the maximum equivalent fast traffic is more than 2,700 Nos. at Sealdah and Dharrumtolla Street crossings.

3.10. The road is 68 ft. wide and although two tram lines pass over the road, it can accommodate quite a large volume of traffic. But the situation at Sealdah Railway Station is very much worse and requires some immediate improvement. Sealdah is a terminus for not less than 300 passenger trains daily and the gates open directly on this road. All passengers have to cross the Circular Road to enter the city and the place remains very heavily congested throughout the whole day. As a result, fast vehicular traffic which might have used the road, if the acute congestion at Sealdah had been eased and removed, now actually follows the Chittaranjan Avenue, thereby causing overloading and this wide road not being fully utilised.

3.11 It is of immediate necessity to remove the bottleneck at Sealdah crossing. Some time ago, the railway authorities were contemplating to shift the Sealdah Station further east and this proposal, if materialised, will solve the problem.

3.12. The immediate remedial measures that can be undertaken on this crossing now are as follows:

(a) The pedestrian crossings may be reduced by providing over-bridges or sub-ways.

(b) Relocation of the entrances and exits of the Sealdah

Railway Station. The railway authorities have already taken some steps in this direction and some of the exits are now closed for vehicular traffic.

(c) Realignment of the tramway lines and relocating the existing tram terminus between Harrison Road and Bowbazar Street.

3.13. **Cornwallis Street:** This road is only 43 ft wide with two tram lines running at the centre. The average fast traffic using the road is only 193 Nos. per hour and attains its maximum value of 465 Nos. of vehicles per hour at Dharrumtolla Street crossing, the corresponding 1950 census figures being 165 and 318 per hour respectively. The maximum equivalent fast traffic on this road is 1,403 at Bowbazar Street crossing. It has already been pointed out that the traffic using this road is more or less local and originates from the areas very adjacent to the road and those leading to the Colleges and very congested residential areas.

3.14. Very little improvement can be effected at present and that also may not be justified. However, it is most desirable to remove the tram cars from this narrow road when the efficiency of the road will be greatly improved and the flow of traffic will be more mobile and easy.

## 4. ACCIDENTS

4.1. Parking of cars, lorries, rickshaws, carts, etc., at random by the sides of a busy thoroughfare is a great impediment to the free flow of traffic. The cumulative effect of such mixed traffic of both slow and fast moving vehicles with so many bottlenecks has resulted in throwing the flow of traffic out of gear. The tendency on the part of drivers to speed up as soon as breathing space is available is natural and is very common. This gives rise to risky and rash driving causing frequent accidents involving either motor vehicles or the pedestrians.

4.2. The accident figures of the city of Calcutta as compiled by the Police Department are shown in the graphical chart, Fig. 4. From this chart wherein traffic accidents are recorded for a period of 10 years, it becomes evident that the rise in the number of accident cases is not much during the period 1947–54 but there has been a very sharp rise during the years 1954–57. It will be noted that though the number of accidents has gone up from 15,300 in 1947 to 30,000 in 1957, the actual death rate (Fig.5)



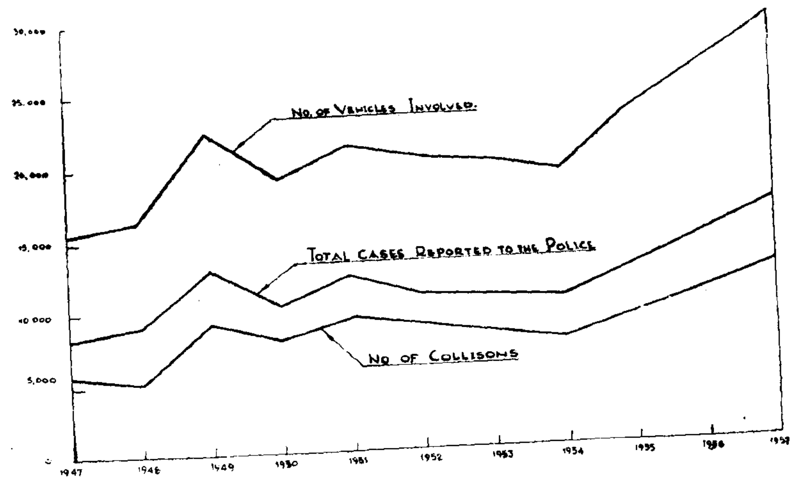


Fig. 4.

**Traffic accidents in Calcutta from 1947 to 1957**

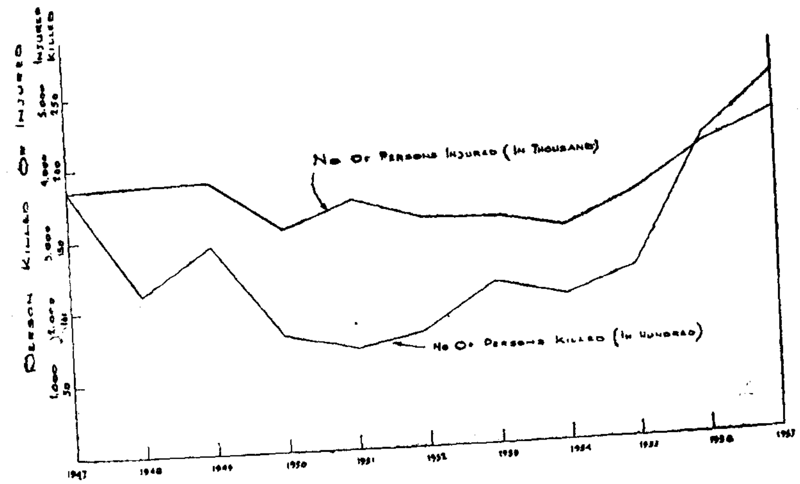


Fig. 3.

**Persons killed or injured due to traffic accidents from 1947 to 1957**

has hardly gone up by 25 per cent, i.e., 184 in 1947 to 251 in 1957. The high death rate in the year 1947 may be accounted for by careless driving of army vehicles. In a population of 3 millions, death of 200 persons and injury to 4,000 may not be really alarming but certainly leaves scope for a whole-hearted attemp to reduce it to a minimum.

4.3. In India, the present death rate is 70 per 10,000 vehicles as against 16 and 8 in U.K. and U.S.A. respectively. When India has 1.2 motor vehicles per mile of road as against 25 and 21 of U.K. and U.S.A., this death rate on traffic yardstick is on the high side.

4.4. The traffic accident figures for Calcutta for the year 1957 are as follows:

| | | |
|---|---|---|
| Total number of cases reported | ... | 16,680 |
| Total number of persons killed | ... | 251 |
| Total number of persons injured | ... | 4,427 |
| Total number of vehicles involved | ... | 29,351 |
| Total numher of collisions without injury | ... | 12,351 |
| Total number of serious injuries proved fatal | | 68 |
| Total number of serious collision cases | ... | 34 |
| Total number of minor traffic violation cases started | ... | 1,57,434 |

4.5. With a mixed total traffic of about 84,000 vehicles, of which 66,672 are fast moving motor vehicles and in a population of 3 millions mostly unconscious about traffic rules and concentrated within 40 sq. miles, the death rate of 27 per 10,000 vehicles speaks well about the Traffic Department of the Calcutta Police. However, it would be a wonderful performance when this figure is brought down by 50 per cent, so as to be within the world standard.

## 5. RECOMMENDATIONS

### I. Internal Traffic

(1) Improvements can be effected by way of scientific utilisation of the road widths available.

(2) Restricting slow traffic and parking of cars on main thoroughfares.

(3) Installation of automatic signals.

(4) Orderly movement of vehicles.

(5) Improvements of crossings, wherever possible, with special attention to pedestrian traffic.



(6) Diversion of traffic by way of construction of Greater Circular Road.

### II. External Traffic

(1) To avoid congestion of traffic within the city the construction of Greater Circular Road as already indicated seems an immediate necessity. Not only will it relieve traffic congestion within the city areas, but it will also carry the traffic which is external in character by-passing the city of Calcutta. A diagram showing the likely pattern of flow of traffic within the city, if the Greater Circular Road had been constructed, is given in Plate VIII, primarily utilising the data of Table 7 for the preparation of this diagram.

(2) It is felt that the traffic congestion in Calcutta may be reduced by providing some sort of alternative thoroughfare with access to the heart of the city. This may be done by one or more of the following ways, viz.:

(i) A circular railway connecting the disjoined railway lines around the city of Calcutta;

(ii) Providing underground railways; and

(iii) Providing elevated railways inside the city.

The first two schemes have already received attention of the State Government but have been temporarily kept in abeyance probably on account of shortage of funds and foreign exchange crisis.

## 6. CONCLUSION

6.1. Traffic census work has been conducted for the city of Calcutta twice, the first time in 1950 and the present one in 1957, and we can with some amount of confidence see a picture of the present position of traffic. But it will be extremely difficult to predict at this stage the future trend and growth of traffic during the next 20 years. Registration of motor vehicles cannot directly indicate the actual number now on the roads. Population statistics can, however, lead us to some extent but these are taken generally at an interval of 10 years which is a long period for our purpose.

6.2. It is always desirable to take traffic census, both for internal and for external traffic, every year to closely study the nature of changes in traffic flows from year to year and also to gauge the effects of changes of traffic pattern after any improvement is carried out either by imposing restrictions, or by physical improvements of roads and crossings or by way of educating the public through propaganda, and publicity. For internal traffic, origin and destination survey will be of little importance in view of the laborious and complicated process which will not provide us with any substantial additional data. For external traffic this is, however, very essential.

6.3. For future surveys of external traffic, the exact travel routes adopted by the drivers of the motor vehicles to reach their destinations should also be ascertained. In case of Calcutta the city being narrow and spreading only on the north-south direction, the entries are very much limited and the travel routes also do not vary very much.

6.4. In a city like Calcutta, it is almost impossible and impractical to take simultaneous counts of traffic on all the important crossings. As is clearly seen from the data sheets, the results compiled from counts taken on differnt dates at particular hours and under almost indentical conditions are quite accurate at least for drawing broad conclusions and small differences, if any, will not affect at all the nature of improvements required.

## 7. ORGANISATION & EXPENDITURE

### 7.1. Training of Personnel

Efficient working out of the census depends on sound teamwork. It is essential to make the enumerators conscious of their duties and responsibilities. Any misunderstanding on the part of the enumerators and the computors will obviously tell upon the actual census figures. Workers should be reminded that nothing should escape their notice and they should magnify nothing and minimise nothing. The aim of the census work is to obtain a true and correct picture of the situation which is the foundation on which necessary improvements can be effected. For this reason, training classes should be held before the census starts to make the personnel familiar with the work.

### 7.2. Personnel Required

(a) **Internal Traffic**: For each station there should be equal number of enumerators as the number of sub-stations. Each team must have a relieving hand and a supervisor whose duty is to run the work efficiently and smoothly. The supervisor will



also relieve any enumerator in difficulty and collect the papers after the day's work. In the census of 1957 in Calcutta the number of man-days required was 509.

(b) **External Traffic**: Any external traffic station is divided into two sub-stations. Each sub-station requires two enumerators and a relieving hand, i e., six in all per shift. They will work under a supervisor who will always co-operate with the enumerators when in difficulty. So, the number of man-days required is 21 per day per station to work round the clock in 3 shifts. In the external traffic census of 1957 around Calcutta the number of man-days required was 1,617 to do the work continuously for 7 days.

7.3. **Forms & Equipment**: For internal census, standard forms, perferably ruled—3,500 Nos. are required. For external census, standard forms preferably ruled and bound in 22 books—6,500 Nos. are required. Adequate number of copying pencils, mill-boards and spring clips have to be supplied to the enumerators in time. For external census, camps and camp equipment including tables, chairs, petromax, red lanterns, etc., are required.

7.4. **Caution Boards & Signboards:** At each external station at least two sign boards are to be fixed at proper places for both up and down traffic and adequate arrangements for lighting them at night should also be made. The specimens are :

(i) "Caution—Traffic Census Station Ahead" to be fixed at least a quarter mile ahead of the actual census station in order to alert the traffic;

(ii) "Please Stop. Traffic Census Station. Kindly give information as requested" — to be fixed close to the census station.

7.5. **Publicity**: Wide publicity in the press and the newspapers is to be given in good time before the actual commencement of the surveys in three languages, such as (a) English, (b) Hindi and (c) Regional language in order to achieve effective support and co-operation of the public.

7.6. **Expenditure** :

| | | Rs | nP. |
|---|---|---|---|
| (a) | Forms for both internal and external traffic surveys ... 10,000 Nos ... | 500 | 00 |
| (b) | Pencils, mill-boards, spring clips and papers etc. L.S. ... | 100 | 00 |

| | | |
|---|---|---|
| (c) Lighting charges (including supply of fuel oil, mantles, chimneys and minor repairs etc. | 250 | 00 |
| (d) Cost of signboards - 44 Nos. at the rate of Rs 6 each ... | 264 | 00 |
| (e) Transportation charges for carrying camp and camp equipment to site for external traffic stations including pitching of tents and dismantling. 22 sets at the rate of Rs 25 each ... | 550 | 00 |
| Total ... | 1,664 | 00 |
| Contingency at the rate of 5 per cent ... | 83 | 00 |
| Rs ... | 1,747 | 00 |

Say Rs 1,750—00

In this estimate, cost of capital goods, such as camps, chairs, tables, lights, etc., are not included. The wages and travelling allowances of the personnel involved are also not taken into account.

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TABLE 1

**Area & population statistics of Calcutta and its immediate surroundings**

| Description | Area in Sq. miles | POPULATION IN NUMBERS | | | | | | Percentage of increase in last 10 years |
|---|---|---|---|---|---|---|---|---|
| | | 1901 | 1911 | 1921 | 1931 | 1941 | 1951 | |
| 1. **Calcutta** | 42 | 9,21,380 | 10,13,143 | 10,46,300 | 11,63,771 | 21,08,891 | 25,48,677 | 21% |
| 2. **Southern Suburbs** | | | | | | | | |
| (a) Tollygunge | 6.6 | 12,821 | 18,433 | 21,637 | 24,476 | 58,594 | 1,49,817 | 75% |
| (b) South Suburban (Behala) | 12.25 | 26,374 | 31,533 | 33,345 | 39,499 | 63,479 | 1,04,055 | |
| *(c) Garden Reach | 3.42 | — | — | — | 32,963 | 85,188 | 1,09,160 | |
| 3. **Northern Suburbs** | | | | | | | | |
| (a) Baranagar | 5.5 | 25,432 | 25,895 | 32,084 | 37,050 | 54,451 | 77,126 | 75% |
| (b) South Dum Dum | 5.98 | 10,904 | 12,874 | 14,030 | 18,471 | 25,838 | 61,391 | |
| (c) Dum Dum | 0.9 | 4,920 | 3,818 | 3,855 | 5,350 | 7,622 | 14,002 | |
| (d) North Dum Dum | 7.0 | 4,996 | 5,047 | 4,369 | 4,535 | 5,974 | 12,156 | |
| 4. **Western (Howrah Side) Suburbs** | | | | | | | | |
| (a) Howrah | 10.18 | 1,57,594 | 1,79,006 | 1,95,301 | 2,24,873 | 3,79,292 | 4,33,630 | 16% |
| (b) Bally | 3.06 | 18,662 | 22,394 | 23,209 | 30,347 | 50,397 | 63,138 | |

*Note:* Figures have been taken from Statistical Digest, West Bengal, issued by the State Statistical Bureau.
* Garden Reach was under Calcutta Corporation upto 1932.

TABLE 2

**Street accidents in Calcutta—monthly averages**

| Year | Total No. of street accident cases reported | Total No. of persons killed in street accidents | Total No. of persons injured in street accidents | Total No. of vehicles involved in street accidents |
|---|---|---|---|---|
| 1946 | 568 | 19 | 251 | 1,131 |
| 1947 | 718 | 15 | 236 | 1,276 |
| 1948 | 753 | 8 | 271 | 1,310 |
| 1949 | 1,082 | 12 | 322 | 1,877 |
| 1950 | 900 | 7 | 261 | 1,598 |
| 1951 | 1,023 | 6 | 292 | 1,773 |
| 1952 | 972 | 7 | 267 | 1,715 |
| 1953 | 947 | 8 | 270 | 1,670 |
| 1954 | 904 | 8 | 256 | 1,587 |
| 1955 | 1,132 | 10 | 289 | 1,939 |
| 1956 | 1,367 | 17 | 341 | 2,445 |
| 1957 | 1,390 | 21 | 374 | 2,446 |
| 1958 (Upto April) | 1,270 | 21 | 341 | 2,024 |



TABLE 3

**List of principal streets diverging from Calcutta & location of external traffic counting stations on them**

| | Name of the roads | Important places it connects with brief details | Location of the counting station | Station No. No. in Plate III | Remarks |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| On northern side (on the east of River Hooghly) | 1. Surya Sen Road (along the east bank of River Hooghly) from Cossipur-Baranagar side) | Connected with G. T. Road via. Willingdon Bridge & Barrackpore Trunk Road on the east of it | Near its junction with Willingdon Bridge approach road | $x_1$ | *Note*: In all the cases enumerations were made for both the inward & outward traffic separately from two sides |
| | 2. Barrackpore Trunk Road—(from Shyambazar side towards north) | Sodepur, Barrackpore and thence with industrial areas like Naihati and Kanchrapara | Beyond its junction with Dum Dum Road | $x_2$ | |
| | 3. Jessore Road or Belgachia Road—(from Shyambazar side towards north & north-east) | Dum Dum, Baraset, Bongaon on border area. It also brings traffic from the principal towns of Nadia and Murshidabad districts | Off its crossing with Railway Line to Dum Dum (over bridge) Patipukur | $x_3$ | |
| On the eastern side | Is the salt lake area and there is no prominent road diverging from the city in this direction | | | | |
| On the southern side | 1. Gariahata - Mathurapur Road (from Ballygunge side) | Dhakuria, Jadavpur, Baruipur, Mathurapur and Sundarban areas in the southern part of the State | Just off its crossing with Railway line to Budge Budge (level crossing)—Dhakuria | $x_4$ | |
| | 2. Russa Road — (from Tollygunge side) | Southern Tollygunge areas, Garia where it connects with Gariahata-Mathurapur Road & through this road a major portion of the traffic from Mathurapur - Baruipur areas enters into the city | Just beyonds the Tollygunge tram depot | $x_5$ | |
| | 3. Diamond Harbour Road — (from Behala & Chetla - Alipore side) | Behala, Bishnupur, Kulpi, Diamond Harbour (an important industrial town in the south) — this is now extending further towards the south, viz., Kakdwip and thence to Namkhana & Sagar Island. This actually forms the principal road of the south areas | Above its junction with Gangarampur Road | $x_6$ | |
| | 4. Budge Budge Road — (from Behala & Kidderpore side) | It connects many important industrial areas like Batanagar, Budge Budge. Arrangements have since been made for a power ferry over River Hooghly to establish its connection with Orissa Trunk Head & National Highway Nos. 5 & 6 to Bombay & Madras, via. Uluberia, Midnapur, Kharagpur, Ghargram in the south-western part of the State. | At its junction with Taratala Road —R. S. Jinjirpur | $x_7$ | |
| On the western side | 1. Andul Road (from Shibpur or South-western side) | Andul & Mourigram and lower part of Howrah Dist. It is now being extended towards where it will connect the Orissa Trunk Road and classified as National Highway Nos. 5 & 6 to Bombay & Madras via. Midnapore, Kharagpur, etc. | Near Amtala Out-post | $x_8$ | |
| | 2. Howrah—Amta Road (from Kadamtala or Howrah townside) | It runs closely parallel to the Martin Railway line to Amta—Jagatballavpur & Amta areas and the central and upper part of Howrah Dist.—this road is also being reconstructed under Road Development Scheme of the State | Near Kadamtala junction | $x_9$ | |
| | 3. Howrah—Chanditala Road (old Benaras or Ahallabad Road—from Salkia side) | It runs closely parallel to the Martin Railway line and connects the principal towns of Hooghly Dist. like Arambagh—It was at one time one of the main roads in the country and will soon be improved as a development scheme for the State | Near Uttar Bantar on Martin Railway | $x_{10}$ | |
| | 4. Grand Trunk Road (from Howrah, Bally & Uttarpara side, northern end | This is a well known road all over the country which needs no introduction. It passes through many important places in the northern India ultimately connecting with Delhi—National Highway No. 2 | At Uttarpara Thana | $x_{11}$ | Number of vehicles utilising the Willingdon Bridge for crossing River Hooghly were conveniently noted during the census |

TABLE 4

**Table showing parts & zones into which Calcutta has been divided for taking census**

| Parts with brief description | Corresponding zones with description of locally known areas | Corresponding zones | Represented in plates by |
|---|---|---|---|
| I. Northern or old town areas | A—Shyambazar & Sovabazar<br>$A_x$—Areas on the north of zones 'A', viz. Cossipore, Belgachia, Dum Dum, etc. | A & $A_x$ | Shyambazar Rotary |
| II. Central or office & commercial areas | B—Jorasanko, College Street, Burra bazar<br>D—Dalhousie, Esplanade, Maiden, Taltola | B & D | Area bounded by Vivekananda Road in north Esplanade in south Central Avenue in east and Hooghly River in west |
| III. Eastern or industrial areas | C—Ultadanga, Manicktola, Narikeldanga and Beliaghata<br>E—Sealdah, Entally, Park Circus | C & E | Junction Lower Circular Road and Park Street |
| IV. Southern or New town areas | $F_2$—Bhowanipur & Kalighat<br>$F_3$—Ballygunge<br>$F_4$—Tollygunge & Behala<br>Areas beyond the zone $F_3$ in Dhakuria, Jadavpur, etc. | $F_2$, $F_3$ and $F_4$ | Junction of Russa Road and Hazra Road |
| V. South-western or dock areas | $F_1$—Alipur & Chetla<br>G—Kidderpore<br>$G_x$—Areas beyond zone G, viz., Metiaburuz etc. | $F_1$, G & $G_x$ | Junction of Garden Reach Road and Diamond Harbour Road |
| VI. Western or Howrah areas | $H_1$—Howrah Station and Town<br>$H_2$—Sibpore<br>$H_3$—Salkia<br>$H_x$—Areas beyond the zone $H_3$ viz., Belur, Bally, etc. | $H_1$, $H_2$, $H_3$, $H_x$ | Howrah Station |

TABLE 5

**Average daily traffic flows between the counting stations and the different zones of the city**

(Fast traffic only)

| Counting station | | Different zones of Calcutta | | | | | | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_x$ | A | B | C | D | E | $F_1$ | $F_2$ | $F_3$ | $F_4$ | G | $H_1$ | $H_2$ | $H_3$ | $H_x$ | | |
| $X_1$ | Away | 48 | 13 | 17 | 4 | 255 | 2 | — | 2 | 1 | — | 1 | 1 | — | — | — | 344 | 679 |
| | Towards | 52 | 10 | 11 | 5 | 247 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | — | — | 1 | 335 | $X_1$ |
| $X_2$ | Away | 31 | 1,313 | 466 | 148 | 580 | 134 | 51 | 87 | 102 | 57 | 31 | 64 | 5 | 1 | 5 | 3,073 | 6,247 |
| | Towards | 12 | 1,500 | 388 | 114 | 666 | 110 | 50 | 79 | 84 | 58 | 45 | 62 | 2 | 1 | 3 | 3,174 | $X_2$ |
| $X_3$ | Away | 13 | 850 | 207 | 63 | 489 | 64 | 34 | 45 | 77 | 54 | 22 | 36 | 2 | — | 5 | 1,961 | 4,036 |
| | Towards | 21 | 863 | 219 | 85 | 497 | 89 | 32 | 46 | 89 | 67 | 20 | 38 | 6 | — | 3 | 2,075 | $X_3$ |
| $X_4$ | Away | 13 | 16 | 85 | 44 | 83 | 54 | 18 | 97 | 263 | 39 | 13 | 444 | 1 | — | 28 | 1,198 | 2,404 |
| | Towards | 15 | 11 | 64 | 27 | 111 | 36 | 18 | 129 | 280 | 31 | 11 | 461 | 1 | — | 11 | 1,206 | $X_4$ |
| $X_5$ | Away | 4 | 3 | 29 | 3 | 57 | 5 | 12 | 40 | 29 | 113 | 8 | 162 | — | — | 5 | 470 | 946 |
| | Towards | 6 | 5 | 24 | 3 | 66 | 5 | 16 | 44 | 26 | 110 | 7 | 162 | — | — | 2 | 476 | $X_5$ |
| $X_6$ | Away | 14 | 189 | 61 | 18 | 168 | 31 | 54 | 180 | 56 | 92 | 356 | 163 | 1 | 1 | 12 | 1,376 | 2,714 |
| | Towards | 14 | 172 | 48 | 13 | 171 | 30 | 48 | 146 | 47 | 87 | 398 | 153 | 1 | 2 | 8 | 1,338 | $X_6$ |
| $X_7$ | Away | 39 | 7 | 44 | 71 | 104 | 16 | 29 | 28 | 27 | 72 | 101 | 13 | 3 | 1 | 14 | 519 | 1,044 |
| | Towards | 36 | 9 | 38 | 25 | 95 | 19 | 26 | 31 | 31 | 77 | 104 | 14 | 6 | 1 | 13 | 525 | $X_7$ |
| $X_8$ | Away | 1 | 2 | 20 | 6 | 6 | 1 | 21 | 4 | 11 | 4 | 1 | 256 | 58 | 1 | 9 | 401 | 823 |
| | Towards | 1 | 2 | 26 | 5 | 2 | 4 | 21 | 12 | 10 | — | 4 | 263 | 67 | 1 | 5 | 423 | $X_8$ |
| $X_9$ | Away | 1 | 9 | 32 | 2 | 13 | 3 | — | 4 | 9 | 1 | 2 | 349 | 9 | 5 | 4 | 443 | 905 |
| | Towards | 2 | 5 | 31 | 5 | 12 | 7 | — | 7 | 6 | 2 | 1 | 360 | 11 | 4 | 9 | 462 | $X_9$ |
| $X_{10}$ | Away | 3 | 2 | 17 | 4 | 4 | 2 | — | 2 | 1 | 1 | 2 | 89 | 2 | 16 | 9 | 154 | 316 |
| | Towards | 2 | 5 | 16 | 3 | 3 | 1 | — | 2 | 2 | 1 | 1 | 99 | 2 | 16 | 9 | 162 | $X_{10}$ |
| $X_{11}$ | Away | 64 | 123 | 293 | 55 | 176 | 37 | 24 | 66 | 63 | 23 | 47 | 63 | 13 | 9 | 170 | 1,226 | 2,534 |
| | Towards | 139 | 52 | 248 | 54 | 187 | 44 | 13 | 71 | 47 | 58 | 40 | 111 | 20 | 27 | 197 | 1,308 | $X_{11}$ |
| $X_{11}$ via Vivekananda Bridge | Away | 129 | 42 | 69 | 24 | 62 | 35 | 7 | 15 | 29 | 9 | 6 | — | — | — | — | 427 | 869 |
| | Towards | 126 | 43 | 67 | 27 | 66 | 43 | 10 | 11 | 26 | 19 | 4 | — | — | — | — | 442 | |
| $X_{11}$ via Howrah Bridge | Away | 9 | 6 | 198 | 7 | 143 | 25 | 25 | 59 | 14 | 35 | 32 | 63 | 13 | 9 | 170 | 808 | 1,665 |
| | Towards | 19 | 4 | 187 | 8 | 112 | 21 | 17 | 50 | 21 | 40 | 23 | 111 | 20 | 27 | 197 | 857 | |

TABLE 6

**Average daily traffic flows between the counting station and the different points of the city.**

| Counting station | Traffic flowing to and from the different parts mentioned below | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | $(A_x+A)$ I | $(B+D)$ II | $(C+E)$ III | $(F_2+F_3+F_4)$ IV | $(F_1+G)$ V | $(H_1+H_2+H_3+H_x)$ VI | |
| $X_1$ | 123 | 530 | 14 | 6 | 3 | 3 | 679 |
| $X_2$ | 2,856 | 2,100 | 506 | 467 | 177 | 141 | 6,247 |
| $X_3$ | 1,747 | 1,402 | 301 | 378 | 108 | 90 | 4,026 |
| $X_4$ | 55 | 343 | 161 | 839 | 60 | 946 | 2,404 |
| $X_5$ | 18 | 176 | 16 | 362 | 43 | 331 | 946 |
| $X_6$ | 369 | 448 | 92 | 618 | 856 | 341 | 2,724 |
| $X_7$ | 91 | 281 | 81 | 266 | 260 | 65 | 1,044 |
| $X_8$ | 6 | 54 | 16 | 41 | 47 | 660 | 824 |
| $X_9$ | 17 | 88 | 17 | 29 | 3 | 751 | 905 |
| $X_{10}$ | 12 | 40 | 10 | 9 | 3 | 242 | 316 |
| $X_{11}$ | 378 | 904 | 190 | 328 | 124 | 610 | 2,534 |
| | 5,672 | 6,366 | 1,404 | 3,343 | 1,684 | 4,180 | 22,649 |
| $X_{11}$ via Vivekananda Bridge | 340 | 264 | 129 | 109 | 27 | — | 869 |
| via Howrah Bridge | 38 | 640 | 61 | 219 | 97 | 610 | 1,665 |

TABLE 7

**Table showing the existing travel routes of external traffic**

(I, II, etc. in Roman letters refer to points marked on Plate).

| Description | Daily average external traffic volume to and from the external counting stations and the routes they would commonly take for their travels to & from the different parts of the city | | | | | |
|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | |
| Existing travel route | I- = 123 | I- = 2,856 | I- = 1,747 | III-I = 55 | IV-II-I = 18 | |
| | I-II = 530 | I-II = 2,100 | I-II = 1,402 | III-II = 343 | IV-II = 176 | |
| | I-III = 14 | I-III = 506 | I-III = 301 | IV-III = 161 | IV-III = 16 | |
| | I-II-IV = 6 | I-II-IV = 467 | I-II-IV = 378 | IV- = 839 | IV- = 362 | |
| | I-II-V = 3 | I-II-V = 177 | I-II-V = 108 | IV-V = 60 | IV-V = 43 | |
| | I-II-VI = 3 | I-II-VI = 141 | I-II-VI = 90 | IV-II-VI = 946 | IV-II-VI = 331 | |
| | Total ... 679 | Total ... 6,247 | Total ... 4,026 | Total ... 2,404 | Total ... 946 | |
| | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ |
| Existing travel route | V-II-I = 369 | V-II-I = 91 | VI-II-I = 6 | VI-II-I = 17 | VI-II-I = 12 | VI-II-I = 38 (via Howrah Bridge) |
| | V-II = 448 | V-II = 281 | VI-II = 54 | VI-II = 88 | VI-II = 40 | VI-II = 640 |
| | V-III = 92 | V-III = 81 | VI-II-III = 16 | VI-II-III = 17 | VI-II-III = 10 | VI-II-III = 61 |
| | V-IV = 618 | V-IV = 266 | VI-II-IV = 41 | VI-II-IV = 29 | VI-II-IV = 9 | VI-II-IV = 219 |
| | V- = 856 | V- = 260 | VI-II-V = 47 | VI-II-V = 3 | VI-II-V = 3 | VI-II-V = 97 |
| | V-II-VI = 341 | V-II-VI = 65 | VI- = 660 | VI- = 751 | VI- = 242 | VI- = 610 |
| | Total ... 2,724 | Total ... 1,044 | Total ... 824 | Total ... 905 | Total ... 316 | 1,665 |
| | | | | | | Via Vivekananda Bridge 869 |
| | | | | | | Total ... 2,534 |

TABLE 8

# HOURLY PEAK AVERAGE TRAFFIC (EQUIVALENT FAST TRAFFIC) ALONG CIRCULAR ROAD AND ON THE CROSS ROADS

| CENSUS STATION | | VOLUME OF HOURLY PEAK AVERAGE TRAFFIC (EQUIVLENT FAST TRAFFIC) ALONG CHITTARANJAN AVENUE CHOWRINGHEE ROAD, ASHUTOSH MUKHERJEE ROAD, AND RUSSA ROAD — NORTHERN PORTION | | | | | | SOUTHERN PORTION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAME | No. | NAME OF ROAD WITH SUB-STATION NOS. | MOTOR VEHICLES | EQUIVALENT FAST TRAFFIC FOR TRAMS | EQUIVALENT FAST TRAFFIC FOR SLOW VIHICLES | EQUIVALENT FAST TRAFFIC FOR CYCLES | TOTAL EQUIVALENT FAST TRAFFIC | NAME OF ROAD WITH SUB-STATION NOS. | MOTOR VIHICLES | EQUIVALENT FAST TRAFFIC FOR TRAMS | EQUIVALENT FAST TRAFFIC FOR SLOW VEHICLES | EQUIVALENT FAST TRAFFIC FOR CYCLES | TOTAL EQUIVALENT FAST TRAFFIC |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1. SHYAMBAZAR ROTARY. | $A_1$ | 1. BARRACKPUR TRUNK ROAD (a+b)<br>2. BAGHBAZAR STREET (k+l) | 265+217 =482<br>82+75 = 157<br>632 | 2(33+43) =152<br>2X(0+0) = 0<br>152 | 4(20+32) =208<br>4(36+24) =240<br>448 | 2(64+54) =236<br>2(32+19) =102<br>338 | 1.570 | 1. UPPER CIRCULAR ROAD (e+f) | 129+125 =254 | 2X(25+23) = 96 | 4X(26+16) =168 | 2X(32+20) =104 | 622 |
| 2. JUNCTION OF UPPER CIRCULAR ROAD VIVEKANANDA ROAD AND BEADON STREET. | $B_8$ | 1. UPPER CIRCULAR ROAD NORTH (a+b) | 361+259 = 620 | 2X(28+27 = 110 | 4X(161+70) = 920 | 2X(84+44 = 256 | 1.906 | 1. UPPER CIRCULAR ROAD – SOUTH (e+f) | 232+236 =468 | 2X(27+25) = 104 | 4X(36+33) = 276 | 2X(42+45) =174 | 1.22 |
| 3. JUNCTION OF UPPER CIRCULAR ROAD AND KESHAB SEN STREET | $B_9$ | 1. UPPER CIRCULAR ROAD NORTH (a+b) | 233+250 = 483 | 2X(26+27 = 106 | 4X(62+46) = 424 | 2X(50+42 = 184 | 1.197 | 1. UPPER CIRCULAR ROAD SOUTH (e+f) | 251+313 =564 | 2X(26+26) =104 | 4X(51+79) = 520 | 2X(39+51) = 180 | 1.368 |
| 4. SEALDAH CROSSING | $E_1$ | 1. UPPER CIRCULAR ROAD (a+b) | 131+258 = 489 | 2X(25+26) =102 | 4X(55+53) = 432 | 2X(50+40) = 180 | 1.203 | 1. LOWER CIRCULAR ROAD – (m+n) | 483+312 = 795 | 2X(68+52 =240 | 4X(209+109 =1.272 | 2X(133+64) = 394 | 2,705 |
| 5. JUNCTION OF LOWER CIRCULAR ROAD AND DHARMATALLA STREET. | $E_2$ | 1. LOWER CIRCULAR ROAD – (a+b) | 297+303 = 600 | 2X(47+56) = 206 | 4X94+96) = 760 | 2X(67+57) 248 | 1.834 | 1. LOWER CIRCULAR ROAD SOUTH – (e+d) | 218+248 = 466 | 2X(26+27) = 106 | 4X(54+88) = 568 | 2X(40+64) =208 | 1,348 |
| 6. JUNCTION OF LOWER CIRCULAR ROAD AND PARK STREET. | $E_3$ | 1. LOWER CIRCULAR ROAD – (a+b) | 250+306 = 556 | 2X(48+51) =198 | 4X(36+35) = 284 | 2X(60+75) =270 | 1308 | 1. LOWER CIRCULAR ROAD SOUTH (e+f) | 191+202 = 393 | 2X(0+0) = 0 | 4X(15+16) = 124 | 2X(25+27) = 104 | 621 |
| 7. JUNCTION OF LOWER CIRCULAR ROAD AND CHOWRINGHEE ROAD. | $D_{21}$ | 1. LOWER CIRCULAR ROAD – EAST (c+d) | 385+436 = 821 | 2X(0+0) = – | 4X(12+9) =84 | 2X(39+29) =136 | 1.041 | 1. LOWER CIRCULAR ROAD – WEST (g–h) | 330+330 =660 | 2X(0+0) = 0 | 4X(9+9) =72 | 2X(31+37) = 136 | |

| CENSUS STATION NAME | VOLUME OF HOURLY PEAK AVERAGE TRAFFIC (EQUIVALENT FAST TRAFFIC) ALONG THE CROSS ROAD — EASTERN PORTION | | | | | | WESTERN PORTION | | | | | | CENSUS STATION NOS. | REMARKS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAME | NAME OF ROAD WITH SUB-STATION NOS. | MOTOR VEHICLES | EQUIVALENT FAST TRAFFIC FOR TRAMS | EQUIVALENT FAST TRAFFIC FOR SLOW VEHICLES | EQUIVALENT FAST TRAFFIC FOR CYCLES | TOTAL EQUIVALENT FAST TRAFFIC | NAME OF ROAD WITH SUB-STATION NOS. | MOTOR VEHICLES | EQUIVALENT FAST TRAFFIC FOR TRAMS | EQUIVALENT FAST TRAFFIC FOR SLOW VEHICLES | EQUIVALENT FAST TRAFFIC FOR CYCLES | TOTAL EQUIVALENT FAST TRAFFIC | | |
| 1 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1. SHYAMBAZAR ROTARY. | 1. R.G. KAR ROAD. (e+d) | 190+120 =319 | 2X(24+20) = 88 | 4X(81+39) =480 | 2X(50+20) =140 | 1,027 | 1. CORNWALLIS STREET (g+h)<br>2. SHYAMBAZAR STREET (i+j) | 68+125=193<br>225+416=741<br>934 | 2X(35+55 =180<br>2X(0+0 = 0<br>180 | 4X(19+34 =212<br>4X(60+70 =520<br>732 | 2X(28+66) =188<br>2X(38+82 =240<br>428 | 2.274 | $A_1$ | |
| 2. JUNCTION OF UPPER CIRCULAR ROAD VIVEKANANDA ROAD AND BEADON STREET. | 1. VIVEKANANDA ROAD–EAST (e+d) | 104+123 =227 | 2X(0+0) = 0 | 4X(89+88) =708 | 2X(57+61) =236 | 1.171 | 1. VIVEKANANDA ROAD WEST–(g+h)<br>2. BEADON STREET (i+j) | 187+192=379<br>72+67=199<br>578 | 2X(0+0 = 0<br>2X(0+0) = 0<br>0 | 4X(113+99 = 848<br>4X(27+25 = 208<br>1056 | 2X(57+53 =220<br>2X(29+20) = 98<br>318 | 1.892 | $B_8$ | |
| 3. JUNCTION OF UPPER CIRCULAR ROAD AND KESHAB SEN STREET | 1. KESHAB SEN STREET–EAST (e+d) | 34+24 =58 | 2X(0+0) = 0 | 4X(71+56) = 508 | 2X(28+28) = 112 | 676 | 1. KESHAB SEN STREET=SOUTH (g+h) | 74+8=160 | 2X(0+0 = 0 | 4X(62+68 = 520 | 2X(29+49 =156 | 836 | $B_9$ | |
| 4. SEALDAH CROSSING | 1. APPROACHES TO THE SEALDAH RLY. STN (c+d+e+f+g+h)<br>2. BELIAGHATA ROAD (i+j)<br>3. BELIAGHATA MAIN ROAD (k+l) | 1. 44+46+93=183<br>2. 87+0 = 87<br>3. 67+261=328<br>598 | 1. 2X(0)=0<br>2. 2X(0)=0<br>3. 2X(0)=0<br>0 | 1. 4X(67+29+92) =752<br>2. 4X(36) 144<br>3. 4X(40+119)=636<br>= 1.532 | 1. 2X(2+3)=10<br>2. 2X(18) =36<br>3. 2X(14+26)=80<br>126 | 2,266 | 1. BOWBAZAR STREET =(o+p)<br>2. HARRISON ROAD –(q+r) | 1. 92+103=195<br>2. 95+103=198<br>393 | 1. 2X(33+33)=132<br>2. 2X(36+36)= =144<br>276 | 1. 4X(82+67) =596<br>2. 4X(71+100) =684<br>1,280 | 1. 2X(36+37 =146<br>2. 2X(2X(14+14)) =56<br>202 | 2.151 | $E_1$ | |
| 5. JUNCTION OF LOWER CIRCULAR ROAD AND DHARMATALLA STREET. | 1. SURESH SARKAR ROAD – (g+h) | 146+213 =356 | 2X(0+0) = 0 | 4X(150+72) = 888 | 2X(50+67 =234 | 1.461 | 1. DHARMATALLA STREET –(e+f) | 117+199 =316 | 2X(24+24 =96 | 4X(74+75 =596 | 2X(33+34 = 134 | 1.142 | $E_2$ | |
| 6. JUNCTION OF LOWER CIRCULAR ROAD AND PARK STREET. | 1. PARK STREET EAST – (c+d) | 176+164 = 340 | 2X(51+50) = 202 | 4X(41+42) = 332 | 2X(67+45 =224 | 1,094 | 1. PARK STREET WEST (g+h) | 169+200 =369 | 2X(0+0 = 0 | 4X(46+53 | 2X(46+54 | 992 | $E_3$ | |
| 7. JUNCTION OF LOWER CIRCULAR ROAD AND CHOWRINGHEE ROAD. | 1. CHOWRINGHEE ROAD –(a+b) | 489+482 =971 | 2X(42+48 = 180 | 4X(1+1) = 8 | 2X(43+46) =172 | 1,331 | 1. ASHUTOSH MUKHERJEE ROAD –(e+f) | 422+420 =842 | 2X(48+51 =198 | 4X(2+6 =32 | 2X(47+43 =180 | 1.252 | $D_{21}$ | |

TABLE 10

## HOURLY PEAK AVERAGE TRAFFIC (EQUIVALENT FAST TRAFFIC) ALONG CHITTARANJAN AVENUE, CHOWRINGHEE ROAD, ASHUTOSH MOOKHERJEE ROAD, RUSSA ROAD AND ON THE CROSS ROADS.

VOLUME OF HOURLY PEAK AVERAGE TRAFFIC (EQUIVALENT FAST TRAFFIC) — ALONG CHITTARANJAN AVENUE CHOWRINGHEE ROAD ASHUTOSH MUKHERJEE ROAD AND RUSSA ROAD

| Census Station | | Northern Portion | | | | | | Southern Portion | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | No. | Name of road with sub-station nos. | Motor vehicles | Equivalent fast traffic: For trams | For slow vehicles | For cycles | Total equivalent fast traffic | Name of road with sub-station nos. | Motor vehicles | Equivalent fast traffic: For trams | For slow vehicles | For cycles | Total equivalent fast traffic |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1. Shyambazar Rotary | $A_1$ | (a) B.T. Road - a+b<br>(b) Bagbazar St. - k+l | 263+217=482<br>82+75=157 | 2x(33+43)=152<br>2x(0+0)= — | 4x(20+32)=208<br>4x(36+24)=240 | 2x(64+54)=236<br>2x(32+19)=102 | 1,577 | Chittaranjan Avenue i+j | 325+416 =741 | — | 4x(60+70) =520 | 2x(38+82) =240 | 1,501 |
| 2. Junction of Chittaranjan Avenue and Vivekananda Road. | $B_1$ | Chittaranjan Avenue North - a+b | 405+552 =957 | 2x(0+0)= — | 4x(76+116) =768 | 2x(42+79) =242 | 1,967 | Chittaranjan Avenue South - e+f. | 738+512 =1250 | — | 4x(129+80) =836 | 2x(93+42) =270 | 2,356 |
| 3. Junction of Chittaranjan Avenue and Harrison Road. | $B_2$ | Chittaranjan Avenue North - a+b | 640+764=1404 | 2x(0+0)= — | 4x(112+131) =972 | 2x(86+81) =334 | 2,710 | Chittaranjan Avenue South - e+f | 743+789 =1,532 | — | 4x(121+328) =1,796 | 2x(83+161) =488 | 3,816 |
| 4. Junction of Chittaranjan Avenue and Bowbazar Street. | $D_1$ | Chittaranjan Avenue North - a+b | 768+824=1592 | 2x(0+0)= — | 4x(149+192) =1,364 | 2x(78+122) =400 | 3,356 | Chittaranjan Avenue South - e+f | 830+635 =1,465 | — | 4x(232+130) =1,448 | 2x(136+73) =418 | 3,331 |
| 5. Junction of Chittaranjan Avenue and Mission Row. | $D_2$ | Chittaranjan Avenue North - a+b | 775+945=1720 | 2x(0+0)= — | 4x(126+221) =1,388 | 2x(92+138) =460 | 3,568 | Chittaranjan Avenue South - e+f | 698+861 =1,559 | — | 4x(198+94) =1,168 | 2x(158+103) =522 | 3,249 |
| 6. Esplanade Junction. | $D_{18}$ | Chittaranjan Avenue North - c+d | 464+463=927 | 2x(0+0)= — | 4x(29+39) =272 | 2x(68+53) =242 | 1,441 | Chowringhee Road i+j | 829+643 =1,472 | — | 4x(2+2) =16 | 2x(134+101) =470 | 1958 |
| 7. Junction of Chowringhee Road and S.N. Banerjee Road. | $D_{19}$ | Chowringhee Road North - a+b | 738+830 =1,568 | 2x(0+0)= — | 4x(5+38) =172 | 2x(84+91) =350 | 2,130 | Chowringhee Road South - e+f | 814+826 =1,640 | — | 4x(2+1) =12 | 2x(73+66) =278 | 1,930 |
| 8. Park Street Junction | $D_{20}$ | Chowringhee Road North - a+b | 802+837 =1,639 | 2x(53+53) =212 | 4x(0+0)= — | 2x(105+78) =366 | 2,217 | Chowringhee Road South - g+h | 536+580 =1,116 | 2x(45+44) =178 | 4x(2+2) =16 | 2x(60+62) =244 | 1,554 |
| 9. Junction of Chowringhee Road and Lower Circular Road. | $D_{21}$ | Chowringhee Road a+b | 489+482 =971 | 2x(42+48) =180 | 4x(1+1) =8 | 2x(43+46) =178 | 1,337 | Ashutosh Mukherjee Road - e+f | 422+420 =842 | 2x(48+51) =198 | 4x(2+6) =32 | 2x(47+43) =180 | 1,252 |
| 10. Junction of Ashutosh Mukherjee Road and Padmapukur Road. | $F_1$ | Ashutosh Mukherjee Road-North - a+b. | 351+362 =713 | 2x(47+49) =192 | 4x(29+33) =248 | 2x(50+59) =218 | 1,371 | Ashutosh Mukherjee Road South - e+f | 352+361 =713 | 2x(49+47) =192 | 4x(28+37) =260 | 2x(62+55) =234 | 1,399 |
| 11. Junction of Ashutosh Mukherjee Road and Hazra Road. | $F_2$ | Ashutosh Mukherjee Road North - a+b. | 282+248 =530 | 2x(32+32) =128 | 4x(24+33) =228 | 2x(35+43) =156 | 1,042 | Russa Road e+f | 318+390 =708 | 2x(52+55) =214 | 4x(27+130) =628 | 2x(45+94) =278 | 1,828 |
| 12. Junction of Russa Road & Rashbehari Avenue. | $F_3$ | Russa Road North a+b | 370+353 =723 | 2x(39+40) =158 | 4x(23+19) =168 | 2x(77+69) =292 | 1,341 | Russa Road South e+f | 264+257 =521 | 2x(19+23) =84 | 4x(29+26) =220 | 2x(74+79) =306 | 1,131 |
| 13. Junction of Russa Road and Tollygunj Circular Road. | $F_7$ | Russa Road North - a+b. | 170+169 =339 | 2x(20+21) =82 | 4x(17+25) =168 | 2x(75+94) =338 | 927 | Russa Road South e+f | 141+143 =284 | 2x(20+20) =80 | 4x(30+29) =236 | 2x(119+115) =468 | 1068 |

VOLUME OF HOURLY PEAK AVERAGE TRAFFIC (EQUIVALENT FAST TRAFFIC) — ALONG THE CROSS ROADS.

| Census Station | | Eastern Portions | | | | | | Western Portion | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | No. | Name of road with sub-station nos. | Motor vehicles | Equivalent fast traffic: For trams | For slow vehicles | For cycles | Total equivalent fast traffic | Name of road with sub-station nos. | Motor vehicles | Equivalent fast traffic: For trams | For slow vehicles | For cycles | Total equivalent fast traffic | Census station nos. | Remarks. |
| 1 | 2 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1. Shyambazar Rotary | $A_1$ | (a) R.G. Kar Road - c+d<br>(b) Upper Circular Road - e+f<br>(c) Cornwallis Street - g+h | 190+129=319<br>129+125=254<br>68+125=193 | 2x(24+20)=88<br>2x(25+25)=100<br>2x(35+55)=180 | 4x(81+39)=480<br>4x(26+16)=168<br>4x(19+34)=212 | 2x(50+20)=140<br>2x(52+20)=104<br>2x(26+66)=184 | 2,422 | | | | | | | $A_1$ | |
| 2. Junction of Chittaranjan Avenue and Vivekananda Road. | $B_1$ | Vivekananda Road East - c+d | 253+292 =545 | — | 4x(138+105) =972 | 2x(59+43) =204 | 1,721 | Vivekananda Road West - g+h | 247+235 =482 | — | 4x(89+92) =724 | 2x(36+33) =138 | 1,344 | $B_1$ | |
| 3. Junction of Chittaranjan Avenue and Harrison Road. | $B_2$ | Harrison Road East c+d | 142+124 =266 | 2x(35+36) =142 | 4x(95+71) =664 | 2x(21+13) =68 | 1,140 | Harrison Road West g+h | 198+235 =433 | 2x(21+35) =112 | 4x(99+76) =700 | 2x(16+15) =62 | 1,307 | $B_2$ | |
| 4. Junction of Chittaranjan Avenue and Bowbazar Street. | $D_1$ | Bowbazar Street East - c+d | 130+109 =239 | 2x(54+56) =220 | 4x(46+53) =396 | 2x(32+29) =122 | 977 | Bowbazar Street West - g+h | 198+198 =396 | 2x(61+56) =234 | 4x(33+45) =312 | 2x(35+23) =116 | 1,058 | $D_1$ | |
| 5. Junction of Chittaranjan Avenue and Mission Row. | $D_2$ | Ganesh Ch. Avenue c+d | 363+462 =825 | — | 4x(120+99) =876 | 2x(71+39) =220 | 1,921 | Mission Row g+h | 646+284 =930 | — | 4x(103+88) =764 | 2x(78+53) =262 | 1956 | $D_2$ | |
| 6. Esplanade Junction. | $D_{18}$ | (a) Dharmatalla St. - g+h<br>(b) Chowringhee Sq. - e+f | 101+65=166<br>26+30=56 | 2x(70+74)=288<br>— | 4x(22+3)=100<br>4x(56+36)=368 | 2x(14+15)=58<br>2x(16+15)=62 | 1,098 | (a) Esplanade East - k+l<br>(b) Bentinck Street - a+b | 54+260=314<br>303+251=554 | 2x(71+81)=304<br>2x(18+17)=70 | 4x(1+13)=56<br>4x(66+61)=508 | 2x(9+15)=48<br>2x(34+46)=160 | 2,014 | $D_{18}$ | |
| 7. Junction of Chowringhee Road and S.N. Banerjee Road. | $D_{19}$ | S.N. Banerjee Road c+d | 215+215 =430 | — | 4x(57+59) =464 | 2x(39+31) =140 | 1,034 | (a) Octerlony Road - i+j<br>(b) Dufferin Road - g+h | 343+448=791<br>175 = 175 | —<br>— | 4x(41+24)=260<br>4x(29)=116 | 2x(24+23)=94<br>2x(37)=74 | 1,510 | $D_{19}$ | |
| 8. Park Street Junction | $D_{20}$ | (a) Park Street - e+f<br>(b) Kyd Street - c+d | 213+596=809<br>105+165=270 | —<br>— | 4x(2+3)=20<br>4x(8+12)=80 | 2x(66+47)=226<br>2x(14+10)=48 | 1,453 | (a) Outram Ghat Road - i+j<br>(b) Mayo Road - k+l | 115+123=238<br>412+593=1,005 | —<br>— | 4x(1+5)=24<br>4x(10+12)=88 | 2x(8+21)=58<br>2x(40+89)=258 | 1,671 | $D_{20}$ | |
| 9. Junction of Chowringhee Road and Lower Circular Road. | $D_{21}$ | Lower Circular Road East - c+d | 385+436 =821 | — | 4x(12+9)=84 | 2x(39+29) =136 | 1,041 | Lower Circular Road West - g+h | 330+330 =660 | — | 4x(9+9) =72 | 2x(31+37) =136 | 868 | $D_{21}$ | |
| 10. Junction of Ashutosh Mukherjee Road and Padmapukur Road. | $F_1$ | Padmapukur Road c+d | 24+2 =26 | — | 4x(47+20) =268 | 2x(33+23) =112 | 406 | Deben Ghosh Road g+h | 29+40 =69 | — | 4x(43+48) =364 | 2x(25+26) =102 | 535 | $F_1$ | |
| 11. Junction of Ashutosh Mukherjee Road and Hazra Road. | $F_2$ | Hazra Road East c+d | 90+92 =182 | — | 4x(24+29) =212 | 2x(15+14) =58 | 452 | Hazra Road West g+h | 209+198 =407 | 2x(14+20) =68 | 4x(22+16) =152 | 2x(21+20) =82 | 709 | $F_2$ | |
| 12. Junction of Russa Road & Rashbehari Avenue. | $F_3$ | (a) Rashbehari Av. East - c+d<br>(b) Southern Avenue - i+j | 182+144=326<br>77+86=163 | 2x(18+18)=72<br>— | 4x(11+10)=84<br>4x(4+6)=40 | 2x(59+20)=158<br>2x(14+31)=90 | 933 | Rashbehari Avenue West - g+h | 63+54 =117 | — | 4x(21+18) =156 | 2x(52+46) =196 | 469 | $F_3$ | |
| 13. Junction of Russa Road and Tollygunj Circular Road. | $F_7$ | | | | | | | Tollygunj Circular Road - e+f | 101+98 =199 | — | 4x(31+30) =244 | 2x(100+85) =370 | 813 | $F_7$ | |

PLATE I

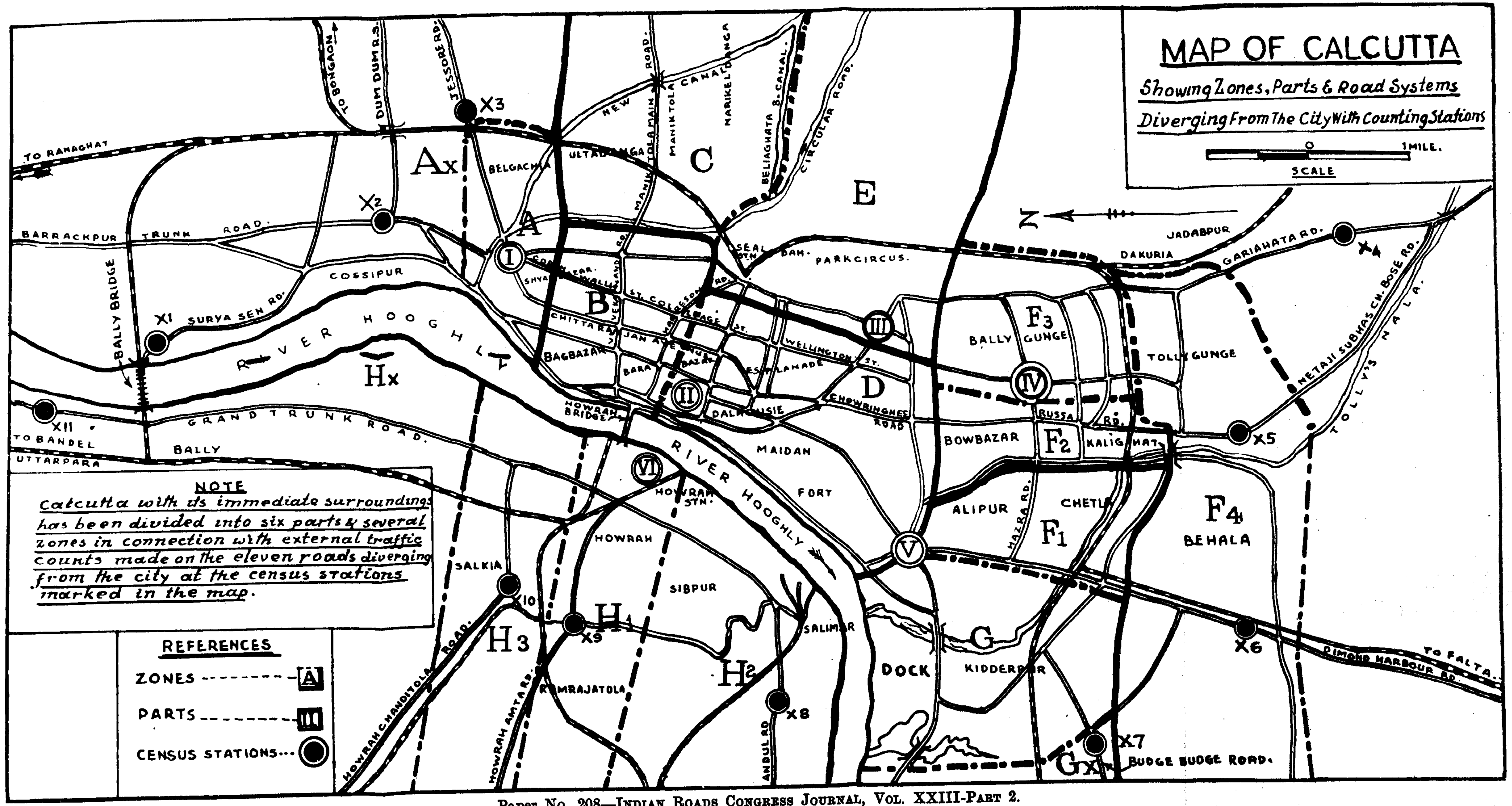

MAP OF CALCUTTA
Showing Zones, Parts & Road Systems
Diverging From The City With Counting Stations
SCALE
1 MILE.
NOTE
Calcutta with its immediate surroundings has been divided into six parts & several zones in connection with external traffic counts made on the eleven roads diverging from the city at the census stations marked in the map.
REFERENCES
ZONES
PARTS
CENSUS STATIONS
RIVER HOOGHLY
GRAND TRUNK ROAD
BARRACKPUR TRUNK ROAD
BUDGE BUDGE ROAD
DIMOND HARBOUR RD.
TO FALTA
MAIDAN
FORT
HOWRAH
SIBPUR
SALKIA
DOCK
KIDDERPUR
ALIPUR
BEHALA
TOLLYGUNGE
BALLYGUNGE
BOWBAZAR
CHETLA
KALIGHAT
DAKURIA
JADABPUR
PARKCIRCUS
COSSIPUR
BELGACHIA
BAGBAZAR
BALLY
UTTARPARA
TO BANDEL
TO RANAGHAT
BALLY BRIDGE
SURYA SEN RD.
HOWRAH BRIDGE
HOWRAH STN.
RAMRAJATOLA
ANDUL RD.
SALIMAR
GARIAHATA RD.
METAJI SUBHAS CH. BOSE RD.
TOLLY'S NALA
CIRCULAR ROAD
BELIAGHATA
NARIKELDANGA
MANIKTOLA MAIN ROAD
JESSORE RD.
DUM DUM R.S.
TO BONGAON
ESPLANADE
DALHOUSIE
WELLINGTON ST.
CHOWRINGHEE ROAD
HAZRA RD.
RUSSA RD.
HOWRAH AMTA RD.
HOWRAH ICHANDITOLA ROAD
A B C D E F1 F2 F3 F4 G Gx H1 H2 H3 Hx Ax
I II III IV V VI
X1 X2 X3 X5 X6 X7 X8 X9 X10 X11

PLATE II

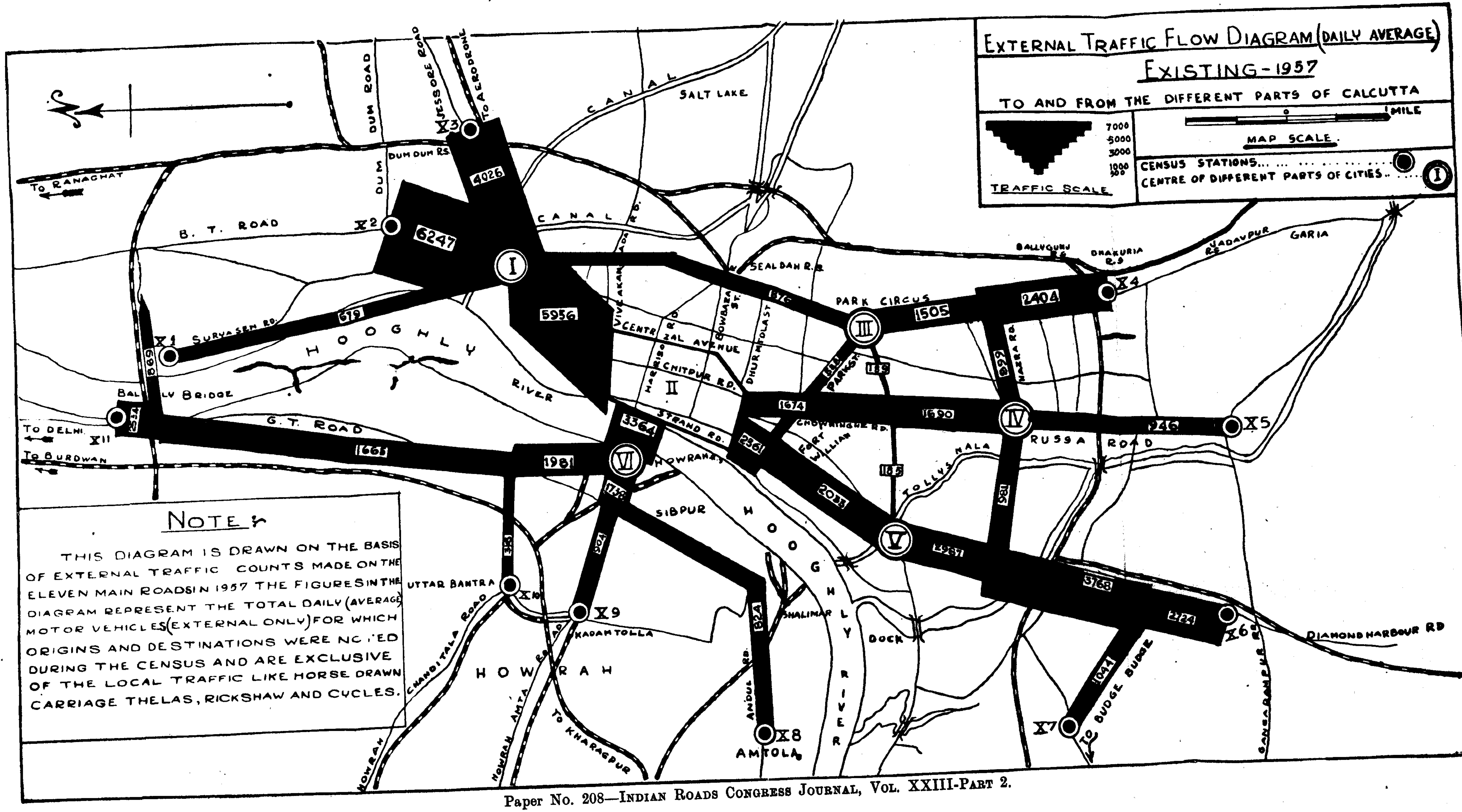

EXTERNAL TRAFFIC FLOW DIAGRAM (DAILY AVERAGE)
EXISTING - 1957
TO AND FROM THE DIFFERENT PARTS OF CALCUTTA
TRAFFIC SCALE
MAP SCALE
1 MILE
CENSUS STATIONS
CENTRE OF DIFFERENT PARTS OF CITIES
NOTE:-
THIS DIAGRAM IS DRAWN ON THE BASIS OF EXTERNAL TRAFFIC COUNTS MADE ON THE ELEVEN MAIN ROADS IN 1957 THE FIGURES IN THE DIAGRAM REPRESENT THE TOTAL DAILY (AVERAGE) MOTOR VEHICLES (EXTERNAL ONLY) FOR WHICH ORIGINS AND DESTINATIONS WERE NOTED DURING THE CENSUS AND ARE EXCLUSIVE OF THE LOCAL TRAFFIC LIKE HORSE DRAWN CARRIAGE THELAS, RICKSHAW AND CYCLES.
TO RANAGHAT
DUM DUM RS
DUM DUM ROAD
JESSORE ROAD
TO AERODROME
SALT LAKE
CANAL
B. T. ROAD
HOOGHLY RIVER
G. T. ROAD
TO DELHI
TO BURDWAN
SEALDAH R.S
PARK CIRCUS
BALLYGUNJ R.S
DHAKURIA R.S
GARIA
RUSSA ROAD
TOLLYS NALA
SIBPUR
SHALIMAR
DOCK
HOWRAH
UTTAR BANTRA
KADAMTOLLA
AMTOLA
TO KHARAGPUR
TO BUDGE BUDGE
DIAMOND HARBOUR RD
4026
6247
5956
679
869
1665
1981
3564
1674
1690
1505
2404
2561
2033
3767
3768
2734
1034
1824
758
924
981
999
946

**PLATE III**

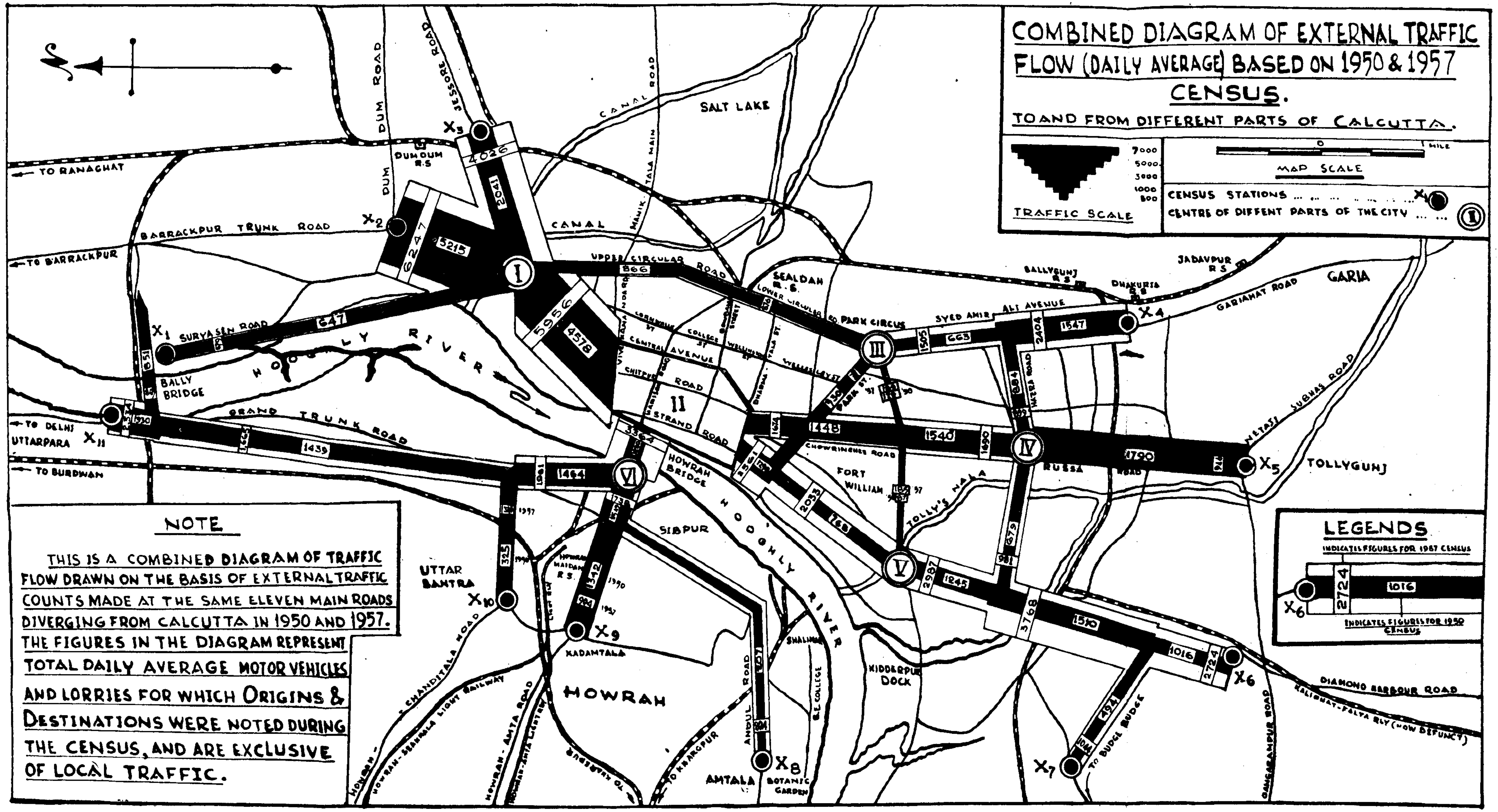

COMBINED DIAGRAM OF EXTERNAL TRAFFIC FLOW (DAILY AVERAGE) BASED ON 1950 & 1957 CENSUS.
TO AND FROM DIFFERENT PARTS OF CALCUTTA.
TRAFFIC SCALE
MAP SCALE
CENSUS STATIONS
CENTRE OF DIFFENT PARTS OF THE CITY
NOTE
THIS IS A COMBINED DIAGRAM OF TRAFFIC FLOW DRAWN ON THE BASIS OF EXTERNAL TRAFFIC COUNTS MADE AT THE SAME ELEVEN MAIN ROADS DIVERGING FROM CALCUTTA IN 1950 AND 1957. THE FIGURES IN THE DIAGRAM REPRESENT TOTAL DAILY AVERAGE MOTOR VEHICLES AND LORRIES FOR WHICH ORIGINS & DESTINATIONS WERE NOTED DURING THE CENSUS, AND ARE EXCLUSIVE OF LOCAL TRAFFIC.
LEGENDS
INDICATES FIGURES FOR 1957 CENSUS
INDICATES FIGURES FOR 1950 CENSUS
TO RANAGHAT
TO BARRACKPUR
TO DELHI
TO BURDWAN
UTTARPARA
BARRACKPUR TRUNK ROAD
DUM DUM ROAD
JESSORE ROAD
SALT LAKE
CANAL
SURYA SEN ROAD
HOOGHLY RIVER
BALLY BRIDGE
GRAND TRUNK ROAD
UPPER CIRCULAR ROAD
SEALDAH
PARK CIRCUS
CENTRAL AVENUE
CHITPUR ROAD
STRAND ROAD
HOWRAH BRIDGE
CHOWRINGHEE ROAD
FORT WILLIAM
TOLLY'S NALA
SYED AMIR ALI AVENUE
BALLYGUNJ
DHAKURIA
JADAVPUR
GARIA
GARIAHAT ROAD
TOLLYGUNJ
SIBPUR
UTTAR BANTRA
KADAMTALA
HOWRAH
AMTALA
BOTANIC GARDEN
KIDDERPUR DOCK
DIAMOND HARBOUR ROAD
TO BUDGE BUDGE
AMBOLE ROAD

PLATE IV

GRAPHICAL REPRESENTATION OF HOURLY PEAK AVERAGE TRAFFIC ON CIRCULAR ROAD & ON CROSS ROADS.

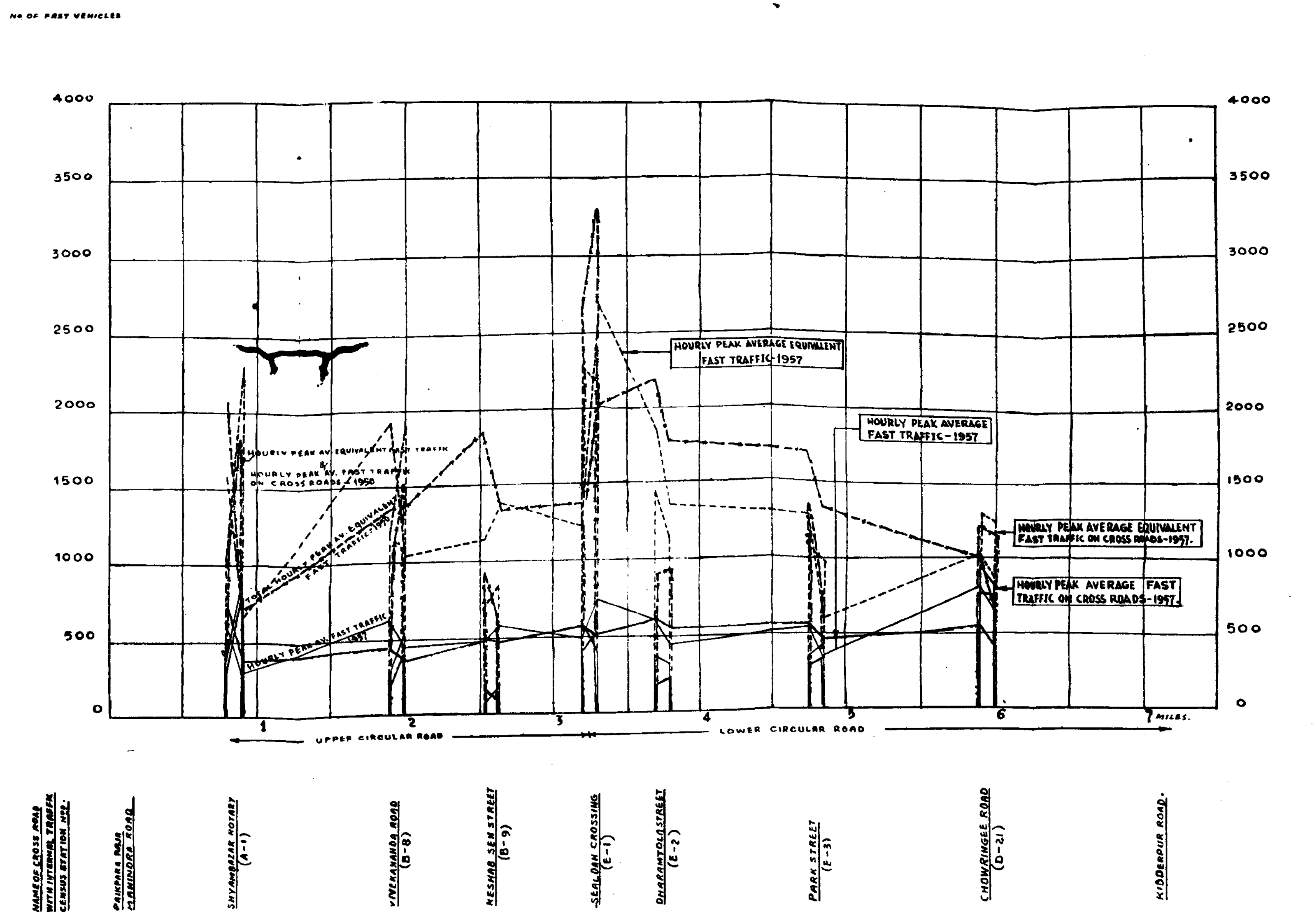


PLATE V

GRAPHICAL REPRESENTATION OF HOURLY PEAK AVERAGE TRAFFIC ON CORNWALLIS STREET, COLLEGE STREET, WELLINGTON STREET, & ON THE CROSS ROADS.

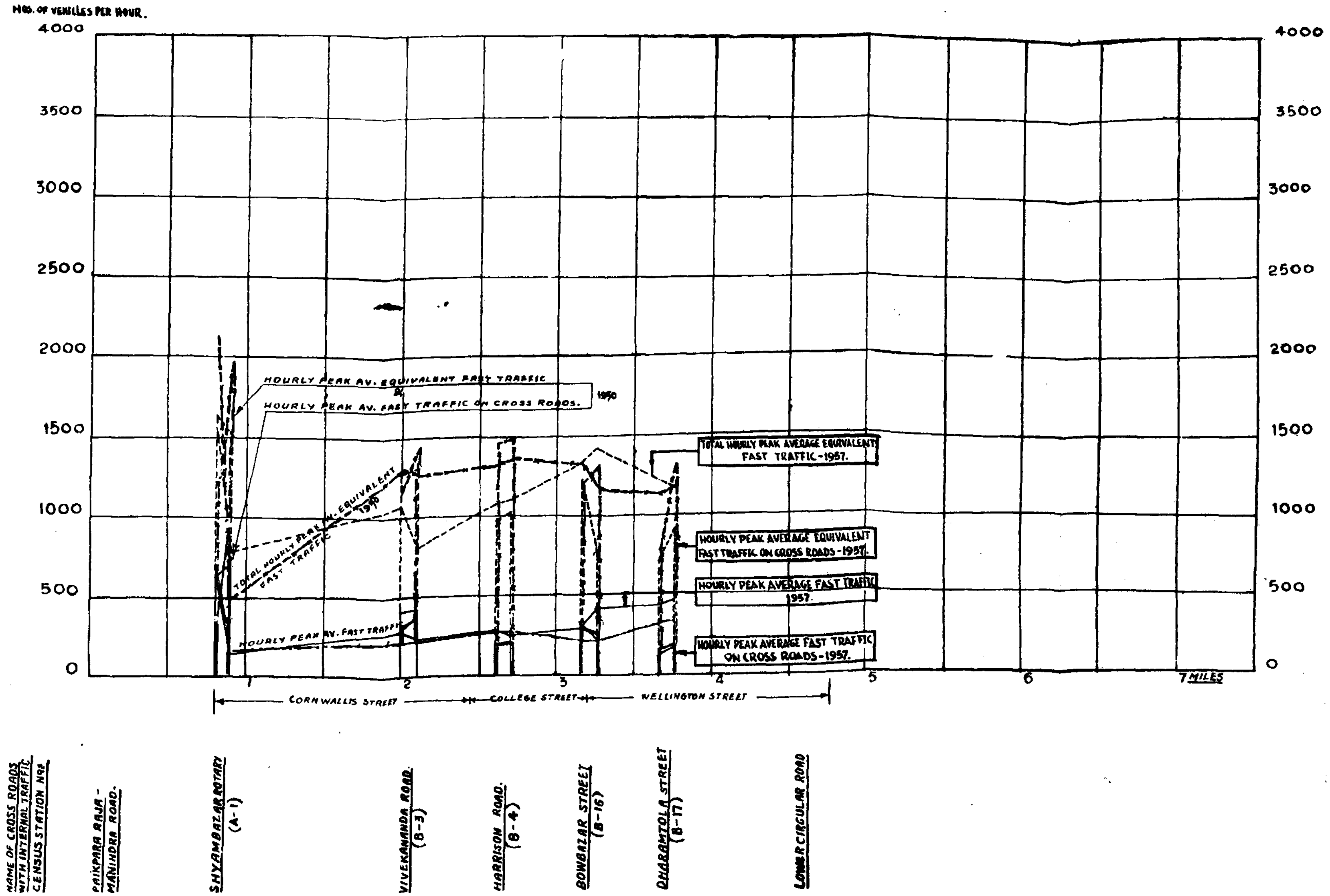
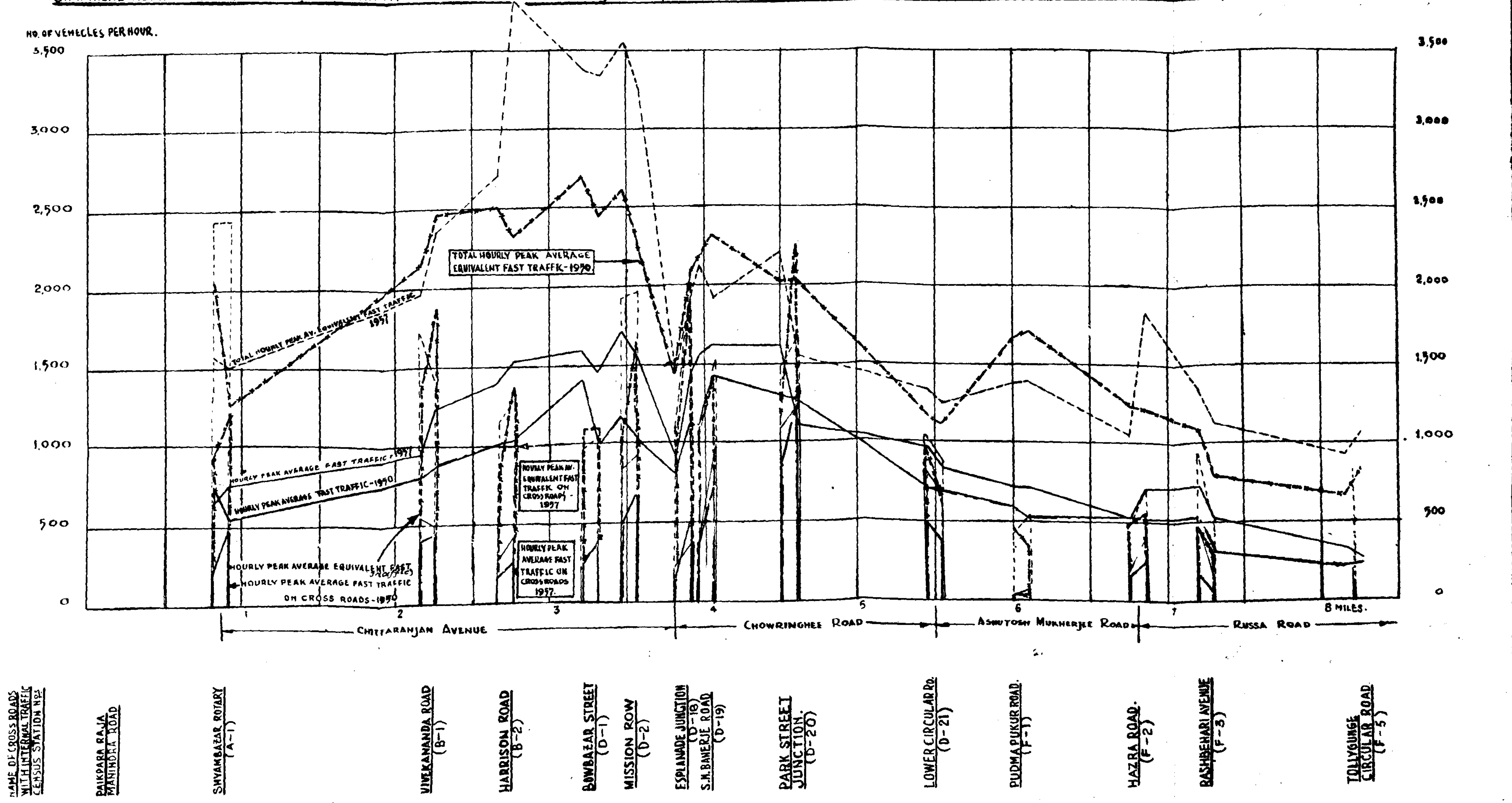


PLATE VI

GRAPHICAL REPRESENTATION OF HOURLY PEAK AVERAGE TRAFFIC ON CHITTARANJAN AVENUE, CHOWRINGHEE ROAD, ASHUTOSH MUKHERJE ROAD, RUSSA ROAD & ON CROSS ROADS.



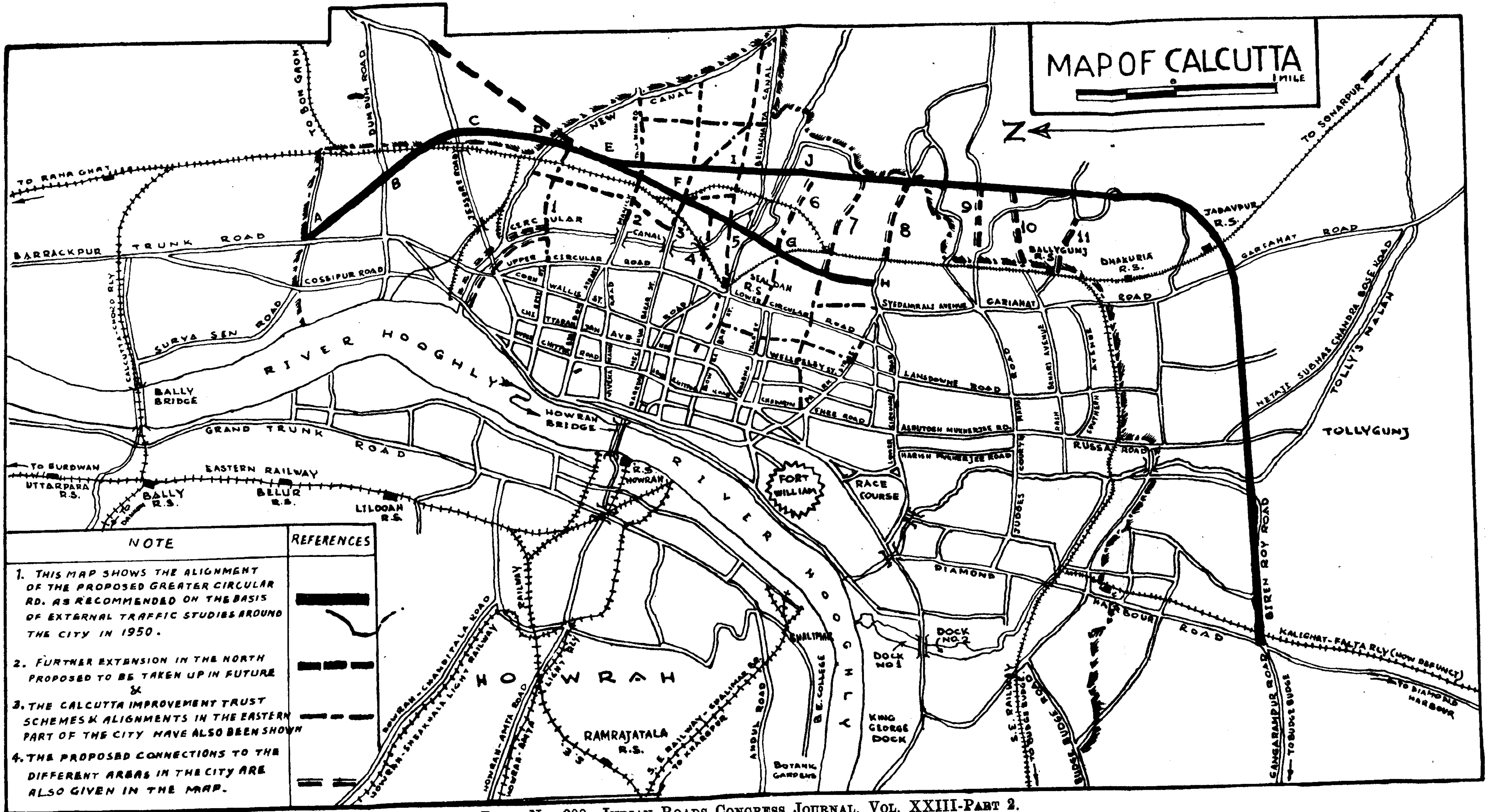
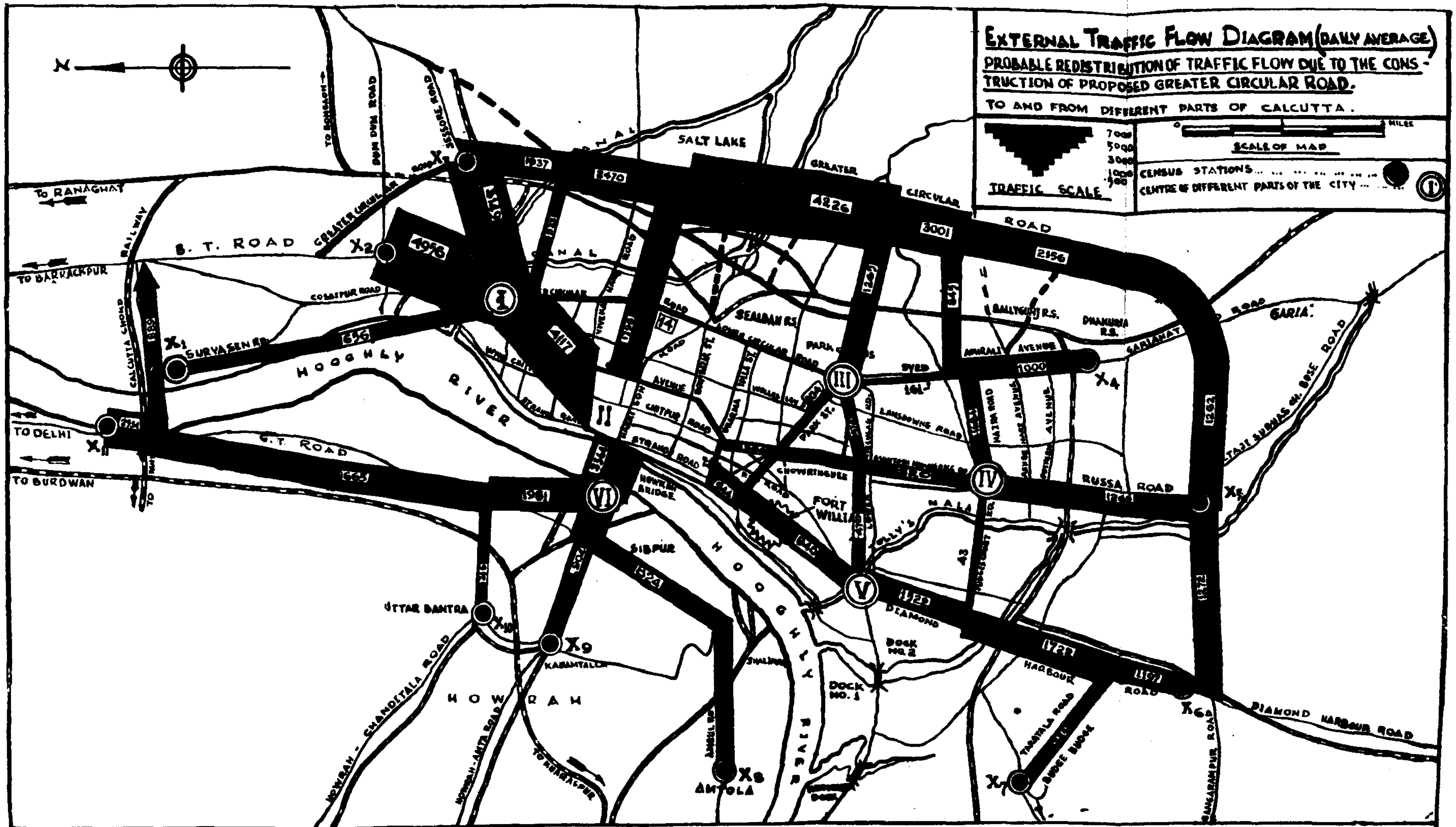

MAP OF CALCUTTA
1 MILE
N
NOTE
1. THIS MAP SHOWS THE ALIGNMENT OF THE PROPOSED GREATER CIRCULAR RD. AS RECOMMENDED ON THE BASIS OF EXTERNAL TRAFFIC STUDIES AROUND THE CITY IN 1950.
2. FURTHER EXTENSION IN THE NORTH PROPOSED TO BE TAKEN UP IN FUTURE &
3. THE CALCUTTA IMPROVEMENT TRUST SCHEMES & ALIGNMENTS IN THE EASTERN PART OF THE CITY HAVE ALSO BEEN SHOWN
4. THE PROPOSED CONNECTIONS TO THE DIFFERENT AREAS IN THE CITY ARE ALSO GIVEN IN THE MAP.
REFERENCES
RIVER HOOGHLY
HOWRAH BRIDGE
FORT WILLIAM
RACE COURSE
HOWRAH
TOLLYGUNJ
BARRACKPUR TRUNK ROAD
GRAND TRUNK ROAD
EASTERN RAILWAY
BALLY BRIDGE
BALLY R.S.
BELUR R.S.
LILOOAH R.S.
UTTARPARA R.S.
TO BURDWAN
TO RANA GHAT
TO BON GAON
DUM DUM ROAD
COSSIPUR ROAD
SURYA SEN ROAD
UPPER CIRCULAR ROAD
CORNWALLIS ST.
SEALDAH R.S.
LOWER CIRCULAR ROAD
WELLESLEY ST.
LANSDOWNE ROAD
ASUTOSH MUKHERJEE RD.
HARISH MUKHERJEE ROAD
RUSSA ROAD
DIAMOND HARBOUR ROAD
GARIAHAT ROAD
BALLYGUNJ R.S.
DHAKURIA R.S.
JADAVPUR R.S.
TO SONARPUR
NETAJI SUBHAS CHANDRA BOSE ROAD
TOLLY'S NALLAH
BIREN ROY ROAD
KALIGHAT-FALTA RLY (NOW DEFUNCT)
TO DIAMOND HARBOUR
GANGARAMPUR ROAD
TO BUDGE BUDGE
BUDGE BUDGE ROAD
S.E. RAILWAY
KING GEORGE DOCK
DOCK NO.1
DOCK NO.2
B.E. COLLEGE
BOTANIC GARDENS
SHALIMAR
ANDUL ROAD
RAMRAJATALA R.S.
HOWRAH-AMTA ROAD
HOWRAH-AMTA LIGHT RLY
HOWRAH-SHEAKHALA LIGHT RAILWAY
HOWRAH-CHANDITALA ROAD
S.E. RAILWAY-SHALIMAR BR. TO KHARAGPUR
R.S. HOWRAH
NEW CANAL
CALCUTTA-CHORD RLY
JESSORE ROAD
A
B
C
D
E
F
G
H
J
1
2
3
4
5
6
7
8
9
10
11

PLATE VIII




NOTE: THE RECOMENDATION OF CONSTRUCTION OF THE GREATER CIRCULAR ROAD AROUND THE CITY OF CALCUTTA WITH PROVISION OF SEVERAL INDEPENDENT ENTRIES TO THE CITY AT DIFFERENT POINTS IN CONFORMITY WITH THE PROGRAMME OF THE CALCUTTA IMPROVEMENT TRUST HAS BEEN MADE. THE TRAFFIC WHICH ARE MORE OR LESS "EXTERNAL" IN CHARACTER CAN CONVENIENTLY BY-PASS THE CITY THROUGH THIS ROAD WITH LEAST INTERFERENCE TO THE INTERNAL TRAFFIC FLOW CAUSING ECONOMY IN TIME, MONEY AND SAFE MOVEMENT. THIS DIAGRAM SHOWS THE PATTERN OF DISTRIBUTION OF FLOW OF TRAFFIC WITHIN THE CITY AS WELL AS ON THE GREATER CIRCULAR ROAD DUE TO EXTERNAL TRAFFIC ONLY.

Paper No. 209

# "AN INVESTIGATION OF A CONCRETE PAVEMENT" FAILURE

*By*

DR. BH. SUBBARAJU* & Y. C. GOKHALE*

## CONTENTS



## SYNOPSIS

An investigation carried out for determining the probable reasons for an early development of cracking of slabs of a cement concrete pavement has been described in this Paper. The probable cause of failure was attributed to the excessive differential swelling and shrinkage properties of the particular subgrade soil. Utilising existing knowledge, an attempt has been made to evaluate induced stresses based on theoretical considerations and also to estimate the probable crack expectancy period based on flexural strength values obtained from beams cut out from the road slabs. Some remedial and precautionary methods have been suggested both for already laid concrete pavements as well as for new concrete pavement construction on highly expansive soil subgrades.

## 1. INTRODUCTION

The existing knowledge about pavement design is far from complete and much effort has to be put in to acquire more information about the various factors that are likely to cause the deterioration of a pavement. It is always felt that much valuable information can conveniently be obtained from a systematic study of any failure that a pavement might have developed.

* Central Road Research Institute, New Delhi,

On account of the anticipated heavy traffic on our highway system with the increased tempo of industrialisation, more mileage of concrete roads is now being undertaken than ever before. Experience in design and construction of concrete roads is limited in this country. Hence it is very useful for future guidance to carry out a systematic study of the performance of some of the existing pavements, including such of those as are actually under the stage of distress.

The Central Road Research Institute happened to take up an investigation of a concrete road situated in the Mysore State where the highway was running through black and red soil regions. The results of this investigation together with the remedial and precautionary measures suggested for portions where the concrete slabs have shown signs of distress by early cracking have been presented in this Paper.

## 2. BRIEF HISTORY OF THE ROAD

### 2.1. General

Out of a total length of 16 miles of the Belgaum-Khanpur Road, the concreted length is about 13 miles and 4 furlongs. The concrete pavement consists of 4 in. thick 1 : 2 : 4 cement concrete slabs of 12 feet width with contraction joints at 20 feet and expansion joints at 120 feet intervals. On both sides of the

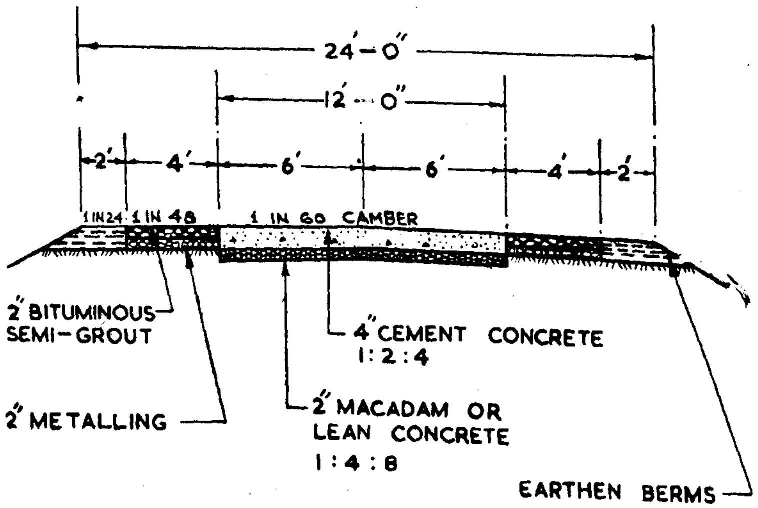



Fig. 1.

A typical cross section of cement concrete pavement



concrete pavement, 4 feet wide haunches consisting of 2-in. thick metalling and 2-in. thick bituminous semi-grout have been provided. The new pavement was laid on an old road crust, the thickness of which varied from 13 in. to 25 in. A typical cross-section of the pavement is shown in Fig. 1. The work of concreting was started in February 1953 and the major portion was completed by May 1955.

### 2.2. Traffic

Traffic census carried out in March 1956 by the State P.W.D. for the road under discussion shows that the intensity of average daily total traffic is about 1300 tons, out of which the iron-tyred traffic contributes about 350 tons. The details of the traffic survey are presented in Table 1.

TABLE 1

**Details of traffic census**

| Date | Cars | Buses | Trucks | | Motor cycles | Iron-tyred vehicles |
|---|---|---|---|---|---|---|
| | | | Loaded | Empty | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 23-3-56 | 165 | 40 | 68 | 46 | 21 | 462 |
| 24-3-56 | 121 | 36 | 80 | 75 | 39 | 893 |
| 25-3-56 | 154 | 36 | 81 | 41 | 24 | 350 |
| 26-3-56 | 83 | 30 | 15 | 19 | 7 | 298 |
| 27-3-56 | 130 | 38 | 54 | 59 | 24 | 138 |
| 28-3-56 | 110 | 38 | 52 | 77 | 18 | 165 |
| 29-3-56 | 146 | 32 | 76 | 57 | 29 | 196 |
| Total | 909 | 250 | 426 | 374 | 162 | 2507 |
| Average weight of one vehicle in tons | 1.25 | 8.5 | 6.4 | 3.0 | 0.2 | 1.0 |
| Total weight | 1136.25 | 2125.00 | 2126.40 | 1122.00 | 32.40 | 2507.0 |
| Average daily traffic tonnage | 162.32 | 303.57 | 303.77 | 160.31 | 4.63 | 358.14 |
| Average total daily traffic intensity in tons | | 1292.74 say 1300 | | | | |

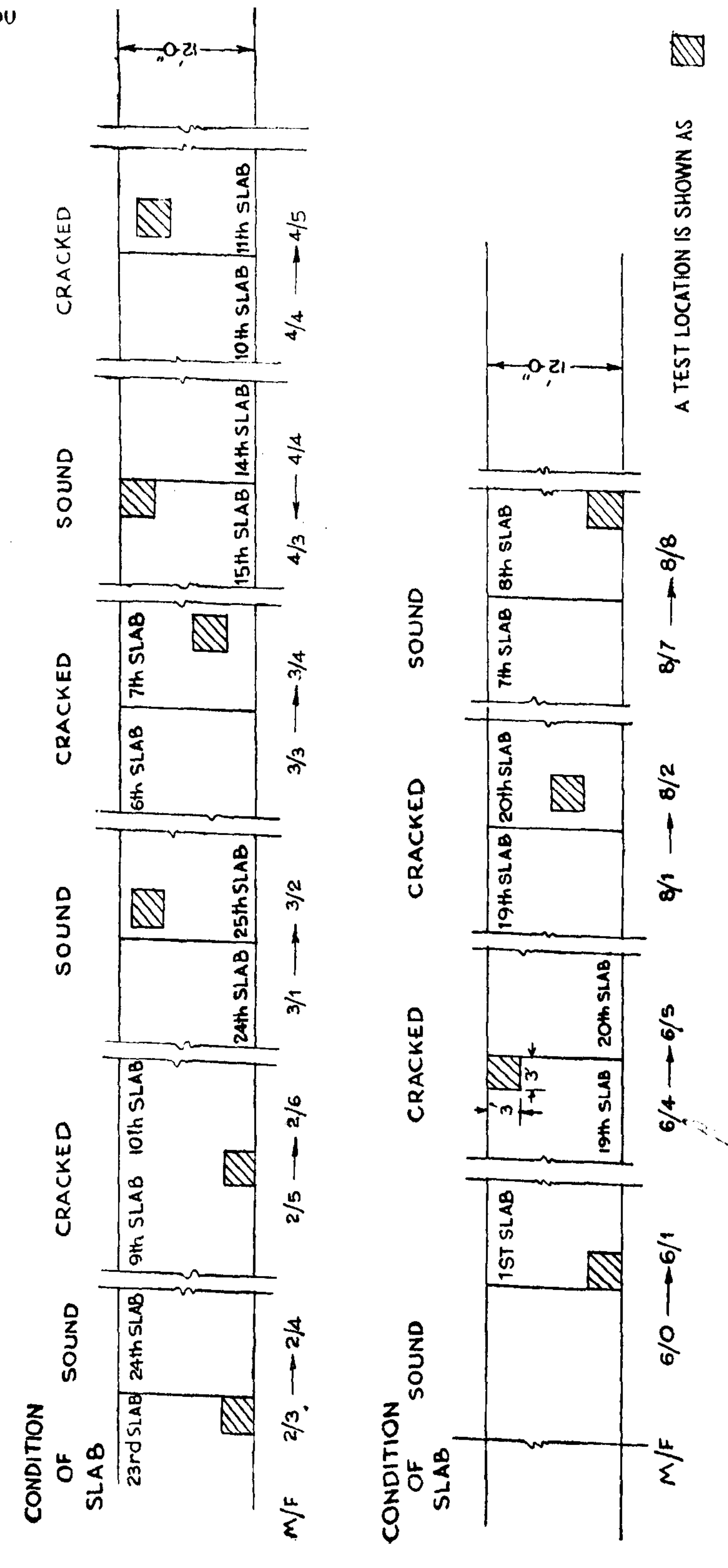



FIG. 2- A GENERAL PLAN OF THE ROAD SHOWING TEST LOCATIONS



### 2.3. Rainfall and Vegetation

The average yearly rainfall is about 60 inches with the monsoon period from May to October. The fluctuations in the water-table in that area are generally reported to be anywhere from about 5 to 30 feet, depending upon the season. In general, the road runs practically at the level of the adjoining terrain with one drain of about four feet depth on either side of the road. The road runs partly in paddy fields and partly in light jungle area.

A general plan of the road indicating the actual test locations is shown in Fig. 2.

## 3. DESCRIPTION OF PAVEMENT FAILURE

3.1. Within two years of construction, some sections of the road were observed to have cracked. In general, the distressed slabs developed either a central longitudinal crack or, in a few cases, two longitudinal cracks at about one-third width of the slabs. As time progressed, transverse cracking developed combined with some more longitudinal cracks to varying extent. A typical longitudinally cracked road section is shown in Photo 1.

TABLE 2

**Details of pavement sections along with dates of construction and cracking**

| | Section | | Date when concreted | Date when cracking was initially noticed |
|---|---|---|---|---|
| | Mile (1) | Furlong (2) | (3) | (4) |
| 1. | 2 | 6,7 | March 1953 | December 1955 |
| 2. | 3 | 3,4 | April 1953 | March 1956 |
| 3. | 4 | 4,5 | May 1953 | September 1955 |
| 4. | 6 | 4 to 8 | January 1954 | November 1955 |
| 5. | 7 | 1,2 | | |
| 6. | 7 | 4 | May 1956 | November 1956 |
| 7. | 7 | 5 | February 1954 | November 1956 |
| 8. | 8 | 1 to 4 | February 1954 | November 1956 |
| 9. | 8 | 7 | April 1954 | November 1954 |
| 10. | 10 | 4,8 | May 1954 | October 1955 |

### 3.2. Time of Crack-development

A list of cracked sections of the road along with the period when the section was concreted and when the cracking was first observed, as extracted from the State P.W.D. records, is presented in Table 2.

A study of Table 2 shows that majority of the slabs cracked generally during the withdrawal period of the monsoon, that is round about the month of November.

### 3.3. Field Observations

It was observed in the field that the subgrade soil for the entire length of the road was of two general types, occurring in intermediate stretches of varying lengths. In the sections where slabs had cracked extensively, invariably the subgrade soil was black soil, while under the sound sections, it was red soil. The plasticity characteristics of the two types of soils are given in Table 3. The complete particle size distribution curves for the two soils are presented in Fig. 3.

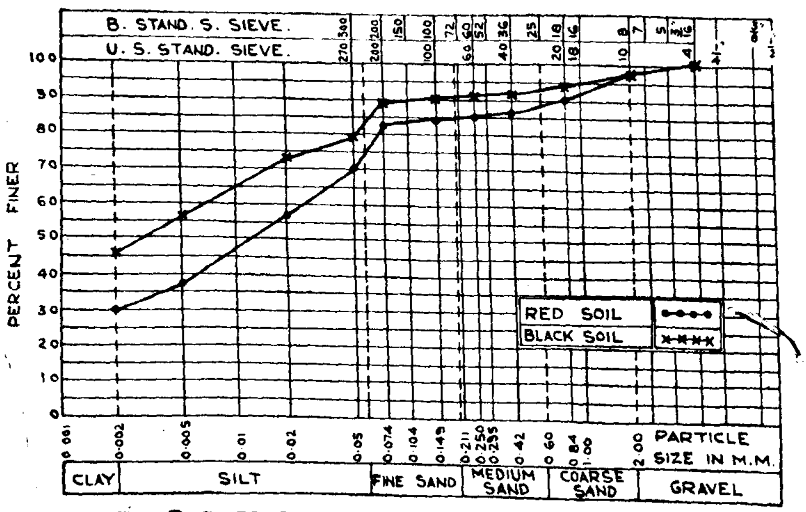



FIG-3. PARTICLE-SIZE DISTRIBUTION CURVES FOR THE RED AND BLACK SUBGRADE SOILS



In some slabs, the longitudinal crack has extended fully across the length and depth of the slab, and the slab is broken up into two separate pieces. In such cases, a differential movement of as much as 1 in. has been noticed.

During field investigations, some of the cracked slabs were cut open for testing purposes. It was then observed that the longitudinal crack in the slab extended visibly down through the metal crust and that the bituminous binder poured in the crack travelled nearly 10 to 12 in. deep into the metal crust.

TABLE 3

**Plasticity characteristics of subgrade soils**

| Soil | Black soil | Red soil |
|---|---|---|
| L. L. | 55 | 45 |
| P. I. | 25 | 18 |
| Classification | MH—CH | ML—CL |

## 4. FIELD INVESTIGATIONS

### 4.1. Tests Carried Out

The following field tests were carried out:

a. Flexural strength of concrete beams cut from the pavement.

b. Modulus of subgrade reaction.

c. Dry bulk density of subgrade soil.

d. Moisture content of subgrade soil.

It has been stated in para. 3.3 that concrete slabs laid on red subgrade soil were in sound condition, while those on black subgrade soil had cracked. Hence, for the sake of comparison, tests were carried out on the slabs laid on both the types of soil. The traffic intensity being the same for both the sections comprising black and red soils, an attempt was made to compare the flexural strength and modulus of subgrade reaction values in the two types of subgrade soil regions. Thus cracked and sound slabs were selected from the respective sections and the field tests mentioned in para. 4.1 were conducted. The criterion adopted for selecting a representative cracked slab was that on each side of the selected slab there would be at least ten cracked slabs in continuation. A similar criterion was applied for the selection of a representative sound slab for the various tests conducted in this investigation.

### 4.2. Description of Tests

4.2.1. **Flexural strength of concrete beams**: Concrete beams of 16 in. length and 4 in. width were cut from the selected slabs using concrete cutter machine and were tested for flexural strength as per A.S.T.M. Specification No. C. 293-54T. Photo 2 shows the cutter machine in operation.

4.2.2. **Modulus of subgrade reaction**: A 3 ft × 3 ft portion of the selected concrete slab was cut by the concrete cutter machine. The plate-bearing test was carried out on the underlying metal road crust with a 30-in. diameter steel plate as per method given in "Procedures for testing soils", American Society for Testing Materials, 1950. The general arrangement of the test, in which two trucks were coupled back to back for getting the required reaction, is shown in Photo 3.

4.2.3. **Dry bulk density and moisture content of subgrade soil:** Dry bulk density and moisture content were determined by the procedure given in the B.S. Specification No. 1377: 1948 for the subgrade soil at each test site.

### 4.3. Test Results

The results of the various field tests are given in Table 4.

## 5. LABORATORY INVESTIGATIONS

### 5.1. Tests Carried Out

It was observed in the field that the range of dry bulk densities of the two soils was of the order of 110 to 90 lb per cu. ft. Hence the following tests were performed on both the soils at three different dry bulk densities, viz., 90, 100 and 110 lb per cu. ft.

a. Per cent swelling of the soil at saturation in the C. B. R. mould,



TABLE 4

**Results of field tests**

| Location Mile (1) | Fur-long (2) | Condition of test slab (3) | Type of subgrade soil (4) | Position of test area in the slab (5) | Average thickness of beam in inches (6) | Flexural strength of concrete in lb per sq. in. (7) | Modulus of subgrade reaction in lb per sq. in. per in. (8) | Dry bulk density of subgrade soil in lb per cu. ft. (9) | Per cent moisture content of subgrade soil (10) |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 4 | sound | red | edge | 3.16 | 917 | 357 | 88.4 | 13.5 |
| 2 | 6 | cracked | black | edge | 3.61 | 744 | 396 | 92.7 | 18.5 |
| 3 | 2 | sound | red | edge | 3.66 | 1107 | 545 | 97.7 | 8.1 |
| 3 | 4 | cracked | black | centre | 3.62 | 1020 | 392 | 111.5 | 11.6 |
| 4 | 4 | sound | red | edge | 3.76 | 913 | 309 | 104.0 | 8.8 |
| 4 | 5 | cracked | black | edge | 3.46 | 958 | 226 | 96.5 | 17.6 |
| 6 | 1 | sound | red | edge | 4.19 | 978 | 501 | 106.5 | 9.7 |
| 6 | 5 | cracked | black | edge | 4.05 | 614 | 175 | 104.2 | 13.9 |
| 8 | 8 | sound | red | edge | 3.93 | 1118 | 450 | 102.8 | 9.0 |
| 8 | 2 | cracked | black | centre | 4.04 | 987 | 297 | 111.3 | 8.7 |

b. Measurement of swelling pressure at increasing moisture content until saturation.

In addition to the above tests the following tests on both the types of subgrade soils were conducted, the results of which are given in Table 3 and Fig. 3.

a. Liquid limit

b. Plastic limit

c. Mechanical analysis

5.2. **Description of Tests**

5.2.1. **Per cent swelling of the soil at saturation in the C. B. R. mould**: Determination of per cent swelling in the C. B. R. mould was done as per procedure given in "Procedures for testing soils", American Society for Testing Materials, 1950.

5.2.2. **Measurement of swelling pressure at increasing moisture content until saturation**: There is no known standard test procedure for measuring swelling pressures of soil at increasing moisture content. Hence a laboratory test was developed for the purpose. It should be noted here that the values of swelling pressures as determined in the laboratory test cannot be taken as absolute values obtainable in the field but can only be used for the sake of comparison of the behaviour of the two soils. A method for determining the absolute value of swelling pressure in the field needs to be evolved.

The procedure adopted for measuring swelling pressure is essentially as follows :

In a brass mould of $2\frac{1}{8}$ in. diameter and $1\frac{1}{2}$ in. height, which was readily available in the laboratory, the soil at the natural moisture content, which was 2.6 per cent for the red soil and 3.2 per cent for the black soil, was compacted to the selected dry bulk density. The compacted height of the soil sample in the mould was $\frac{3}{4}$ in. The bottom of the brass mould was then capped with a circular piece of a filter paper. A thin circular brass plate with diameter slightly less than $2\frac{1}{8}$ in. was placed on top of the soil sample. The brass mould with the soil sample was then kept in a metal receptacle, with suitable quantities of water being added for absorption by the soil sample in the brass mould through the filter paper, which in turn was kept on the rigid base



of the load frame. The prooving ring of 600 lb capacity was fitted in a load frame resting on top of the circular brass plate. Absorption of water caused the soil sample to swell and the swelling force developed was recorded by the prooving ring. Using the swelling force developed and the circular area of the sample under test, the swelling pressure was calculated in terms of tons per sq. ft. The set-up of the apparatus is shown in Photo 4.

In order to get the values of swelling pressure at increasing moisture absorption by the soil sample, it was necessary to remove the brass mould from the load frame at some regular intervals during the test, to weigh it in order to find out the degree of moisture absorption and to refix the mould in the load frame at the same reading of the prooving ring at which it was removed. This procedure was likely to cause some error in the values of swelling force recorded on account of intermediate release of stresses during testing, but it was considered inevitable in order to get the required relationship between swelling pressure and moisture content.

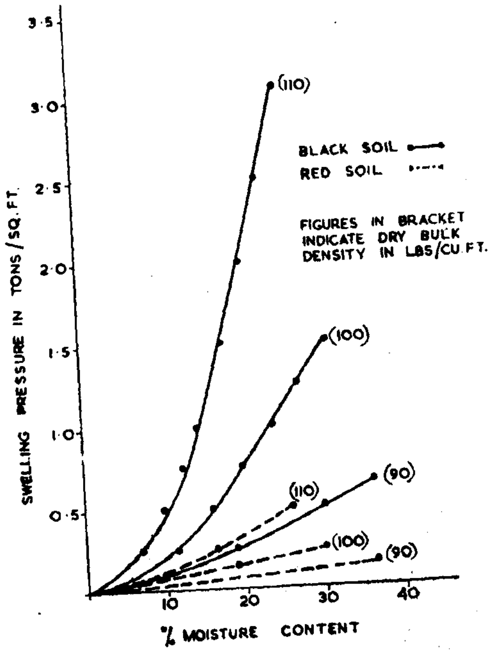



Fig. 4.

**Relationship between swelling pressure and moisture content at different dry bulk densities**

5.3. **Test Results**

The results of the two tests indicating maximum percentage swelling and maximum swelling pressure for both the soils are given in Table 5. The relationship between moisture content and swelling pressure is shown in Fig. 4.

TABLE 5

**Results of laboratory tests**

| Type of soil | Dry bulk density in lb per cu. ft. | Percent swelling at saturation in C. B. R. mould | Maximum swelling pressure at saturation in tons per sq. ft. | Saturation time in swelling pressure test in minutes |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| Black soil | 90 | 12.2 | 0.65 | 20 |
| | 100 | 18.1 | 1.50 | 65 |
| | 110 | 24.1 | 3.05 | 245 |
| Red soil | 90 | 5.6 | 0.15 | 4 |
| | 100 | 7.9 | 0.25 | 7 |
| | 110 | 11.5 | 0.45 | 15 |

## 6. THEORETICAL CONSIDERATIONS

6.1. **General:** With a view to have a better understanding of the reasons for early cracking in some of the stretches investigated, an attempt has been made to calculate the load and temperature stresses expected under the traffic and climatic conditions existing on the road under investigation. The load stresses are calculated as per modified Westergaard's formulae based on Arlington tests and the temperature stresses are calculated using Thomlinson's theory. Using Bradbury's analogy it is also attempted to estimate the crack expectancy in the cement concrete slab under the prevailing traffic and climatic conditions. Even though the several assumptions which are made in these calculations are subject to criticism, in the absence of more precise data, the assumptions made are considered reasonable and the presentation of such theoretical considerations is expected to make the designers more and more interested in adopting a rational approach for designs instead of adopting empirical methods only.



6.2. **Calculation of Load Stresses**

Formulae developed by Westergaard and modified by Teller and Sutherland[1] have been used in the calculation of load stresses due to corner, edge and interior loading.

a. For corner loading

$$\sigma c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

b. For edge loading

$$\sigma e = 0.529\,(1 + 0.54\mu)\,\frac{P}{h^2}\left[\log_{10}\left(\frac{Eh^3}{kb^4}\right) + \log_{10}\left(\frac{C}{1-\mu^2}\right) - 1.0792\right]$$

c. For interior loading

$$\sigma i = 0.275\,(1 + \mu)\,\frac{P}{h^2}\left[\log_{10}\left(\frac{Eh^3}{kb^4}\right) - 54.54\left(\frac{l}{L}\right)^2 Z\right]$$

where

$\sigma c$ = greatest tensile stress produced by corner loading in lb per sq. in.

$\sigma e$ = greatest tensile stress produced by edge loading in lb per sq. in.

$\sigma i$ = greatest tensile stress produced by interior loading

$P$ = wheel load in lb. According to the traffic census, the heaviest vehicle is an $8\frac{1}{2}$ ton bus. Assuming the load on the rear axle to be 6 tons, the wheel load on dual tyres works out to 6,720 lb.

$E$ = modulus of elasticity of concrete
= $5 \times 10^6$ lb per sq. in.

$h$ = thickness of slab, based on the figures given in Table 4, two values viz., 3.6 in. and 4 in. have been considered

$a$ = radius of contact area of the dual tyre assembly.[2]
= 7 in.

$b$ = equivalent radius of contact area
 = 7 in. as $a > 1.724\,h$.

$\mu$ = Poisson's ratio for concrete
 = 0.24 for dynamic loading.

$k$ = modulus of subgrade reaction in lb per sq. in per in. In the present calculations, the extreme values of $k$ = 175 and 400 lb per sq. in. per in. for the black soil region and of $k$ = 300 and 550 lb per sq. in. per in. for the red soil region have been considered

$l$ = radius of relative stiffness

$$= \sqrt[4]{\frac{Eh^3}{12\,(1-\mu^2)k}}$$

$$\frac{l}{L} = 0.2$$

$$Z = 0.2$$

The values of tensile stresses developed due to the three types of loading are presented in Table 6.

### 6.3. Calculation of Temperature Stresses

Based on Thomlinson's theory [1] the temperature stresses are worked out as indicated below:

$$\text{Stress factor } F = \frac{\varepsilon E \theta_0}{1-\mu};$$

where

$\varepsilon$ = coefficient of thermal expansion of concrete
 = $5 \times 10^{6}$ per °$F$.

$E$ = modulus of elasticity of concrete
 = $5 \times 10^{6}$ lb per sq. in.

$\theta_0$ = amplitude of temperature cycle at exposed surface
 = 30°F.

$\mu$ = Poisson's ratio for concrete
 = 0.15 for slowly applied stress.

Substituting the values, F = 883

Assuming a diffusivity value of 0.009 C.G.S. units, the Thomlinson's relationship gives $\alpha$, the depth function, equal to 0.53 for $h$ equal to 3.6, and $\alpha$ equal to 0.62 for $h$ equal to 4.0.



TABLE 6

**Combined stresses for 3.6 in. and 4.0 in. thick concrete slabs**

| Thickness of slab in inches. | Modules of subgrade reaction in lb per sq. in. per in. | Load Stresses in lb per sq. in. due to | | | Temperature stresses in lb per sq. in. | Combined stresses in lb per sq. in. due to | | |
|---|---|---|---|---|---|---|---|---|
| | | Corner loading $\sigma_c$ | Edge* loading $\sigma_e$ | Interior loading $\sigma_i$ | | Corner loading | Edge loading | Interior loading |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| 3.6 | 175 | 823 | 591 | 407 | 221 | 823 | 812 | 628 |
| | 300 | 695 | 537 | 366 | 221 | 695 | 758 | 587 |
| | 400 | 616 | 492 | 344 | 221 | 616 | 713 | 565 |
| | 550 | 518 | 477 | 320 | 221 | 518 | 698 | 541 |
| 4.0 | 175 | 721 | 504 | 350 | 255 | 721 | 759 | 605 |
| | 300 | 628 | 459 | 316 | 255 | 628 | 714 | 571 |
| | 400 | 568 | 435 | 298 | 255 | 568 | 690 | 553 |
| | 550 | 499 | 411 | 278 | 255 | 499 | 666 | 533 |

* These stresses are reduced by 25 per cent.

Referring to Table 63 of "Concrete Roads" by Sparkes and Smith, for the values of $a$ mentioned above, the stress constants are 0.251 and 0.289 respectively. By multiplying the stress factor (i.e., 883) by these stress constants, the maximum tensile stress developed due to temperature works out to 221 lb per sq. in. for 3.6 in. thick concrete slab and 255 lb per sq. in. for 4 in. thick concrete slab.

### 6.4. Combined Stresses

The combined stresses due to load and temperature are given in Table 6.

It is assumed[1] that the stresses due to edge loading can be reduced by 25 per cent on account of availability of increased subgrade support and, that in the case of corner loading, temperature stresses can be neglected while working out combined stresses.

### 6.5. Estimated Flexural Strength of the Concrete at 28 Days Life and at the Time of Cracking

Except compressive strength values at 28 days of the concrete used for the slabs under discussion, no flexural strength values are available from the P. W. D. records. As flexural strength values are used for the design of the slab, an attempt has been made to predict the probable flexural strength values at the time of cracking, i.e., at about 2 years period and at 28 days life using the relationships[3] as given in "Concrete Road Construction" by the Road Research Laboratory, U.K. Even though it is fully realised that the same relationship may not hold good for all types of concrete, in the absence of any better data, the same is used for arriving at the probable values of flexural strength at the time of cracking for purposes of crack expectancy calculations.

From the study of Table 2, it can be seen that the concrete pavement laid over the black subgrade soil has cracked after being subjected to one to three monsoon periods at an average life of 2 years. The average flexural strength of concrete beams taken out from sound slabs at the age of about 4 years is 1000 lb per sq. in.

For flexural strength, the concrete beams in this investigation were tested with single point loading while the standard practice is to test them with two-point loading. According to Sparkes and Smith[1], the values obtained in the former case are about 20 per cent higher than in the latter case. Hence applying this

Photo 1.
**A typical longitudinally cracked road section**

Photo 2.
**Concrete cutter machine in operation**

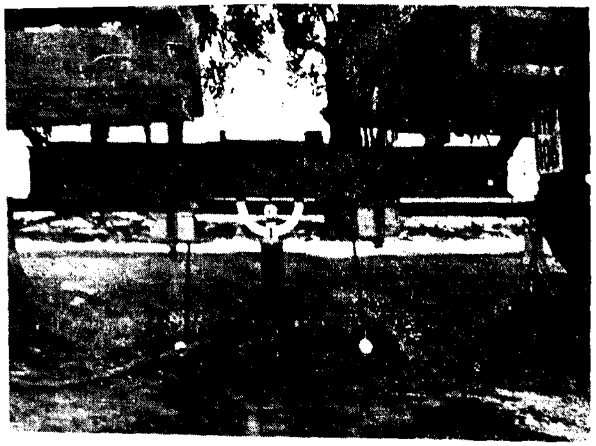


Photo 3.
A set-up of plate-bearing test

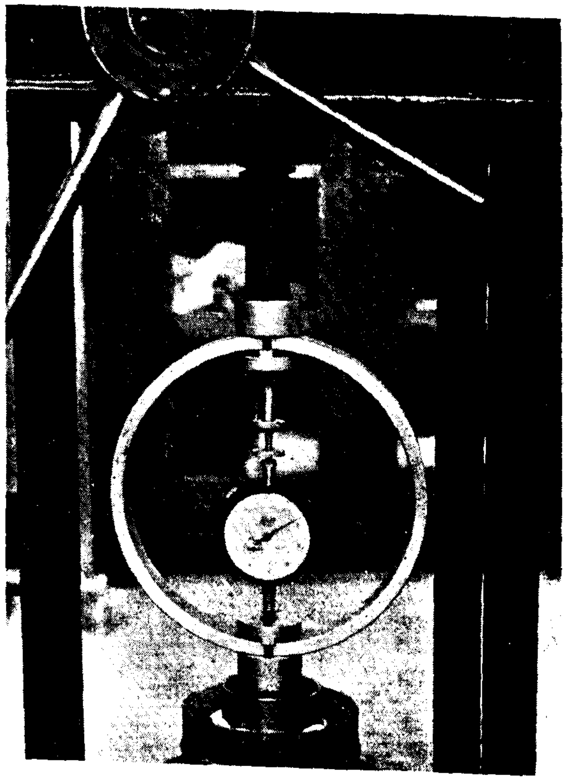


Photo 4.
A set-up of swelling pressure test



correction, the flexural strength of the concrete at the age of 4 years comes to 833 lb per sq. in.

The crushing strength of 6 in. concrete cubes at 28 days at the time of construction varied from 3100 to 5800 lb per sq. in., the average value being about 4200 lb per sq. in. Referring to the curves given by Gonnerman and Lerch[4] showing relationship between age and strength of concrete, for concrete of compressive strength of 4200 lb per sq. in. at 28 days, the strength values at the age of 2 and 4 years are estimated to be about 6,700 and 7,200 lb per sq. in. respectively.

The Road Research Laboratory, U. K., have shown that the relationship between flexural strength and compressive strength[3] can be expressed by

$$F_t = K\sqrt{F_c}.$$

where $F_t$ = flexural strength of concrete in lb per sq. in.

$F_c$ = compressive strength of concrete in lb per sq. in.

$K$ = constant, the value of which depends upon the design mix and the materials used.

For $F_t = 833$ lb per sq. in. and $F_c = 7200$ lb per sq. in. at the age of 4 years, $K$ works out to 9.82. Using this value of $K$, the flexural strength values of the concrete at the time of construction, i.e., 28 days strength and at the time of cracking of the pavement, which is taken on average as 2 years come to about 640 and 800 lb per sq. in.

### 6.6. Calculations for Crack Expectancy

Taking advantage of Bradbury's[5] theoretical consideration for calculating crack expectancy in concrete pavements, and based on the estimated flexural strength of the concrete slabs at the time of cracking, an attempt has been made to understand the reasons for cracking at such an early stage, using the popularly known theoretical considerations.

For purposes of calculations of crack expectancy, the following considerations have been made with the assumptions mentioned. Even though innumerable points can be raised for and against the validity of these assumptions, this section is included mainly to create interest in this direction and to get more data with a view to have better understanding of this phase of the subject.

The width of the concrete pavement is only 12 ft and the number of fast-moving vehicles per day is of the order of about 150 vehicles in either direction. The traffic being so scarce, the majority of the vehicles generally use the central portion of the pavement. The 4 ft wide haunches are used only for the purpose of overtaking and crossing over. Under such circumstances, the chances for the traffic to use the edge of the pavement are rare compared to the use of the central 6 ft track. For the purpose of calculation of the stresses due to the largest number of repetitions, the central track which stimulates the interior loading of the slab is taken into account.

### ASSUMPTIONS

i. The maximum daily temperature differential of positive sign exists for a period of 2 hours.

ii. For the region in which the road under consideration is located, and for the purpose of calculating fatigue based on load and thermal stresses, the following assumptions have been made for temperature differentials occurring round the year.
Two summer months during the hottest 2 hrs. the temperature differential 30°F.
Remaining 10 months, during the hottest 2 hrs. the temperature differential 20°F.
Rest of the 22 hrs. of the day in the entire year on average, the temperature differential 10°F.

iii. For arriving at the zone subjected to most repeated stresses, two feet wide tracks with the centre to centre distance as 6 ft and spaced symmetrically with respect to the central line of the pavement are taken into consideration.

iv. Considering 2 ft width of the wheel track and 6 in. tyre width, four coverages are considered for purpose of calculating the total repetitions for the most severe section.

Considering all these assumptions, the factors in the three cases of temperature differentials are worked out and presented in Table 7, which are used for calculating the annual wheel load repetitions for estimating the crack expectancy period.

The number of repetitions of different categories of wheel loads worked out from the traffic census along with the combination of interior load and temperature stresses for both the slab thicknesses of 3.6 in. and 4 in. for $k$ value equal to 400 lb per sq. in. is given in Tables 8 and 9.



TABLE 7

**Calculation of factors based on temperature differentials**

| Temperature differential (1) | Factor (2) |
|---|---|
| 30°F. | $2/12 \times 2/24 \times 1/4 = 1/288$* |
| 20°F. | $10/12 \times 2/24 \times 1/4 = 5/288$ |
| 10°F. | $12/12 \times \frac{22}{24} \times 1/4 = 11/48$ |

* For example,

i. Two summer months per year $= 2/12$

ii. Hottest 2 hours per day $= 2/24$

iii. Repetition of 6 in. wide tyre on any section of 2 ft wide track $= \frac{1}{4}$
Factor $= 2/12 \times 2/24 \times \frac{1}{4} = 1/288$

The flexural strength of concrete at the age of 2 years, i.e., at the time of cracking, is about 800 lb per sq. in. If the applied stress is less than 50 per cent of the flexural strength, the pavement can take infinite number of wheel load repetitions. Hence only the 4480 and 6720 lb wheel loads need be considered.

The probable crack expectancy values for both the thicknesses under consideration are given in Tables 10 and 11 using the fatigue test results [5] as given in Fig. 5.

### 6.7. Discussion

6.7.1. The calculated maximum combined stresses in a 4 in. thick concrete pavement caused by the corner and edge loadings are 721 and 759 lb per sq. in. respectively. The estimated flexural strength at 28 days life, i.e., at the time of opening the road to traffic, is only 640 lb per sq. in. Though it is realised that there are several unknown factors in the calculations of induced stresses and flexural strength values, the significant excess of induced stresses over the flexural strength of concrete indicates that the design thickness of 4 in. for many of the concrete roads in this country is not enough, especially when it is taken into account that the wheel loads as well as the traffic intensities are going to increase at a rapid pace.

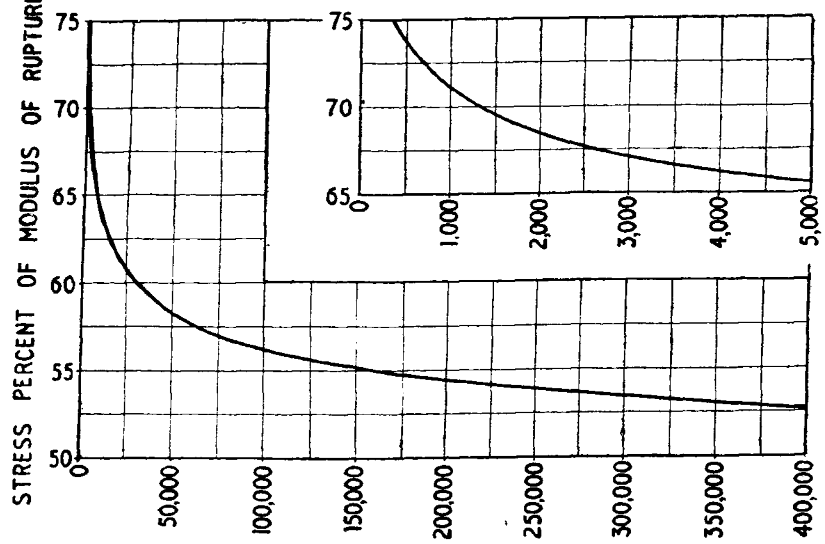



Fig. 5. **Fatigue curve for plain concrete in flexure**

(REPRODUCED FROM REINFORCED CONCRETE PAVEMENT BY R. D. BRADBURY)



TABLE 8

**Calculation of combined stresses due to different wheel loads and temperature differentials and of actual wheel load repetitions per year for a slab thickness of 3.6. inch**

| Wheel load in lb | No. of repetitions per day | Stresses in lb per sq. in. | | | | | | | Actual repetitions per year | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\sigma i$ | $\sigma t_{10}$ | $\sigma t_{20}$ | $\sigma t_{30}$ | $\sigma i+\sigma t_{10}$ | $\sigma i+\sigma t_{20}$ | $\sigma i+\sigma t_{30}$ | $t_{10}$ Factor 11/48 | $t_{20}$ Factor 5/288 | $t_{30}$ Factor 1/288 |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| 1120 | 1000 | 57 | 74 | 148 | 221 | 131 | 205 | 278 | — | — | — |
| 2800 | 300 | 144 | 74 | 148 | 221 | 218 | 292 | 365 | — | — | — |
| 4480 | 125 | 230 | 74 | 148 | 221 | 304 | 378 | 451 | — | — | 156* |
| 6720 | 75 | 344 | 74 | 148 | 221 | 418 | 492 | 565 | 627 | 470 | 94 |

* For example, calculation of actual annual repetitions for 30°F. temperature differential for the wheel load of 4480 lb—125 × 365 × 1/288 = 156.

TABLE 9

**Calculation of combined stresses due to differential wheel loads and temperature differentials and of actual wheel load repetitions per year for a slab thickness of 4.0 in.**

| Wheel load in lb | No. of repetitions per day | Stresses in lb per sq. in. | | | | | | | Actual repetitions per year | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\sigma i$ | $\sigma t_{10}$ | $\sigma t_{20}$ | $\sigma t_{30}$ | $\sigma i + \sigma t_{10}$ | $\sigma i + \sigma t_{20}$ | $\sigma i + \sigma t_{30}$ | factor 11/48 | factor 5/288 | factor 1/288 |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| 1120 | 1000 | 50 | 85 | 170 | 255 | 135 | 220 | 305 | — | — | — |
| 2800 | 300 | 124 | 85 | 170 | 255 | 209 | 294 | 379 | — | — | — |
| 4480 | 125 | 199 | 85 | 170 | 255 | 284 | 369 | 454 | — | — | 156 |
| 6720 | 75 | 298 | 85 | 170 | 255 | 383 | 468 | 553 | — | 470 | 94 |



TABLE 10

**Determination of crack expectancy period for a slab thickness of 3.6 in.**

| Induced stress in lb per sq. in. (Refer Table 8) | Per cent of flexural strength | Actual repetitions per year | Repetitions required to cause rupture | Equivalent repetitions |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| 451 | 56.4 | 156 | 90,000 | = 156 |
| 418 | 52.3 | 627 | 420,000 | $627 \times \frac{90,000}{420,000} =$ 135 |
| 492 | 61.5 | 470 | 16,000 | $470 \times \frac{90,000}{16,000} =$ 2,640 |
| 565 | 70.6 | 94 | 1,100 | $94 \times \frac{90,000}{1,100} =$ 7,700 |
| | | | | Total 10,631 |

$$\text{Crack expectancy period} = \frac{90,000}{10,631} = 8\tfrac{1}{2} \text{ years.}$$

TABLE 11

**Determination of crack expectancy period for a slab thickness of 4.0 in.**

| Induced stress in lb per sq. in. (Refer Table 9) | Per cent of flexural strength | Actual repetitions per year | Repetitions required to cause rupture | Equivalent repetitions |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| 454 | 56.8 | 156 | 80,000 | = 156 |
| 468 | 58.5 | 470 | 45,000 | $470 \times \frac{80,000}{45,000} =$ 835 |
| 553 | 69.1 | 94 | 1,600 | $94 \times \frac{80,000}{1,600} =$ 4,700 |
| | | | | Total 5,691 |

$$\text{Crack expectancy period} = \frac{80,000}{5,691} = 14 \text{ years.}$$

6.7.2. The crack expectancy period even for the road sections which are sound at present is expected to be of the order of $8\frac{1}{2}$ to 14 years depending upon the actual thickness of the concrete slab which varied between 3.6 in. to 4 in. These calculations are based on the traffic intensity prevailing in 1956. From the past experience, it is reasonable to believe that there will be increase in traffic volume as time passes and thus the crack expectancy period becomes even less than $8\frac{1}{2}$ to 14 years.

From the point of economical and other considerations the present trend is to design concrete pavements to serve 30 years or even more. The low value of crack expectancy period again suggests that the 4 in. thick concrete pavement is not sufficiently strong to give a serviceable life of 30 years and more for our fast increasing traffic.

6.7.3. Even though the crack expectancy period of the road under investigation, based on the usual assumptions of the theory, is about $8\frac{1}{2}$ to 14 years, the concrete pavement sections laid over the black subgrade soil have cracked in about 2 years' time, whereas slabs laid on red soils under similar conditions are performing satisfactorily so far. This shows that in the particular case of black soil subgrade, there are other factors involved apart from those which have been taken into account in the theoretical calculations presented in this Paper. From the laboratory investigations as presented in Table 5 the excess swelling and shrinkage characteristics of the black soil causing uneven subgrade support is probably the main reason for early crack development of the cement concrete slabs laid on black soil areas.

## 7. DISCUSSION OF TEST RESULTS

### 7.1. Flexural Strength of Concrete Beams

A study of Table 4 shows that the concrete slabs laid on red subgrade soil have an average flexural strength of concrete of 1007 lb per sq. in. within a range of 1118 to 913 lb per sq. in. at the time of investigation, i.e., at about 4 years life. The slabs laid on black subgrade soil indicated an average flexural strength of 865 lb per sq. in. within a range of 1020 to 614 lb per sq. in. Since the construction of the concrete pavement was done by the same agency continuously as per the same specifications, and as the two types of subgrade soils occur intermittently within short intervals, the difference in flexural strength values for concrete slabs laid on the two subgrade soils is probably due to the fatigue received by the slabs over the black soil subgrade which have



cracked compared to the slabs laid on red soil subgrade which are still in sound condition.

As no tests were conducted for finding the flexural strength of concrete at the time of construction, the estimated strength by calculation both at the time of cracking and at 28 days life are given in para. 6.5.

### 7.2. Modulus of Subgrade Reaction

The average value of the modulus of subgrade reaction *i.e.* $k$ value for the sound sections covered by this study, laid on the red subgrade soil is 432 lbs. per sq. in. per in. within a range of values of 545 to 309 lbs. per sq. in. per in., while that for the cracked sections works out to 297 lbs. per sq. in. per in. within a range of values from 396 to 175 lbs. per sq. in. per in. For this difference in '$k$' values obtained on the two types of subgrade soils, the tensile stress developed in a 4-in. thick concrete slab laid on the black soil subgrade works out to be about 7 per cent greater for the same wheel load than that developed in a slab laid on the red soil subgrade.

### 7.3. Dry Bulk Density of the Subgrade Soils

In the case of black subgrade soil, the dry bulk density varies from about 97.5 to about 111.4 lbs. per cu. ft. With the red subgrade soil, the average dry bulk density varies from about 88.4 to about 106.5 lbs. per cu. ft.

### 7.4. Moisture Content of the Subgrade soils

The average moisture content at the time of testing for the black soil works out to 14.0 per cent within a range of 8.7 per cent to 18.4 per cent while that for the red soils is 9.8 per cent within a range of 8.1 per cent to 13.5 per cent.

### 7.5. Per cent swelling and swelling pressure

A study of Table 5 shows that the per cent swelling and the swelling pressure both increase with the dry bulk density of the subgrade soil. Fig. 4 indicates that within the range of saturation moisture, the swelling pressure of a soil of given dry bulk density increases with the increase in moisture content.

The difference in the values of per cent swelling and swelling pressure, in the case of the two soils, appears to be quite significant. Comparing the black and red soils at the same dry bulk density, the values obtained in the case of black soil are higher than those obtained with red soil. The high swelling property of the black soils seems to be the principal cause of failure of the pavement.

Since the failures are mostly occurring during the withdrawal of the monsoon from the region and since the pavement is provided with 4 ft deep drains on both sides due to the rapid rate of evaporation of moisture from the sides, i.e., from the edges than from the centre of the pavement, especially in the case of clay soils such as the black and red soils covered by this investigation, it is quite logical to expect a moisture gradient from the centre to the edge of the pavement. For example assuming a moisture content of 20 per cent at the centre and 12 per cent at the edges, the approximate relative swell pressures that can be expected at an average dry bulk density of 100 lbs. per cu. ft. are presented in Table 12.

TABLE 12

**Swelling pressures of black and red soils at a dry bulk density of 100 lb. per cu. ft. at different moisture contents**

| Type of soil | Swelling pressure in tons per sq. ft. | |
|---|---|---|
| | Centre of slab at 20 per cent moisture content | Edge of slab at 12 per cent moisture content |
| (1) | (2) | (3) |
| Black soil | 0.75 | 0.225 |
| Red soil | 0.15 | 0.075 |

Another interesting feature of the two subgrade soils, that is brought out from the laboratory tests is the difference in the time required for saturation in the two cases. The black soil requires more time to get saturated than the red soil. It is reasonable to expect a similar phenomenon during the drying process also, giving steeper moisture gradient in the case of black soil than in the case of red soil. Thus with the drying up of the soil subsequent to the withdrawal of the monsoon, steeper moisture gradient in the black soil will give higher difference in swelling pressures between the values at the centre and at the edges of the concrete slab than that in the case of the red soil.



In the background of the above mentioned phenomenon and with the information presented in Table 12 regarding differential swelling pressure from centre to edge calculated for a general case, it is easy for one to visualize that the seriousness of this aspect is more in the case of black soils than in the case of red soils.

Even though it is common for both the types of soils, another factor that might be coming into play is the differential degree of confinement of the subgrade soil in the centre of the slab and at the edges. The edges are exposed on account of the provision of 4 ft deep drains. The soil in the centre of the slab being confined on all sides is likely to exert more upward thrust than the soil at the edges.

## 8. PROBABLE CAUSES OF FAILURE

Under the influence of the vertical thrust values caused by the differential swelling on the one hand and non-uniform shrinkage during the drying period on the other, the concrete slab will not be supported uniformly. The support that the subgrade is likely to offer particularly in the case of black soil may be visualised as shown in Fig. 6.

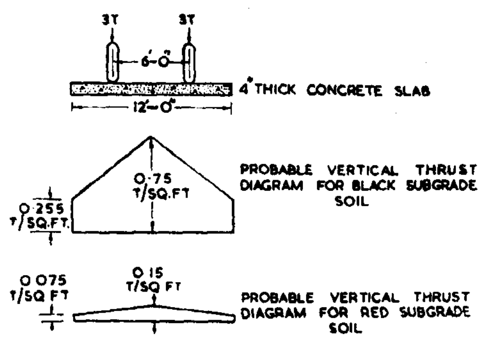



Fig. 6.

**Probable mechanism of longitudinal cracking of concrete slab**

Under the action of the rear wheels of an 8½ ton bus and the uneven support offered by the subgrade, the concrete slab laid over the black subgrade soil is likely to crack longitudinally with tension being developed at the top of the slab. It appears that under similar conditions of smaller upward thrust differentials, the concrete slab laid over the red subgrade soil does not develop critical flexural stresses so as to crack longitudinally. The values of swelling pressures as determined in the laboratory are not absolute but only comparative. Hence it is not possible to determine precisely at what differential subgrade support values the concrete pavement cracks.

The non-significant differences in the flexural strength of concrete slabs laid over the black and red subgrade soils, and in the moduli of subgrade reaction obtained over the metal crust overlying the black and red subgrade soils, and the significant differences in per cent swelling and swelling pressures of red and black soils confirm that the cracking observed in the concrete slabs laid over the black subgrade soil may be due to excessive swelling and shrinkage characteristics of the black soil, resulting from moisture differentials of the subgrade from centre to edge of the pavement.

## 9. SUGGESTIONS

### 9.1. Remedial measures for the already existing concrete pavements constructed on highly expansive soils.

#### 9.1.1. For concrete pavements constructed on expansive soils and which are already in the advanced stage of cracking but still retaining the aggregate interlock at the cracks.

(i) Enveloping the foundation region of the concrete pavement, right up to the equilibrium moisture depth, with an impervious layer such as treatment with straight run bitumen, primer, heavy duty tar felt etc. with a view to minimise the moisture variation in the subgrade soil during the service period ; and

(ii) Strengthening the pavement by a suitable overlay.

#### 9.1.2. For all concrete pavements constructed on expansive soils with and without initial stage of cracking.

(i) Enveloping the foundation region of the concrete pavement, right up to the equilibrium moisture depth with an impervious layer as described under 9.1.1 (i) of these recommendations.

(ii) In cases where the cracking has not yet started, cutting a central longitudinal joint may help in avoiding development of unsightly cracks, thus facilitating easy maintenance.

(iii) Wherever the concrete road slabs are only 4 in. thick on such expansive soils and are carrying loads of the order of 8 to 10 ton vehicles, strengthening the same straight-away by suitable overlays is recommended if a service life of more than about 15 years is expected.

### 9.2. Precautionary measures for new constructions of concrete pavements on expansive soils.

(i) In cases where only a small quantity of highly expansive soil is involved, the easiest method is its complete removal, if the same is economically feasible.

(ii) If the swelling pressures are not excessive, a layer of non-expansive type soil over the expansive soil subgrade may be laid in suitable thickness so as to eliminate the swelling influence.

(iii) Treating such soils with lime up to suitable depths.

(iv) Provision of longitudinal joints at closer spacing than the conventional spacing of 12 feet.

(v) Enveloping the foundation region by an impervious layer up to the equilibrium moisture depth.



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A Note for Panel Discussion

# "ROADS IN WATERLOGGED AREAS"

*By*

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CONTENTS



## 1. INTRODUCTION

Waterlogging is unfortunately spreading fast in certain areas. Besides damage to agriculture, it is causing progressive deformation of roads which have so far carried the traffic successfully. The urgent problems are :

(a) How to treat existing roads in such areas which are rapidly deteriorating.

(b) What precautions to take on new roads in such areas.

This note, which is of the nature of a field study only, attempts to outline some specific remedies for both the conditions stated above.

The note may appear to be sketchy. but the problems involved being urgent and there being no time available for long range studies, it is felt that it will have served its purpose if, in the light of a free and open discussion in the I. R. C. Session, it can provide the basis for an I. R. C. tentative specification for roads in waterlogged areas.

## 2. GENERAL

In recent years, it has been noticed that large scale damage is occurring on many miles of roads in certain areas, as a result of the effects of waterlogging accentuated in many cases by flooding. An additional contributory cause of damage is the presence of detrimental salts in some waterlogged areas.

With a view to analyse the processes involved and therefrom to suggest experimental work on possible remedies, the following damaged roads were studied in detail:

TABLE 1

**Particulars of roads studied in U. P.**

| S. No. | District | Name of the road |
|---|---|---|
| 1. | Meerut | Meerut-Bhaghpat |
| 2. | ,, | Modinagar-Hapur |
| 3. | ,, | D/M Road |
| 4. | ,, | Meerut-Mowana |
| 5. | ,, | Muzaffarnagar-Bijnor |
| 6. | Etawah | A. E. F. Road |
| 7. | Mainpuri | Etawah-Mainpuri |
| 8. | ,, | E. F. Road to Karhal |
| 9. | Bulandshahr | Sikandarabad-Dankapur Road |
| 10. | ,, | Bulandshahr—Jhajher |

TABLE 2

**Particulars of roads studied in Punjab**

| S. No. | District | Name of the road |
|---|---|---|
| 1. | Rohtak | Delhi-Hissar—Sulemanki Road, mile 42 between Jat College Hostel and Canal Bridge |
| 2. | ,, | Sonepat-Kharkandar Road |
| 3. | ,, | Sonepat-Guhana Road |
| 4. | ,, | G. T. Road 23/0 to 25/0 |

It seems that with more and more introduction of irrigation channels running above the level of the adjoining country with



insufficient drainage outlets, vast areas have become victims of waterlogging and flooding. It goes without saying that unusual rains in some years still worsen the situation. The continuous supply of seepage water from such well-netted irrigation channels, insufficient drainage facilities from such grids blocked by either canal bunds, railroads or highway embankments, have become the potential factors for creating waterlogged conditions and flooding for most of these areas. The seriousness of this waterlogging is aggravated by the general practice of constructing highways flush with the adjoining land in these areas. As a result of some of these factors the water table is rising from time to time and in some places the water table was as high as one to two feet below the ground level at the time of inspection. Local enquiries indicated that during the monsoon period, the water table was observed at still higher levels.

### 3. NATURE OF THE DAMAGE CAUSED TO ROADS BY WATERLOGGING

The damage to roads by waterlogging appears to be on account of the fact that due to the rising water table in such areas, the capillary moisture wets the subgrade soil to varying degrees, reducing its bearing value accordingly, at different times of the year. The prevailing traffic loads, which after dispersion through the pavement were successfully supported by the comparatively dry subgrade before, cause a certain amount of deformation now, when the subgrade is moistened by capillary moisture and has, therefore, less bearing value. This deformation of the subgrade is reflected on the surface of the pavement and goes on increasing with repetition of loading due to traffic.

The deformation is maximum during the period when the subsoil water level is highest in the yearly cycle.

This progressive deformation is, in some cases, accentuated by ingress of water from the top of the surface, where, due to prolonged flooding and passing of water over the bituminous surface, stripping of the binder takes place and results in destroying the waterproofness of the surface treatment. This permits ingress of moisture from the top as well which, in addition to further softening the subgrade, also helps the traffic in causing a failure of the road crust itself.

In areas infested with detrimental salts like sodium sulphate and to a lesser extent magnesium sulphate and sodium carbonate, the salts keep moving up with capillary moisture, and when the concentration of such salts towards the exposed pavement becomes sufficiently high, damage can be caused to the pavement. The damage is caused as a result of repeated hydration and dehydration of the salt under suitable temperature and humidity conditions, and the consequent repeated increase and decrease in the volume of the salt lodged in the voids causes destructive movement under the pavement and in some cases in the pavement itself.

## 4. REMEDIAL MEASURES

The remedial measures would appear to lie in the following directions :

(a) To depress the level of subsoil water, where possible, by drainage.

(b) To increase the thickness of the road crust, so much that the prevailing traffic loads, after dispersion through the thickness of the crust, become so low that the subgrade soil in its saturated condition can safely support them.

(c) To provide a capillary cut off, to arrest the moisture fluctuations and the upward movement of detrimenta salts in salt infested areas.

### (a) Depressing of water table

If the water table can be depressed by drainage, it will improve the bearing value of the subgrade considerably and arrest further damage. A self sufficient drainage system for draining the roads only may be expensive in many cases. But, in view of the fact that the irrigation departments concerned are already launching proper drainage schemes for reclamation of waterlogged areas, it would be well worth investigating whether road boundary drains 5 or 6 feet deep could be connected up with the irrigation drainage system, without undue cost. The road land on both sides of the road should obviously be sloped towards the boundary drains.

These drains will not only keep draining the subsoil water during dry weather, but will also ensure speedier run off during rains, thus reducing considerably the rise in subsoil water level during monsoons.

This measure should obviously be adopted immediately, wherever economically feasible, and where excessive damage to road has not already taken place, because it is likely to go a long way in arresting further damage and in prolonging the useful life of the road,



### (b) Increase in thickness of pavement

The C.B.R. or any other accepted method of design of thickness of flexible pavements can be used for determination of the total hard crust or moisture resisting thickness of pavement required over the saturated subgrade. This should apply obviously to all new construction and reconstruction of completely failed pavements.

As the failed pavement will have already got badly deformed, the obvious thing to do would be to dig up the existing pavement and to redesign the thickness with a view to reuse as much of the old material as is fit for use, by adding fresh material as required. As much of this thickness should be made up with compacted soil as design will allow.

In the case of lengths of road which have suffered only partial damage and the riding quality has so far not been too badly affected, it would obviously be a question for consideration as to whether an increase in thickness of the pavement should be immediately provided and, if so, whether the increase required by design should be affected by adding water resisting hard crust to the existing pavement, or whether the pavement should be dismantled and reconstructed with old and new material, using compacted soil in the lower layer.

If the increase required is a matter of 3 or 4 inches only and the existing surface is not badly deformed, it would perhaps be best to add this small thickness straightaway to the existing pavement in surface treated water-bound macadam. If, on the other hand, the required additional thickness is considerable, it would perhaps work out much cheaper and more satisfactory to dig up and reconstruct the pavement by using compacted soil and soft local aggregates in the lower layers and the dug out soling and macadam in the upper layers by adding a little fresh material and surface dressing the road.

In the latter case, the existing pavement could continue to be used as long as ordinary patch repair could maintain a reasonable riding surface. Drainage could help a case like this very considerably.

### (c) Capillary cut off

A capillary cut off is absolutely necessary in waterlogged areas which are infested with detrimental salts (sodium sulphate and, to a lesser extent, sodium carbonate).

If it is found that the necessary additional thickness can be provided by adding a few inches of macadam to the existing surface treated pavement, then the bituminous surfacing which is already there, if properly patched up and revived as required, will be a very effective cut off. For proper bond of the water-bound macadam with the bituminous surface, a thin bituminous tack coat is to be provided in any case as a seal which automatically revives the surface.

In cases where the existing pavement is to be dug up and reconstructed, the cut off can be provided either by a layer of coarse sand or a very thin layer of bitumen impregnated soil.

The thickness of sand layer can be worked out as given in Appendix 1.

It will be seen that unless the sand available is very coarse the thickness required will be excessive.

Bituminous impregnation is carried out by spraying shell primer No. 1 (50 per cent bitumen 80/100 + 50 per cent high speed diesel oil) or its equivalent in two sprays of 20 lb per 100 sq. ft. each, allowing the first spray to penetrate before putting on the second. The sides of the crust are to be similarly treated.

The capillary cut off should be placed below the compacted soil layer of pavement to take additional advantage of keeping moisture out of this layer.

## 5. PHASED PROGRAMME

It is obvious that the entire length of the roads in the vast areas which have become waterlogged cannot be reconstructed at once due to the limited funds available for the purpose.

The following general recommendations are, therefore, made for adoption as a phased programme:

### (i) Waterlogged areas not subject to flooding

As an immediate measure, 5 to 6 feet deep drainage channels should be dug on the road boundary in waterlogged areas wherever it is possible to provide suitable out-falls either by connecting with natural drainage or with irrigation drainage system, existing or under contemplation.

### (ii) Provision of suitable thickness of the crust

The total thickness of crust required over a saturated sub-grade should be designed for each area, using as much compacted soil and soft local aggregate in the lower layers as design criteria will allow. (A typical design is attached, Appendix 2.)



Where the additional thickness required is of the order of 3 or 4 inches only, this should be provided immediately as surface treated water bound macadam over the existing surface after patching up as required.

Where the existing pavement has failed already and is due for renewal, it should be constructed as per above design and the existing dug out material used, as far as possible, in the upper layers with addition of some new material. All new construction should be properly designed.

### (iii) Improved drainage

Where the existing pavement is still serviceable, and the designed additional thickness is considerable, suitably connected side drainage should be provided, if possible, and the surface maintained by patching at a reasonable level of riding quality till it becomes too expensive to do so.

Then action for reconstruction as at (ii) above should be taken.

### (iv) Salt infested waterlogged areas

Where detrimental salts exist in waterlogged areas, a capillary cut off should be provided below the compacted soil layer, forming part of the designed pavement thickness, and on the sides.

Calculated thickness of coarse sand or two sprays of suitable bituminous primer at the rate of 20 lb per 100 sq. ft. for each spray is recommended.

### (v) Waterlogged areas liable to flooding

In those lengths where prolonged flooding over the existing road is likely to be allowed as a drainage measure, a double lane concrete surfacing of designed thickness is necessary, as any bituminous surfacing under these conditions is likely to suffer from stripping of binder and consequent serious damage to the pavement.

Those lengths which have to be reconstructed and are not required to be kept low for drainage purposes should obviously be given a free-board of about one foot or so above normal flood level.

Those lengths which cannot be reconstructed immediately should with advantage be given a thin spray of binder just before the flood season to reinforce the surface against stripping.

### Appendix 1

## Method of Calculating the Required Thickness of Sand Layer for Capillary Cut Off

The thickness of sand to stop the capillary rise of moisture can be determined in the laboratory by means of a capillarimeter. Photo 1 shows the general set up of a capillarimeter. This consists of sintered glass funnel the lower end of which is joined with a rubber tube to a sliding burette tube against a graduated brass scale. There is a rack-and-pinion arrangement worked by a thumb screw which moves a pointed needle against the brass scales as well as the burette scale. The funnel is filled with water by inserting a rubber bung at the top, inverting it, and joining it to the rubber tube leading to the burette. The connecting rubber tube is kept full of water when it is joined to the funnel, and if the burette tap is kept slightly open, the flow of water insures an air-free joint. It is essential that no air be allowed to remain at the lower surface of the filtering disc. Excess water is removed from the funnel and is replaced by a quantity of sand to give a layer about 0.5 cm. thick with some free water standing on top.

At the start, the level of water on top of the sand and the burette is the same. The burette tube is lowered in steps of 1 cm. or so and the rise of water is noted in terms of the graduation on the tube. As the burette tube is lowered, the pointed needle is raised with the thumb screw so that any rise of water is compensated and the reading on the brass scale gives the true values of pressure deficiency which the sand is subjected. Obviously, as long as there is free water, there is very little change in the scale reading because of this compensating device. As soon as the free water disappears the tension produced by the lowering of the burette tube is taken up by the surface tension of the water and any difference in the scale reading from the original value gives the true value of pressure deficiency. From this point onward, further lowering of the burette tube causes no rise in the level of the water contained in it. This constant value continues until the pressure difference exceeds the capillary pull of the sand, and the water again begins to rise in the burette tube. The length in centimeters by which the burette is lowered to cause this break in the rise of water gives the thickness of sand layer required.

The thickness can also be obtained by determining the mean diameter of sand after subjecting it to detailed mechanical analysis. The results obtained by both the methods are almost identical. Further details of either of the methods can be had from "Soils—Their Physics & Chemistry" by A.N. Puri, chapter III, Capillary moisture, page 346.

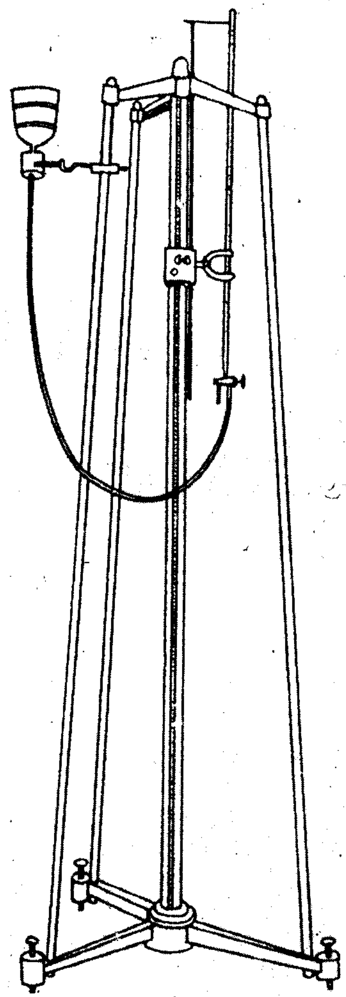


Photo 1
Diagram of the Capillarimeter

**Appendix 2**

## Typical Design for the Total Thickness of Crust Required over the Subgrade Based on California Bearing Ratio Method

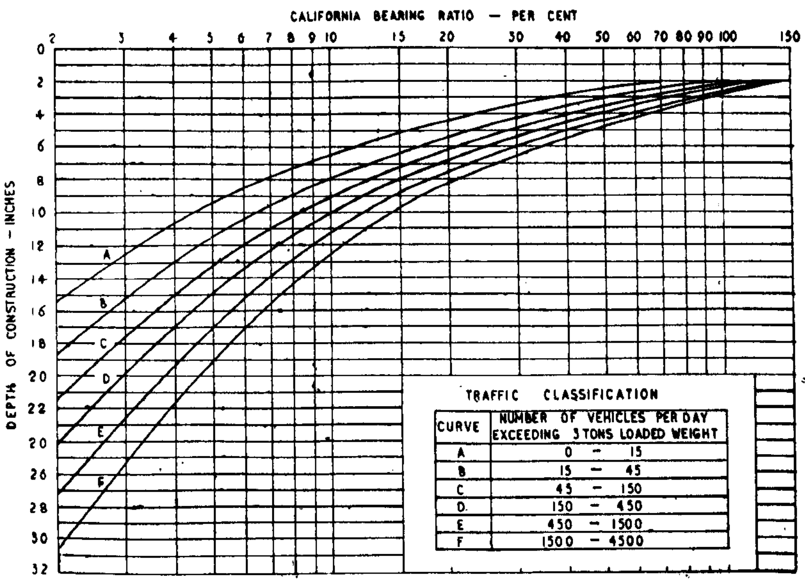
Problem : Requisite thickness of flexible pavement is to be worked out for the following site conditions :

1. Anticipated traffic - About 150-450 commercial vehicles per day (exceeding 3 tons)

2. C. B. R. of subgrade in saturated condition- 3 per cent

3. Other locally available material which can be used in the construction :

i. Local soil from borrow pits - C. B. R. of 9 per cent (compacted)




PROPOSED C.B.R. DESIGN CURVES FOR DIFFERENT CLASSES OF ROAD

Fig. 1.

ii. Local sandy soil * or other locally available soft road materials. - C. B. R. of 15 per cent (suitable as sub-base)

iii. Crushed limestone - C. B. R. of 100 per cent.

**DESIGN**

From the C.B.R. design curve given in Fig. 1.

| | | |
|---|---|---|
| (a) | Total thickness of superimposed layer required over a subgrade (of C. B. R. of 3 per cent) | - 20 in. |
| (b) | Thickness of superimposed layer required over compacted soil from borrow pits (of C.B.R. 9 per cent) | - 11 in. |
| (c) | Thickness of superimposed layer required over sandy soil or other locally available soft road material (of C.B.R. 15 per cent) | - 8 in. |
| (d) | Thickness of superimposed layer required over crushed limestone/locally available stone (of C.B.R. of 100 per cent) | Surface dressing of $\frac{3}{4}$ in. |

Hence the pavement structure should consist of :

1. $\frac{3}{4}$ in. thick surface dressing.
2. $7\frac{1}{2}$ in. or say 7 in. of water-bound macadam including soling according to local practice.
3. 3 in. of sandy soil or other local material (of C.B.R 15 per cent)
4. 9 in. of compacted soil taken from borrow pits (of C.B.R 9 per cent).

Total: 20 in.

* Sandy soil of P. I. about 5 to 7 and sand content not less than 50 per cent either natural or blended or similar thickness of locally available soft material like kankar can be used.

The method given in this example is only one among several others which are in vogue such as the Wyoming method of design etc.

Wherever testing facilities are not available, the typical design given in Appendix 2 may be adopted in the case of poor subgrades. Wherever there are detrimental salts present, a capillary cut off is necessary.



# 1. GAP GRADED CONCRETE FOR PAVEMENT CONSTRUCTION

# 2. SELECTION OF SUITABLE STABILISER FOR CHECKING CAPILLARY RISE OF WATER FROM THE SUBGRADE

# "GAP GRADED CONCRETE FOR PAVEMENT CONSTRUCTION"

*By*

K. S. Sankaran *

## CONTENTS



## SYNOPSIS

The Paper advocates a method of concrete mix design in areas where the locally available sands are poorly graded for purposes of the conventional continuous grading and imported well-graded sands are too expensive for the purpose. The concrete designed by this method is termed Gap Graded Concrete.

The investigation deals with the design of concrete mixes by using four typical sands with poor gradations, on the gap graded principle, wherein the gradation of coarse aggregate is adjusted after deliberately omitting certain particle sizes, so as to accommodate the available sand grading without particle interference. The study indicates that concrete mixes, designed in the above fashion, using the four typical "poor" sands, compare very well with a "standard" continuous graded concrete mix in terms of strength properties. Further, these gap graded mixes seem to actually bring about a saving in cement as compared with the corresponding continuously graded mixes, thereby resulting in further economy.

Gap graded mixes are not suitable for volume batching as normally used in this country. However, the results suggest that a fair trial should be given to gap graded mixes in projects where weigh batching and proper quality controls are contemplated, and in cases where the locally available sands are not properly graded.

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## 1. INTRODUCTION

### 1.1. General

M. Feret established the "laws of discontinuous mixtures" long before Fuller established his curve of maximum density; Fuller's "ideal curve", according to Boyd Mercer, [1] was responsible for the commencement of the landslide against the theory of Feret in the early years of the present century. Most of the research studies that ensued had Fuller's curve as the basis of their design, although Bolomey had modified it with better results. The various investigators that followed focussed their attention on continuous gradation of aggregates and produced many types of continuous gradations of aggregates as are available today—each one depending upon the degree of compromise chosen between the demands of workability and strength.

Few investigators like Coquet, Mc. Neilley, Stewart and others have reverted frequently to the idea of Feret and have found that the use of gap grading theory leads to a better economy of concrete proportioning. Yet, the general consensus of engineering opinion at present is in favour of continuous grading, even though it has been established beyond doubt that gap grading has an important place in the design of concrete mixes.

### 1.2. Definition

Concrete is said to be gap graded (or discontinuously graded concrete) when certain particle sizes in the grading of aggregate are omitted. The absence of certain particle sizes is brought about either (i) by using natural aggregates as they are obtained or (ii) by deliberately introducing them or (iii) by combining both with a view to obtain a better compaction of concrete of low workability, resulting in high quality concrete and economy in the use of cement.

### 1.3. Principle of Gap Graded Concrete

Gilkey [2] and Stewart [3] have recognised that any benefit obtained by the use of gap grading is due to the reduction in the wedging action caused by the omission of intermediate sizes and, to obtain the full benefit, gap graded concrete has to be compacted by vibration.

Williams [4] has pointed out that when a plastic concrete is vibrated, the particles are set in motion, reducing the inter-particle friction and they are in a state of segregation, thereby giving the concrete its mobility. Therefore, in the first stage of



compaction, the subsidence of the mix takes place and during this process bigger sized particles settle down to form a compacted framework of solids. In the next stage of compaction, the smaller particles attempt to penetrate into the voids of the packed aggregates with the aid of the cement grout and de-aeration takes place. The third and the final stage of compaction results in a general stabilization of the green concrete. If the mix is not properly proportioned, materials in excess of the requirement are forced out to the surface.

From the above, it is clear that for full compaction of concrete by vibration with the least amount of work, it is essential that (i) the grading of the coarse aggregate be such that when they settle down to form a network of solids, they should not cause particle interference, (ii) the gradation of the coarse aggregate should be governed by the predominant particle sizes of fine aggregate and (iii) the proper proportioning of the mix should be done.

### 1.4. Advantages

A properly designed gap graded concrete, when fully compacted, according to Stewart[5], would shrink and creep less than a continuously graded one, provided the proportions remain the same, because in the gap graded concrete the coarse aggregate is brought into intimate contact, forming a rigid skeleton which cannot be shortened owing to loss of moisture. Again, the creep is confined in a large degree to the plastic deformation associated with the rock from which the coarse aggregate is derived.

According to Fritsch[6], by making gaps in the gradation, it is not only possible (other conditions being equal) to reduce the required quantity of the cement paste, but also to increase considerably the concrete strength.

Further, in high quality concrete economy is obtained through gap grading as the co-efficient of variation, i.e., the margin between the average and minimum strength, can be reduced. In continuous graded concrete, segregation of different particle sizes normally occurs during handling and transport. This results in variation in the quality and strength of concrete and is taken care of by the margin between the average and the minimum strengths. This margin can be reduced by gap grading, as there are fewer different sized particles and there are lesser possibilities of segregation during handling and transportation.

From the design point of view, the advantage of gap grading is that a coarse aggregate can be built up so as to possess the requisite amount and size of voids to cater to the needs of absorbing the available sand grading. The present practice in mix design is to grade the aggregate (both fine and coarse) in such a manner as to reduce the voids in them to a minimum and thereby reduce the quantity of the cement paste required, so as to produce a concrete mix that is workable for easy placement and compaction with a minimum water-cement ratio. A low void ratio often requires such a small percentage of sand that, except under special conditions of vibrations, the mix cannot be compacted. The gap created in the grading by the omission of certain sizes can be used to open the coarse material so that it can accept a more workable volume of sand as well as a sand of a coarse grading.

## 2. PROBLEM

The general practice in India with respect to concrete proportioning today, although the knowledge of mix design is quite well advanced and appreciated, is to adopt, unfortunately, the conventional 1 : 2 : 4 concrete and the amount of water is stipulated so as to give ½ to 1 in. slump for concrete pavements. However, concrete required for pavements should be of a high quality wherein high strength and uniformity are aimed at. To produce such a concrete, a mix carefully designed, based on the available aggregates and mode of compaction, together with a proper control over the uniformity of the ingredients, method of batching and mixing, placing and curing is desired.

The specification in vogue for the fine aggregates restricts very much the quality of sand in respect of its gradation. Therefore, in many cases, sands have to be brought from far off places and the cost of concrete increases considerably depending upon the lead.

It has been pointed out earlier that good quality concrete can be produced by deliberately introducing proper gaps in the coarse aggregate gradation, while using locally available sands which are considerably "poor" as compared with the specification. The use of vibration, together with the rational design, makes it possible not only to obtain relatively high strength characteristics, but also enables one to use a mix which is leaner by an appreciable amount than that normally employed.

The object of the present study is to illustrate that a high quality pavement concrete can be produced by using gap graded concrete principle, with sands which are considered quite inferior when compared with specification limits and also to compare the



cement content as well as the strength characteristics of such gap graded concrete mixes with those of continuously graded ones.

## 3. MATERIALS

### 3.1. Fine Aggregates (Sands)

The four gradations of sands used in this study are shown below in Table 1 and Fig. 1, and are based on the four zones (see Appendix 1) proposed by Newman and Tychenne[7] and accepted by the British Standards. The individual gradations were so chosen that (1) each gradation falls in each zone, (2) they

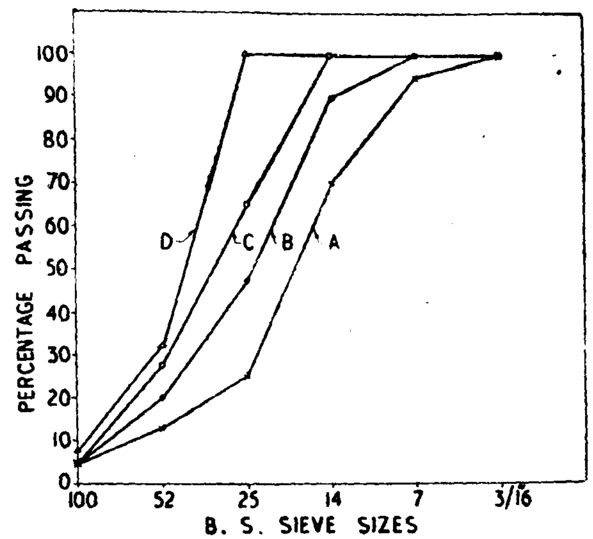


FIG-1. GRADING OF SANDS

produce as much gaps as possible and (3) they follow the medians of the zones where gaps are not provided.

It may be pointed out at this juncture that the gradations have been chosen to represent poor gradations of sands only and the method of selection of the grading has no special significance except that the four gradings fall in the four zones classified by Newman and Tychenne.

The sand used was Badarpur sand, washed, screened into different sizes and recombined to give the desired gradation.

TABLE 1

| Sieve size | Percentage by weight passing | | | |
|---|---|---|---|---|
| | Sand "A" | Sand "B" | Sand "C" | Sand "D" |
| 3/16 in. | 100 | 100 | 100 | 100 |
| B.S.S. No. 7 | 95 | 100 | 100 | 100 |
| 14 | 70 | 90 | 100 | 100 |
| 25 | 25 | 47 | 65 | 100 |
| 52 | 13 | 20 | 28 | 33 |
| 100 | 5 | 5 | 5 | 8 |
| Fineness modulus (F.M.) | 2.92 | 2.38 | 1.92 | 1.59 |

### 3.2. Coarse Aggregate

The coarse aggregate used in the study was Delhi quartzite, a crushed material. The aggregate was washed, sieved and recombined to get the desired gradation.

### 3.3. Cement

Cement was the one obtained from Delhi market. All of it was thoroughly blended together and carefully stored in air-tight containers.

## 4. DESIGN PROCEDURE

### 4.1. General

In the design of the standard mix, as well as the gap graded mixes, the following points were taken into consideration:

1. The water-cement ratio was kept at 0.5, as the water-cement ratio for pavement concrete used abroad generally varies from 0.49 to 0.52[8].

2. The workability of the concrete mix was determined by the Vee Bee apparatus in terms of Vee Bee degrees (refer Appendix 2).



The workability of pavement concrete, generally used in India, is to give ½ to ¾ inch slump, based on the available machinery for compacting the plastic concrete. Therefore, the concrete mixes were designed to give a workability of 11 Vee Bee degrees, which was approximately equivalent to ½ in. of slump.

3. In the standard mix, the gradation of aggregates as given in Road Note No. 4[9] was used. The gradation is given in Fig. 2.

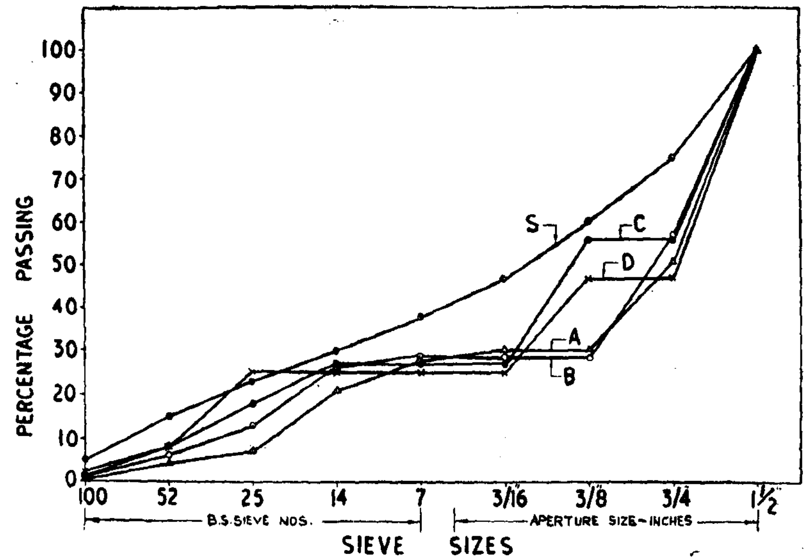


FIG:-2. GRADING OF COMBINED AGGREGATES

### 4.2. Standard Mix

As the gradation of the aggregate is fixed, the operation of designing the standard mix becomes much simplified in that the aggregate cement ratio of the standard mix (i.e.) the cement content of the mix) is varied, keeping the water-cement ratio the same in all cases, so as to obtain the mix which would give the desired workability.

### 4.3. Gap Graded Concete Mixes

#### 4.3.1. Sand content of the mixes

The sand content in the gap graded mixes was as given in Table 2. This was based on preliminary trials made by using the four sand gradings. In the preliminary trials appropriate gaps in the coarse aggregate grading were given depending upon the particle size distribution of fine aggregates. Gap in 3/8 in. to 3/16 in. size group was given while using sands "A" and "B" and gap in 3/4 in. to 3/8 in. size group was given while using sands "C" and "D". The sand contents were varied from 20 to 35 per cent of the total aggregate. The final sand contents were based on visual observations during mixing and handling and on the slumped concrete, the Vee Bee workability and the compacted concrete.

TABLE 2

| Sand | Percentage by weight of combined aggregate |
|---|---|
| A | 30 |
| B | 28.5 |
| C | 27.0 |
| D | 25.0 |

### 4.3.2. The gradation of the coarse aggregate

The coarse aggregates consisted of three sizes (1) $1\frac{1}{2}$ to $\frac{3}{4}$ in. (X) (2) $\frac{3}{4}$ to 3/8 in. (Y), and (3) 3/8 to 3/16 in. (Z) and with each sand gradation under study one size (say Y) was omitted but the ratio between the other two sizes (X & Z) was maintained the same as existing in the original gradation of coarse aggregate for the standard mix.

In gap graded mixes, after fixing the sand content and the gradation of the coarse aggregate, the aggregate cement ratio of the mixes was varied (as in the design of the standard mix) keeping the water-cement ratio constant till the mixes gave the desired workability.

After proportioning the mixes in the above fashion, the ratio between the two sizes was varied and keeping the aggreggate cement ratio constant, the workability was determined. The gradation of the aggregate which gave a high workability (i.e., a lower number of Vee Bee degrees) was taken and then the aggregate cement ratio of the mix was varied to give the desired workability.



The above process had to be done since the ratio between any two sizes of coarse aggregates is a function of the sand content of the mix (vide para. 1.3).

4.4. The concrete was mixed in a pan mixer for two minutes. Cubes and beams were cast, the compaction being done by table vibrators and the compressive and flexural strengths were determined after curing the specimens for 14 and 28 days.

## 5. RESULTS

The results of this investigation are given in Tables 3 and 4. The combined gradation of gap graded aggregates as well as that of the "standard" continuously graded aggregate is given in Fig. 2.

TABLE 3

| Sieve size | Percentage by weight passing | | | | |
|---|---|---|---|---|---|
| | Combined aggregate with | | | | Standard mix(S) |
| | Sand A(A) | Sand B(B) | Sand C(C) | Sand D(D) | |
| $1\frac{1}{2}$ in. | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| $\frac{3}{4}$ in. | 51.0 | 57.0 | 56.0 | 47.0 | 75.0 |
| 3/8 in. | 30.0 | 28.5 | 56.0 | 47.0 | 60.0 |
| 3/16 in. | 30.0 | 28.5 | 27.0 | 25.0 | 47.0 |
| B.S.S.7 | 28.5 | 28.5 | 27.0 | 25.0 | 38.0 |
| 14 | 21.0 | 26.5 | 27.0 | 25.0 | 30.0 |
| 25 | 7.5 | 13.0 | 18.0 | 25.0 | 23.0 |
| 52 | 4.0 | 6.0 | 8.0 | 8.0 | [illegible] |
| 100 | 0.5 | 1.0 | [illegible] | 2.0 | [illegible] |
| Fineness modulus | 6.28 | 6.11 | [illegible] | 6.07 | 5.07 |

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TABLE 4

**Properties of the various mixes**

| Mix No. | Aggregate/cement ratio by weight | Yield cement content | | Strength | | | |
|---|---|---|---|---|---|---|---|
| | | | | Compressive* | | Flexural** | |
| | | bags/cu. yd. | bags/100 cu. ft. | 14 days | 28 days | 14 days | 28 days |
| A | 5.4 | 5.26 | 19.45 | 3626 | 4713 | 408 | 492 |
| B | 5.3 | 5.36 | 19.90 | 3738 | 4832 | 398 | 525 |
| C | 5.55 | 5.16 | 19.20 | 3477 | 4720 | 418 | 558 |
| D | 5.35 | 5.30 | 19.65 | 3601 | 4685*** | 409 | 502 |
| S | 4.9 | 5.65 | 20.90 | 3489 | 4751 | 381 | 516 |

* Average of 6 specimens.

** Average of 4 specimens.

*** Average of 5 specimens.

## 6. DISCUSSION

### 6.1. Properties of the Mixes

6.1.1. **Workability:** The study deals with "dry" concrete mixes as practised in our country for concrete pavements. It is well known that the slump test does not measure the workability of concrete for "dry" mixes; further, it cannot distinguish clearly two different mixes when their slump is less than one inch. However, the slump test measures the wetness of the mix and it is understandable for employing it in the field to control the water content of the design mixes.

The Swedish workability test known as "Vee Bee Test" which is a natural descendent of Power's apparatus [10] has been employed to measure the workabilities of the various mixes as it has been claimed [11] that Vee Bee Test is the most suitable workability test for dry mixes requiring vibration.

6.1.2. **Compressive and flexural strengths**: Even a cursory glance at the strength results will indicate that the compressive and flexural strengths of the gap graded mixes compare very well with that of the standard mix; in fact, there is no variation at all and the deviations among the strength values can be easily accounted for as being due to testing error. To determine whether the claims made by early investigators with regard to the increased strengths in gap graded mixes are correct, innumerable tests have to be carried out and the data have to be statistically analysed. But the data so for collected serves the purpose of indicating that good quality concrete can be produced with locally available aggregates using gap graded aggregate principle.



6.1.3. **Sand content of the mixes**: The sand content in any concrete mix depends upon the voids in the coarse aggregate, the quality of the mortar and the compactive effort. According to Stewart[13] when the ratio of coarse to fine aggregate is 3.5, there is no excess of mortar (i.e., free mortar) in concrete. In other words, the sand content required to fill in the voids of the coarse aggregate would be 22 per cent of the combined aggregate. In an ideal gap graded mix it would be better to keep the sand content as low as possible so as to yield enough mortar to fill the voids in the coarse aggregate frame work; for other conditions remaining the same compressive strength of the mortar is less than that of concrete and hence the greater the volume of extra mortar, the lesser the compressive strength. But, in terms of workability the sand content cannot be kept so low as 22 per cent of the combined aggregates.

The extra mortars in all the mixes are worked out and are shown in Table 5. (For details see Appendix 3). From the Table it is clear that the "extra mortar" in all gap graded mixes is less than that of the Standard mix. It is, therefore, justifiable to believe that the designed gap graded mixes will give higher strengths for the same water-cement ratio and type of aggregrates provided they are fully compacted.

TABLE 5

| Mix No. | Extra mortar as per cent of the total volume of concrete |
|---|---|
| "A" | 19.5 |
| "B" | 20.2 |
| "C" | 20.5 |
| "D" | 19.8 |
| "S" | 43.0 |

6.1.4. **Segregation**: In gap graded mixes where the disparity between the coarse and fine aggregate sizes is considerable, one is prone to worry about the problem of "segregation" especially when the sand content is kept low but the design of gap graded concrete mix is a function of the vibrator (external stimulant) which imparts the mobility and fluidity to the concrete during the process of compaction. The plastic gap graded concrete mixes which appeared to be "segregated", when once placed in the mould and vibrated, resulted in a well compacted concrete without any honeycombing. This is further confirmed by the strength results.

6.1.5. **Limitations**: In this connection, it should be borne in mind that the mixes are designed for high quality concrete where weigh-batching and quality control are absolutely essential. Gap graded concrete mixes are not suitable for volume batching of materials as being adopted in road construction in our country. However, the findings of this study should encourage the adoption of gap graded principle in air field constructions where facilities for producing high grade concrete are available.

### 6.2. Economy of the Mixes

6.2.1. **General**: In order to compare the economy of gap graded concrete mixes with that of the "standard" continuously graded concrete mix, for the purpose of discussion the costs are considered for one mile length, 24 feet width and 6 inches uniform thickness of concrete pavement.

It is an accepted fact that the variation in the cost of concrete road construction depends mainly upon:

(1) the cement content of the mixes

(2) the "lead" of the materials

As the material cost at site and the construction charges remain generally the same in all parts of our country, the merits of gap graded concrete mixes in terms of economy are analysed as follows:

(1) Saving in cement

(2) Saving in lead



6.2.2. **Saving in cement**: The results given in Table 4 have clearly indicated that the gap graded mixes designed with four types of "poor" gradations of sand used in the study are leaner, i.e., their cement content is lower than that of the standard mix.

The quantity of saving in cement and the amount of saving in the cost of construction are given in Table 6 (for details see Appendix 4).

TABLE 6

| Mix | Saving in cement (bags) when compared with mix "S" | Saving in cost of road construction Rs |
|---|---|---|
| "A" | 906 | 6,342.00 |
| "B" | 634 | 4,438.00 |
| "C" | 1080 | 7,560.00 |
| "D" | 792 | 5,544.00 |

The saving in cost for the mix B is the least but even then the saving is a sizeable amount which suggests the use of gap graded concrete principle in designing mixes for high quality concrete.

Mix proportions could have been worked out with the sand gradation in question without adopting gap graded aggregate principle to give the desired strength by increasing the richness of the mix, i.e., the cement content. Such mixes, apart from being uneconomical, are liable to shrink and creep more as shrinkage and creep are generally associated with the richness of the mixes.

Therefore, when one is confronted with the problem of designing mixes for pavements with "poor" sands the only way of proportioning is to adopt a gap gradation of aggregates. It may be added that even when the sands available satisfy the specification requirements it is worth while designing mixes both as continuous and discontinuous graded concrete and to choose the leaner of the two mixes in terms of saving in cement.

6.2.3 **Saving in "lead"**: For the purpose of discussion it is assumed that there is no lead for coarse aggregate and even if there is a lead it is same for all the mixes. The assumption is quite valid in as much as the analysis is only to find out the savings effected in the lead of sands while using the locally available " poor " sands.

The lead of fine aggregates varies very much from region to region and is of the order of 10 miles to 50 miles and in extreme cases even 90 miles.

Once again, for convenience, the mix is assumed as 1 : 2 : 4 by volume.

The cost involved for the various extra leads of sands required for the construction of one mile length of road is shown in Table 7 (for details see Appendix 5).

TABLE 7

| | Extra lead in miles | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| Extra lead cost in Rs | 4750 | 7400 | 9700 | 11900 | 14300 |

From the Table it is clear that the extra cost of lead even for 20 miles is a substantial amount and the savings obtained by using the locally available sand are enormous. There may, however, be slight increase in cost due to the use of certain combinations of coarse aggregate sizes in some mixes. With judicious selection of mixes, the extra cost involved is expected to be negligible. Therefore, it can be logically concluded that when the local sands satisfy the requirements of the specifications except in terms of particle size distribution they should be used in high quality concrete, designed on gap graded theory rather than importing sand from far off regions and consequently increasing the total cost of concrete roads.

## 7. CONCLUSIONS

(1) The results of the study indicate that even with the use of poorly graded local sands, such as the four types examined in the study, a high quality concrete can be produced using the gap graded principle.

(2) Concrete mixes designed on gap graded principle permit the use of locally available poor sands, thus resulting in substantial saving in the cost of construction, in as much as the saving due to the extra lead involved in bringing sand from distant places may, in certain cases, be substantial. There may, however, be a slight increase in cost due to the use of certain



combinations of coarse aggregate sizes in some mixes. With a judicious selection of mixes, the extra cost involved due to this is expected to be negligible.

(3) The use of gap graded concrete besides utilising local sands, can also result in a saving of cement.

## ACKNOWLEDGMENT

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## Appendix 1

### Suggested limits for the four grading zones

| B. S. sieve size | Percentage by weight passing B. S. sieve size | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| 3/16 in. | 90—100 | 90—100 | 90—100 | 95—100 |
| 7 | 60— 95 | 75—100 | 85—100 | 95—100 |
| 14 | 30— 70 | 55— 90 | 75—100 | 90—100 |
| 25 | 15— 34 | 35— 59 | 60— 79 | 80—100 |
| 52 | 5— 20 | 10— 30 | 15— 40 | 15— 50 |
| 100 | 0— 10 | 0— 10 | 0— 10 | 0— 15 |



## Appendix 2

### Determination of workability by Vee Bee Apparatus

**Apparatus**

The Vee Bee apparatus consists of (1) a vibrator table resting upon elastic supports, (2) a metal pot, (3) a sheet metal cone, open at both ends, and (4) a standard iron rod.

The vibrator table is 38.0 cm. long and 26.9 cm. wide and is supported on rubber shock absorbers at a height of about 30.5 cm. above floor level. The table is mounted on a base which rests on three rubber feet and is equipped with an electrically operated vibrator mounted under it operating on 220 volts, three phase, 50 cycles alternating current. A sheet metal cone open at both ends is placed in the metal pot and the metal pot is fixed on the vibrator table by means of two wing-nuts. The sheet metal cone is 30. cm. high and its bottom diameter is 20 cm. and top diameter 10 cm. A swivel arm holder is fixed to the base and into this is telescoped another swivel arm with funnel and guide sleeve. The swivel arm can be readily detached from the vibrating table. The graduated rod is fixed on to the screws. The divisions of the scale on the rod records the slump of the concrete cone in centimetres and the volume of concrete after vibration of the cone in the pot. The standard iron rod is 2.0 centimetre in diameter and 50. cm. in length. The electrical appliances mounted on the base of the equipment consist of a fixed plug and connector for the electric supply cable – plug and socket contacts for the detatchable cable connected to the vibrator and a control switch.

**Procedure**

A slump test as described in Appendix C of IS: 456 is performed in the sheet metal cylinderical pot of the apparatus. The glass disc attached to the swivel arm is moved and is placed just on top of the slump cone in the pot and, before the cone is lifted up, the position of the concrete cone is noted by adjusting the glass disc attached to the swivel arm. The metal cone is then lifted up and the slump is noted on the graduated rod by lowering the glass disc on top of the slumped concrete cone. The electrical vibrator is then switched on and the concrete is allowed to spread out in the pot. The vibration is continued until the whole concrete surface uniformly adheres to the glass disc and the time taken for this to be attained is noted with a stop-watch. The time is recorded in seconds.

The workability of the concrete is expressed in VB-degrees which are equal to the time in seconds recorded.

(Based on the Draft Indian Standard Methods of Testing Concrete).

## Appendix 3

### Extra mortar in various mixes

**Specific Gravity of Materials**

| | | |
|---|---|---|
| Cement | = | 3.14 |
| Sand | = | 2.62 |
| Coarse aggregate | = | 2.63 |
| Water | = | 1.00 |

### Unit weight of coarse aggregates

| Mix No. | Unit weight (pounds per cubic foot) |
|---|---|
| "A" | 104 |
| "B" | 105 |
| "C" | 109 |
| "D" | 110 |
| "S" | 107 |

**Example :** Consider mix "B".

Aggregate cement ratio = 5.3

Sand content as percentage of combined aggregate = 28.5

Unit weight. of coarse aggregate = 105 lbs. per cu. ft.

Absolute volume of aggregate $= \dfrac{105}{2.63 \times 62.5} = 0.637$ cu. ft.

Volume of voids in coarse aggregate $= 1 - 0.637$

$= 0.363$ cu. ft.

Volume of voids as percentage of absolute volume of coarse aggregate $\left.\right\} = \dfrac{0.363 \times 100}{0.637} = 57$ per cent



| Materials | Weight in pounds | Absolute volume in cu. ft. |
|---|---|---|
| Cement | 100 | $\dfrac{100}{3.14 \times 62.5} = 0.510$ |
| Sand | 151 | $\dfrac{151}{2.62 \times 62.5} = 0.914$ |
| Coarse aggregate | 379 | $\dfrac{379}{2.63 \times 62.5} = 2.290$ |
| Water | 50 | $\dfrac{50}{62.5} = 0.795$ |
| | Total volume | $= 4.509$ cu. ft. |

Absolute volume of mortar (cement + sand + water) $= 2.219$ cu ft.

Volume of mortar required to fill the voids in coarse aggregate $= \dfrac{2.290 \times 57}{100} = 1.305$ cu. ft.

Extra mortar in the mix $= 2.219 - 1.305 = 0.914$ cu. ft.

Extra mortar (absolute volume) as percentage of concrete (absolute volume) $= \dfrac{0.914}{4.509} = 20.2$ per cent

## Appendix 4

### Saving in cement

Concrete road :—length — one mile : width -- 24 ft and uniform thickness = 6 in.

Volume of concrete for one mile road = 63360 cu. ft.

Cement = Rs 140 per ton.

1. **Yield of concrete**

*Example*: Consider mix "C"

Aggregate cement ratio = 5.55 by weight

Sand content = 27 per cent of combined aggregate

| Materials | Weight in pounds | Absolute volume in cu. ft. |
|---|---|---|
| Cement | 100 | $\frac{100}{3.14\times 62.5}=0.510$ |
| Sand | 149.5 | $\frac{149.5}{2.62\times 62.5}=0.902$ |
| Coarse aggregate | 405.5 | $\frac{405.5}{2.63\times 62.5}=2.461$ |
| Water | 50.0 | $\frac{50.0}{62.5}=0.795$ |

Total volume = 4.668 cu. ft.

100 lb of cement yields = 4.668 cu. ft. of concrete

Cement required for one cubic yard of concrete $=\frac{100\times 27}{4.668}$ lb

(1 bag of cement = 112 lb) = 5.16 bag

Similarly, cement required for 100 cu. ft. of concrete

$$=\frac{(100\times 100)}{4.668}\times\frac{1}{112}=19.20 \text{ bags}$$



YIELD

| Mix No | Cement in bags per cubic yard | per 100 cu. ft. |
|---|---|---|
| "A" | 5.26 | 19.45 |
| "B" | 5.36 | 19.90 |
| "C" | 5.16 | 19.20 |
| "D" | 5.30 | 19.65 |
| "S" | 5.65 | 20.90 |

2. **Saving in cement when compared with standard mix** (mix "S").

*Example*.—mix "D".

Cement saving while using mix "D" instead of the standard mix "S" per 100 cu. ft. of concrete = 20.90—19.65 = 1.25 bags. Saving in bags while using mix "D" instead of mix "S" in one mile length of concrete road (6,33,60 cu. ft.)

$= 1.25\times 633.6 = 792$ bags = Rs 5,544.00

## Appendix 5

### Extra lead cost for sand

Concrete 1 : 2 : 4 by volume.

Concrete road: length one mile; width 24 ft.: uniform thickness = 6 in.

Sand content = *44.5 cu. ft. per 100 cu. ft. of concrete.

| Lead | | *Cartage charges per 100 cu.ft. of sand |
|---|---|---|
| | | Rs |
| 10 miles | — | 16.81 |
| 20 miles | — | 26.19 |
| 30 miles | — | 34.31 |
| 40 miles | — | 42.46 |
| 50 miles | — | 50.56 |

* Based on C.P.W.D., Delhi schedule of rates, and analysis of rates 1955.

*Example* : 20 miles extra lead cost

Volume of concrete = (24) (0.5) (5280) = 63,360 cu. ft.

Volume of sand = 63,360 × 0.445 = 28,195 cu. ft.

Extra cost of lead = Rs 7384, say Rs 7400.

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# " SELECTION OF SUITABLE STABILISER FOR CHECKING CAPILLARY RISE OF WATER FROM THE SUBGRADE "

*By*

Dr. I. S. UPPAL*

CONTENTS



## 1. INTRODUCTION

1.1. It is well known to all those connected with the construction and maintenance of roads that under similiar conditions of subgrade soil, thickness of the road crust and traffic intensity, the deformation of roads is comparatively much greater in the waterlogged areas than in the drier areas. Due to the rise in the height of water table, particularly in the rainy

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season when the water table at many places rises to a level close to the ground surface, the subgrade becomes saturated and its bearing capacity becomes low with the result that the road begins to settle under traffic and fails in due course.

1.2. In some cases the failure of the road is also due to the presence of harmful salts, like sodium sulphate, which expand on hydration and disrupt the surface. These salts travel up with the capillary moisture from the subgrade and crystallise near the surface resulting in its disintegration.

1.3. It is, therefore, necessary that a special design providing some sort of treatment for checking the capillary rise of subgrade moisture to the road crust should be prepared for the construction of roads in waterlogged areas.

1.4. Application of certain cold penetration bituminous materials on the surface of the subgrade has been recommended by Mehra and Uppal for checking capillarity[1]. This method has been tried in a couple of miles in the field as an experimental measure and the results are under observation. While adopting this treatment on the field scale it was, however, felt that very great care has to be exercised in spraying the primer uniformly and guarding it till the next soil layer has been laid over it. The primer layer, being thin, chips off even with the feet when some one walks over it, thus providing a point for the water to penetrate easily. As such, the treatment presents practical difficulties in its field application on a large scale.

## 2. OBJECT OF THE STUDY

2.1. Further laboratory investigations were, therefore, undertaken to find out a more suitable treatment for checking the capillary rise of water from the subgrade to the base course. As bitumens are known to be good waterproofing materials and are commercially available, the study was confined to their use only. Accordingly, the following five bituminous products were tried:

1. Shellmac RC 3 } (Burmah Shell Product)
2. Adobe cutback } (Burmah Shell Product)
3. Liquid asphalt No. 2 (Standard Vacuum Oil Product)
4. Bitumen emulsion containing 60 per cent bitumen
5. Bitumen cut-back locally prepared from 80/100 bitumen.



2.2. In the first instance, experiments were carried out on sandy loam soil only as this type of soil having greater bearing strength in wet state than the other soils is usually recommended for base course. The soil used had the following physical characteristics:

| | |
|---|---|
| Liquid limit | 31.5 |
| Plasticity index | 6.9 |
| Sand content | 56.7 |
| Sulphate | Nil |

Optimum moisture required for compaction = 13.0 per cent

## 3. PREPARATION OF TEST SPECIMENS

3.1. 200 gms. of 10 mesh soil mixed with the requisite quantity of stabiliser were compacted as usual in the modified[2] Abbot's compacting apparatus giving 40 blows of 5½ lbs rammer falling through a height of 12 in. in a cylindrical pipe of 2.5 in. internal diameter. The blocks were first dried in the sun and then in the oven at 70°C. to a constant weight.

3.2. The stabilisers were mixed in the wet soil at higher moisture content (about 25 per cent water by weight of dry soil). The mixtures were then spread in the open till the moisture came down to the optimum when they were compacted into specimen blocks. Bitumen emulsion was diluted with water to the extent of optimum moisture and was then mixed in the soil. In all cases optimum moisture was determined for each mixture separately and compaction done at that moisture content.

## 4. TESTS PERFORMED

4.1. The specimen blocks prepared with different binders were subjected to the following tests:

(i) Dry bulk density

(ii) Compressive strength in dry condition

(iii) Resistance to softening action of water by actual immersion in water

(iv) Moisture absorption through capillary action

(v) Compressive strength in wet state

4.2. Dry bulk density was determined as usual by mercury displacement method while the compressive strength was determined by means of Laboratory Carver Press. For testing the resistance to softening action of water, the blocks were immersed under water contained in a trough and their condition noted every day for a period of seven days. Moisture absorption by those blocks which remained intact was then determined. The results of all these three tests are shown in Table 1, from which it would be seen that the density and compressive strength improved with the addition of 2 per cent of each of the above five stabilisers but there was no further improvement in these properties on increasing their quantities even to 6 per cent. The resistance to moisture absorption, however, improved with the increasing quantities of bituminous products. The liquid asphalt No. 2 and the cutback prepared in the laboratory were found better in this respect as even with the addition of 4 per cent of these stabilisers in the soil, the total moisture absorbed was much below the optimum moisture. Even the presence of 2 per cent of these products in the soil made the blocks stand intact in water for a week although the moisture absorbed was slightly more than the optimum moisture.

TABLE 1

| S. No. | Stabiliser | % age used | Density gms./c.c. | Compressive strength (dry) (lb per sq.in.) | % moisture absorbed after 7 days' immersion in water |
|---|---|---|---|---|---|
| 1. | Shellmac RC 3 | 2 | 1.87 | 810 | Disintegrated |
| | | 4 | 1.86 | 790 | 18.1 |
| | | 6 | 1.87 | 841 | 8.0 |
| 2. | Adobe cut-back | 2 | 1.92 | 636 | — |
| | | 4 | 1.93 | 600 | 18.0 |
| | | 6 | 1.91 | 610 | 8.5 |
| 3. | Liquid asphalt No. 2 | 2 | 1.93 | 790 | 16.2 |
| | | 4 | 1.95 | 816 | 8.5 |
| | | 6 | 1.95 | 790 | 7.5 |
| 4. | Laboratory made cut-back (9:1 of Bitumen : K. oil) | 2 | 1.91 | 760 | 15.4 |
| | | 4 | 1.92 | 816 | 10.2 |
| | | 6 | 1.89 | 790 | 6.6 |
| 5. | Bitumen emulsion | 2.5 | 1.93 | 720 | — |
| | | 5.0 | 1.89 | 690 | 16.1 |
| 6. | Blank | — | 1.85 | 475 | Disintegrated at once |



### 4.3. Moisture Absorption through Capillary Rise and compressive strength in Wet State

Each test block was placed over 1 in. thick layer of wet sand contained in a cylindrical iron mould having false bottom. These moulds were then placed over wet sand with water level about 1/8 in. above the sand in a trough. The moisture absorbed was noted at intervals of 24 hours for seven days. The observations were further continued till the blocks got saturated and absorbed no more water. The number of days required for saturation of each block was noted. The results are given in Table 2.

4.4. It would be seen from these results (Table-2) that the addition of Liquid Asphalt No. 2 and laboratory made cutback again proved much more effective in reducing the rate of moisture absorption as well as the total amount of water absorbed. With the presence of 4 per cent of these stabilisers in the soil the saturation point was obtained within a fortnight although the total moisture was of the order of 12 per cent and still below the optimum moisture of the soil. The tops of the blocks were still dry although the moisture appeared on the sides. Rate of moisture absorption with 4 per cent stabiliser in soil mass is graphically shown in Fig. 1.

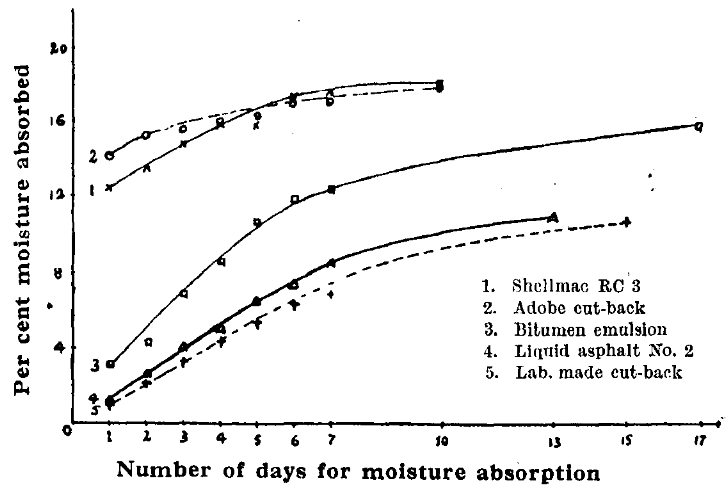


Fig. 1.

4.5. The saturated blocks were now subjected to compressive force and the results are shown in the last column of Table 2. It would be seen from these results that the compressive strength under wet conditions increased with increasing quantities of

TABLE 2

**Effect of the stabilisers on the capillary rise of water in stabilised soil blocks, and on the compressive strength of blocks in saturated state**

| S. No. | Name of stabiliser | Percentage used | Per cent water absorbed after.........days 1 | 2 | 3 | 4 | 5 | 6 | 7 | General condition after 7 days | No. of days for saturation | Saturation moisture | Compressive Strength of the blocks in wet state lbs per sq. in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Shellmac R. C. 3 | 2 | 15.4 | 17.0 | 17.3 | 17.65 | 17.96 | 18.1 | 18.2 | All wet | 8 | 18.3 | 110 |
| | | 4 | 12.5 | 13.5 | 14.8 | 15.9 | 15.8 | 17.4 | 17.7 | do. | 10 | 18.0 | 155 |
| | | 6 | 1.4 | 2.1 | 2.9 | 3.5 | 4.0 | 4.61 | 5.28 | Top dry, sidespartly wet | 19 | 9.5 | 257.7 |
| 2. | Adobe cut back | 2 | 15.95 | 16.95 | 17.2 | 17.5 | 17.7 | 18.0 | 18.2 | All wet | 8 | 18.4 | 70.0 |
| | | 4 | 14.1 | 15.3 | 15.7 | 16.0 | 16.3 | 17.0 | 17.0 | do. | 10 | 17.8 | 100.0 |
| | | 6 | 1.3 | 2.03 | 2.8 | 3.04 | 3.83 | 4.42 | 5.0 | Sides partly wet, top dry | 18 | 11.05 | 188.4 |
| 3. | Liquid asphalt No. 2 | 2 | 13.12 | 14.36 | 15.16 | 16.97 | 16.97 | 17.17 | 17.2 | All wet | 7 | 17.2 | 110.0 |
| | | 4 | 1.3 | 2.7 | 4.12 | 5.14 | 6.5 | 7.5 | 8.5 | Top dry | 13 | 10.9 | 230.0 |
| | | 6 | 0.72 | 1.2 | 1.7 | 2.1 | 2.5 | 3.8 | 4.8 | do. | 21 | 8.5 | 306.0 |
| 4. | Bitumen emulsion | 2.5 | 13.47 | 14.45 | 15.3 | 15.5 | 16.0 | 16.5 | 16.7 | All wet | 97 | 17.8 | 191.2 |
| | | 5.0 | 3.2 | 4.3 | 6.8 | 8.6 | 10.7 | 11.9 | 12.4 | do. | 17 | 15.9 | 167.2 |
| 5. | Lab. cut back | 2 | 10.2 | 13.5 | 13.9 | 14.6 | 14.7 | 15.2 | 15.7 | All wet | 9 | 16.1 | 107 |
| | | 4 | 1.1 | 2.2 | 3.4 | 4.4 | 5.4 | 6.3 | 6.8 | Top dry | 15 | 10.7 | 190 |
| | | 6 | 0.7 | 1.6 | 2.6 | 3.4 | 4.3 | 4.9 | 5.5 | do. | 21 | 8.7 | 270 |



bituminous materials and the results obtained with asphalt No. 2 and laboratory made cut-back were again better than those obtained with other stabilisers used in this study.

## 5. RESISTANCE TO ABRASION

Although the resistance to abrasion is not actually relevant to the study because the experiments were conducted for the sub-base which is not directly exposed to traffic, yet this test was performed on the specimen blocks to see the effect of various stabilisers on this property. For this purpose, Dorry's abrasion testing machine was used and the loss in weight was determined after 500 revolutions. Coarse sand passing 10 mesh and retained over 40 mesh was used as abrasive material. The blocks were kept under a weight of 200 gms. while under test. Loss in weight per square inch of the surface area was determined. The results are presented in Table 3 from which it will appear that the resistance to abrasion appreciably improved with increasing quantities of bituminous materials. In this case also the liquid asphalt No. 2 and laboratory made cut-back gave better results.

TABLE 3

**Effect of various stabilisers on the abrasive resistance of the stabilised soil**

| S. No. | Stabilisers | Percentage used | Loss of weight per sq. in. in gms. per sq. in. area after 500 revolutions |
|---|---|---|---|
| 1. | Shellmac R. C. 3. | 2.0 | 29.6 |
| | | 4.0 | 14.0 |
| | | 6.0 | 1.6 |
| 2. | Adobe cut-back | 2.0 | 27.2 |
| | | 4.0 | 8.8 |
| | | 6.0 | 1.8 |
| 3. | Liquid asphalt No. 2 | 2.0 | 16.8 |
| | | 4.0 | 7.0 |
| | | 6.0 | 1.2 |
| 4. | Bitumen emulsion | 2.5 | 19.6 |
| | | 5.0 | 5.2 |
| 5. | 9 parts bitumen of 80/100 + 1 part of kerosene oil cut-back | 2 | 19.9 |
| | | 4 | 4.4 |
| | | 6 | 1.2 |

## 6. EFFECT OF BITUMEN CUT-BACK ON THE PROPERTIES OF OTHER SOILS

6.1. Perusal of the preliminary results given in the preceding pages will show that the incorporation of 4 per cent laboratory made cut-back in the soil gave satisfactory results with regard to the all round improvement in the various engineering properties of the soil mass. Investigations were, therefore, further extended on the use of this material in different types of soils available in Punjab and attempt was made to find out the optimum quantity of bitumen cut-back required for waterproofing them. The composition of the cut-back was, however, slightly changed to make it more workable. 80 parts of 80/100 bitumen were blended with 20 parts of kerosene oil and 1 part of hard paraffin wax was added to the mixture because in another study conducted in connection with the waterproofing of mud mortars it was found to have improved the waterproofing properties of the bitumen to a considerable extent.

6.2. The characteristics of the soils used in these investigations are given below:

| S. No. | Type of soil | Sand content | L. L. | P. I. |
|---|---|---|---|---|
| 1. | Sandy loam | 54.7 | 24.5 | 6.4 |
| 2. | Loam | 43.6 | 31.3 | 10.8 |
| 3. | Silty loam | 17.2 | 29.1 | 10.2 |
| 4. | Clayey soil | 9.5 | 41.2 | 19.4 |

6.3. The method used for the preparation of specimen blocks was the same as given before and the tests performed were also the same. An additional test for determination of swelling due to saturation of moisture was, however, performed on these blocks.

## 7. DENSITY, COMPRESSIVE STRENGTH & WATER ABSORPTION

The results of density and compressive strength in dry and wet state and the per cent saturation moisture attained by



immersion are given in Table 4. It would be seen therefrom that in the sandy soil the compressive strength steadily improved with the addition of cut-back up to 5 per cent, whereas in the graded soil the maximum compressive strength and density were obtained with 4 per cent cut-back and further addition of cut-back tended to weaken the blocks. In the case of silty soil also maximum strength was obtained with 4–5 per cent cut-back and further increase in the proportion of cut-back decreased the strength. In the clayey soil, however, the strength increased with the addition of only 2–3 per cent cut-back and further increase in the stabiliser resulted in weakening of the blocks even to lower strength than the plain blocks. The saturation moisture decreased with the increasing quantities of cut-back in almost all the soils and was the lowest in the case of loam soil which also showed good compressive strength under saturated condition. Silty soil blocks absorbed maximum amount of water. In the case of clayey soil the blocks containing 2 and 3 per cent cut-back cracked when placed in water for some time, but those containing higher quantities of cut-back stood very satisfactorily. Water absorption in clayey soil, however, increased when the quantity of cut-back was increased beyond 5 per cent. On the whole, the addition of 5 per cent cut-back in the sandy soil and 4 per cent in the remaining three soils gave satisfactory results. The compressive strength results of dry blocks are represented in Fig. 2 (A).

## 8. EFFECT OF ADDITION OF BITUMEN CUT-BACK ON THE CAPILLARY RISE OF WATER, SWELLING & COMPRESSIVE STRENGTH OF THE COMPACTED BLOCKS WHEN PLACED OVER WET SAND

8.1. The blocks were placed in hollow cylindrical moulds having false bottom which were then placed over wet sand with water level about $\frac{1}{8}$ in. above the sand contained in a trough. The moisture absorbed was determined at intervals of twenty-four hours for nine days and the results are shown in Table 5. The results indicated in 216 hours column also represent the saturation point attained by the blocks due to the capillary rise. The swelling of the blocks on saturation was determined by measuring the volume of dry blocks and then after saturation. These results are also shown in Table 5. After saturation these blocks were also subjected to compression test to find out their resistance to loading and the results are shown in the last column of Table 5.

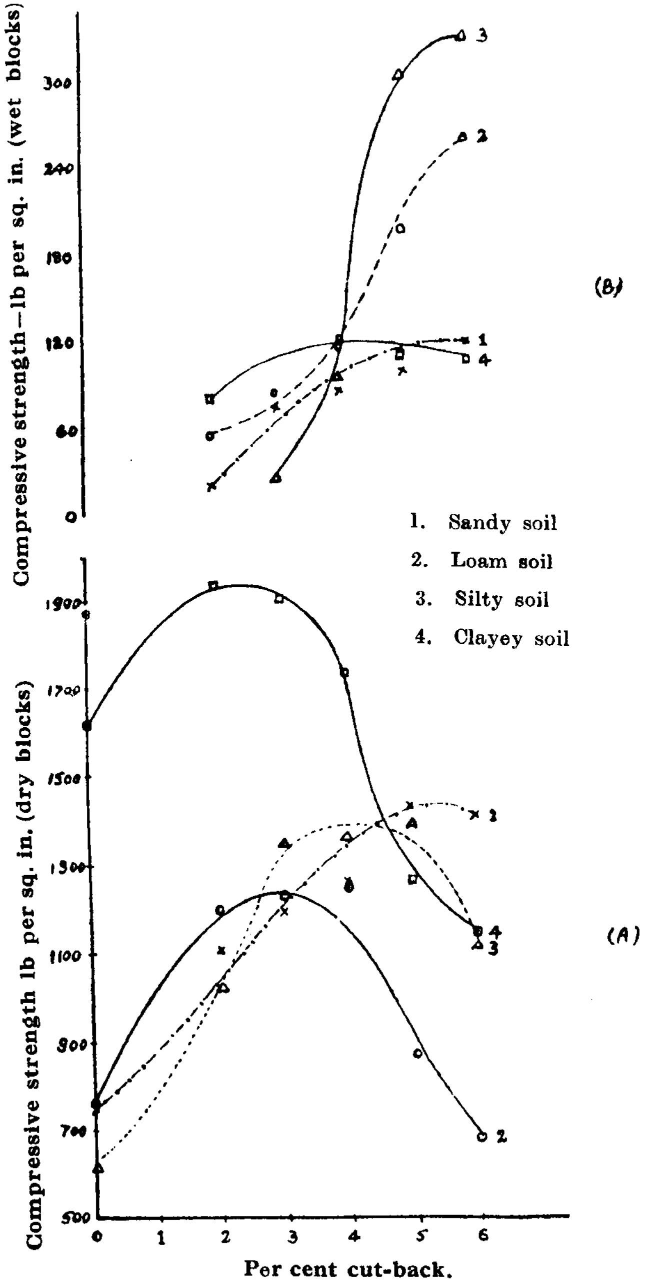


Fig. 2



TABLE 4

**Effect of addition of bitumen cut-back on the density, compresssive strength and moisture absorption capacity of various soils**

| Nature of soil | Per cent cut-back | Density | Compressive strength (dry) | Per cent saturation moisture attained by immersion under water for 10 days | Compressive strength in wet state |
|---|---|---|---|---|---|
| | | Gms. per c.c. | Lb per sq. in. | | Lb per sq. in. |
| Sandy | 0 | 1.91 | 750 | Failed in 40 mts. | — |
| | 2 | 1.99 | 1116 | 13.6 | 22 |
| | 3 | 1.95 | 1200 | 12.5 | 75 |
| | 4 | 1.92 | 1268 | 7.2 | 86 |
| | 5 | 1.90 | 1443 | — | — |
| | 6 | 1.95 | 1417 | 7.5 | 70 |
| Loam | 0 | 1.82 | 771 | Failed in 5 hrs. | — |
| | 2 | 1.90 | 1200 | 12.7 | 141 |
| | 3 | 1.90 | 1230 | 11.7 | 136 |
| | 4 | 1.91 | 1250 | 10.4 | 131 |
| | 5 | 1.84 | 880 | 6.1 | 169 |
| | 6 | 1.84 | 677 | 6.1 | 224 |
| Silty | 0 | 1.88 | 615 | Failed in 2 hrs. | — |
| | 2 | 1.92 | 1023 | Cracked | — |
| | 3 | 1.91 | 1350 | 18.1 | 21.60 |
| | 4 | 1.91 | 1362 | 16.3 | 28.80 |
| | 5 | 1.84 | 1400 | 14.5 | 55.00 |
| | 6 | 1.84 | 1117 | 10.8 | 67.00 |
| Clayey | 0 | 1.99 | 1625 | Failed in 5 hrs. | — |
| | 2 | 1.99 | 1040 | Cracked | — |
| | 3 | 1.85 | 1908 | Cracked | — |
| | 4 | 1.84 | 1742 | 8.4 | — |
| | 5 | 1.84 | 1267 | 7.1 | — |
| | 6 | 1.84 | 1154 | 12.6 | 96.00 |

8.2. It would be seen from these results that all the soils containing bitumen cut-back attained saturation within a period of 144–168 hours. Except in the case of clayey soils, in which case the moisture absorption first decreased with increasing quantities of bitumen upto 5 per cent and then started increasing, the saturation moisture due to the capillary rise of water as well as the swelling steadily decreased with the increasing quantity of cut-back. Here also 4–5 per cent cut-back gave good results in all the soils. The silty loam blocks which absorbed sufficient moisture, when immersed in water (Table 5), gave very encouraging results when subjected to capillary test both with regard to the moisture absorption as well as the com

TABLE 5

**Effect of addition of bitumen cut-back on the rate of capillary rise of water and swelling of the compacted blocks when placed over Wet sand**

| S. No. | Soil | Per cent cut-back | Per cent moisture absorbed at the end of......hrs. | | | | | | | | | Per cent Swelling | Compressive Strength (wet) lbs per sq. in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 24 | 48 | 72 | 96 | 120 | 144 | 168 | 192 | 216 | | |
| 1. | Sandy | 2 | 2.6 | 4.6 | 6.6 | 8.2 | 9.6 | 10.4 | 10.4 | 10.4 | 10.4 | 5.1 | 22 |
| | | 3 | 0.82 | 2.1 | 4.1 | 6.6 | 8.1 | 9.3 | 10.1 | 10.1 | 10.1 | 6.6 | 75 |
| | | 4 | 0.5 | 1.9 | 3.0 | 3.8 | 5.0 | 6.0 | 7.1 | 7.7 | 7.7 | 3.7 | 86 |
| | | 5 | 0.8 | 1.0 | 1.3 | 1.8 | 1.9 | 2.1 | 2.1 | 2.1 | 2.1 | 0.8 | 110 |
| | | 6 | 0.9 | 1.2 | 1.3 | 1.7 | 1.8 | 2.0 | 2.1 | 2.3 | 2.3 | 0.6 | 121 |
| 2. | Loam | 2 | 3.1 | 5.4 | 7.7 | 9.5 | 11.2 | 11.8 | 13.1 | 13.1 | 13.1 | 8.6 | 56 |
| | | 3 | 3.7 | 5.2 | 6.4 | 8.2 | 9.3 | 10.2 | 11.2 | 11.2 | 11.2 | 7.0 | 86 |
| | | 4 | 2.2 | 3.5 | 4.8 | 6.1 | 7.6 | 8.6 | 9.7 | 9.7 | 9.7 | 2.1 | 117 |
| | | 5 | 1.6 | 3.0 | 4.5 | 6.4 | 7.8 | 8.4 | 8.4 | 8.4 | 8.4 | 1.4 | 199 |
| | | 6 | 0.6 | 1.7 | 2.1 | 3.2 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 0.3 | 264 |
| 3. | Silty | 2 | 9.1 | 14.4 | 15.9 | 16.9 | Cracked | | | | | | |
| | | 3 | 3.9 | 6.7 | 8.9 | 11.3 | 13.1 | 14.2 | 15.1 | 15.1 | 15.1 | 6.6 | 28 |
| | | 4 | 2.8 | 4.3 | 5.8 | 7.1 | 7.9 | 8.7 | 9.6 | 9.6 | 9.6 | 3.5 | 96 |
| | | 5 | 1.5 | 1.8 | 1.9 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 0.5 | 308 |
| | | 6 | 1.1 | 1.3 | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.8 | 334 |
| 4. | Clayey | 2 | 8.5 | 10.4 | 11.9 | 13.1 | 13.8 | 14.1 | 14.5 | 14.5 | 14.5 | 3.1 | 81 |
| | | 3 | 5.9 | 7.3 | 0.2 | 11.8 | Cracked | | | | | | |
| | | 4 | 1.2 | 2.5 | 3.7 | 4.4 | 4.8 | 4.8 | 4.8 | 4.8 | 4.1 | 3.3 | 121 |
| | | 5 | 1.4 | 2.3 | 2.9 | 3.5 | 3.8 | 4.1 | 4.1 | 4.1 | 4.8 | 1.6 | 121 |
| | | 6 | 3.4 | 5.1 | 6.4 | 7.3 | 8.2 | 8.6 | 8.6 | 8.6 | 8.6 | 0.7 | 101 |



pressive strength in saturated condition. The tops of all the blocks containing 4 per cent and above of the cut-back were found dry after the experiment. The results of compressive strength in wet state are graphically represented in Fig. 2 (B) and those of saturation moisture due to capillarity are shown in Fig 3.

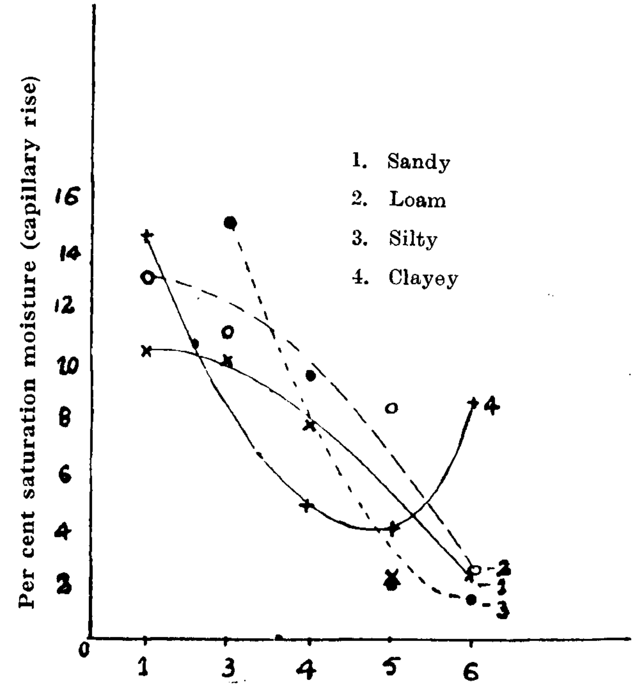


Fig. 3

## 9. CONCLUSIONS

Addition of 5 per cent cut-back (4 per cent active bitumen content) prepared from 80/100 bitumen to any type of soil covered by the range of four soils tried in the presesnt investigation can appreciably increase its normal resistance to softening action of water and deformation under saturated condition. This percentage can, therefore, be used for stabilising and waterproofing of such soils for the construction of the sub-base particularly in the heavily waterlogged areas, before the road crust is laid. A highly clayey soil may prove tricky with slight variation in quantity of cut-back but sandy and graded soils can be safely used for this treatment.

## 10. TRIALS UNDER FIELD CONDITIONS

10.1. In another set of experiments the effect of an intermediate layer of bituminised soil on the capillary rise of water through the subgrade to the upper soil layer was studied by creating artificial waterlogging conditions in the laboratory. For this purpose, a rectangular wooden hollow mould having two opposite wooden sides fixed and the other two opposite sides fitted with sliding glass plates was used. At the bottom of this mould a brass wire of 40 mesh was fixed and then clayey soil was compacted upto 4 in. height to represent subgrade in the field. Over this another layer of 4 in. thick compacted soil of base course specifications (P. I. =6 per cent and sand content=50 per cent) was laid.

10.2. In another similar mould, a 2.0 in. thick compacted layer of sandy (base course) soil premixed with 4 per cent by its weight of bitumen cut-back was sandwitched between the subgrade and the base course layers.

10.3. For the sake of comparison, a third similar mould was prepared in which a layer of shell primer prepared by dissolving 50 parts of 80/100 bitumen in equal quantity of diesel oil was given between the subgrade and base course layers. The quantity of shell primer used was at the rate of 40 lb per sq. ft. as recommended by Mehra and Uppal [1]. The primer was used hot in two coats and allowed to penetrate into the subgrade soil and set on the surface before putting the base course layer. Compaction of soil in all the three moulds was done under similar conditions to ensure uniform density in all cases.

10.4. All the three moulds were then placed over wet sand contained in seperate enamelled trays. Sufficient water was maintained in the trays to ensure its thorough contact with the subgrade at its lower end. The arrangement is shown in Photo Samples were taken from each mould and at the same height at different intervals by boring the soil layers horizontally with the cork borer. The results are given in Table 6. It would be seen therefrom that in the case of mould containing no waterproofing treatment the capillary rise of water into the base course was quite rapid as within a fortnight the lower half of the base course absorbed 12 per cent moisture. In the second mould containing bituminised soil layer there was practically no absorption of water by this layer for two months and the top base course soil was quite dry. After about five months, however, this bituminous layer was found to have absorbed 3.5 per cent moisture, but the top base course layer was found to have absorbed only 1.8 per cent water.

10.5. In the case of the third mould in which primer was used to check up the capillarity, moisture started penetrating

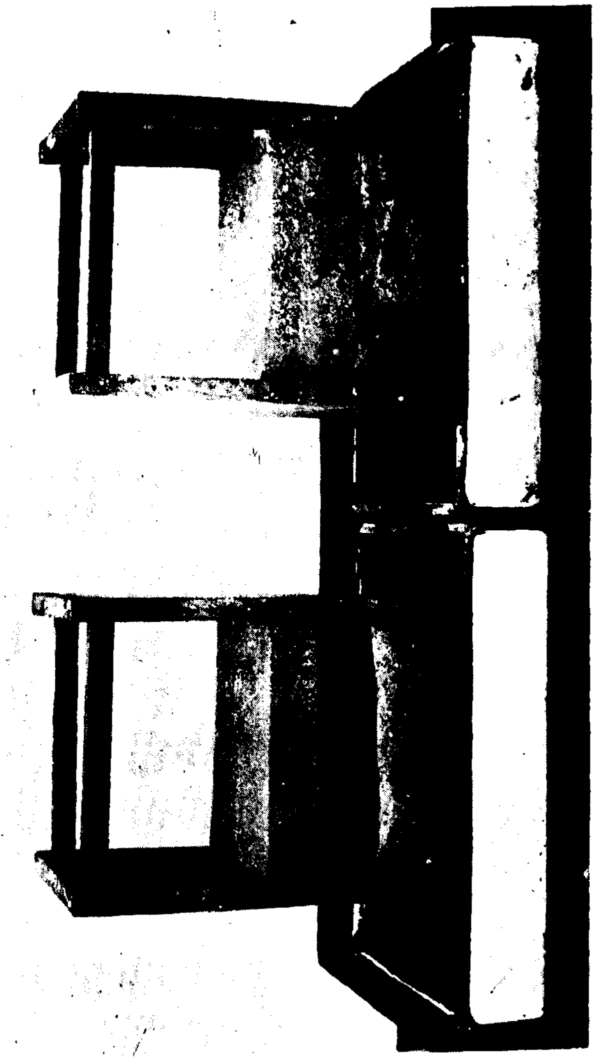

Photo 1

Table 6

| Description | Per cent moisture observed after......days | | | | | | |
|---|---|---|---|---|---|---|---|
| | Initial | 15 | 20 | 40 | 55 | 130 | 151 |
| **Mould No. 1 (Blank)** | | | | | | | |
| Top of subgrade | 1.96 | 14.5 | 15.8 | — | 16.7 | 18.3 | — |
| Lower half of B. C. | 0.90 | 10.7 | 10.8 | 11.5 | 12.0 | 14.0 | — |
| **Mould No. 2.** | | | | | | | |
| Subgrade (top) | 1.6 | — | 16.8 | 15.9 | 17.4 | 25.7 | — |
| Bituminous layers (centre) | 0.3 | — | 0.3 | 0.2 | 0.5 | — | 3.5 |
| Base course (lower half) | 0.7 | 0.7 | 0.4 | 0.3 | 0.4 | — | 1.83 |
| **Mould No. 3.** (primer treatment) | | | | | | | |
| Subgrade layer | 1.2 | 18.4 | 18.8 | — | 20.5 | 22.1 | — |
| Base course layer (lower half) | 0.7 | 0.9 | 2.0 | 4.2 | 5.2 | 7.4 | 7.9 |

through the primer layer after about a fortnight so that at the end of about 1½ month the lower layer of the base course had absorbed over 5 per cent water and at the end of 5 months almost the whole of the base course was found to be wet having absorbed about 7.5 per cent water.

10.6. To check on the above results, fresh moulds were prepared with the last two specifications and subjected to the same test. Three samples in each case were taken from right, centre and left at a point 1 in. above the top of subgrade at intervals of 45 and 90 days and tested for moisture content. The results along with the average of the three readings are given below:

| Treatment | No. of days | Per cent moisture | | | |
|---|---|---|---|---|---|
| | | Right | Centre | Left | Average |
| 1. Primer | 45 | 5.5 | 7.4 | 6.8 | 6.6 |
| | 90 | 7.0 | 7.0 | 7.8 | 7.3 |
| 2. Bituminised soil layer | 45 | 1.1 | 1.3 | 0.7 | 1.03 |
| | 90 | 1.7 | 0.2 | 3.5 | 1.80 |

It would appear from these results that the compacted layer of bituminised soil is far more effective in checking the capillary rise of water than the primer treatment.

10.7. The quantity of bitumen cut-back at 4 per cent by weight of soil for 100 sq. ft. of the 2 in. thick loose layer compacted to about 1.5 in. would be approximately 45 lb as against 40 lb of primer for 100 sq. ft. area. The difference of 5 lb is not much as compared with the advantage gained over the primer treatment.

### ACKNOWLEDGMENT

Sarvshri Hem Raj Aggarwal and A. P. Jerath, Research Assistants assisted the Author in carrying out the laboratory investigations.

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**Information Section**

## 1. REPORT OF PANEL DISCUSSION ON CEMENT CONCRETE ROAD SURFACING

## 2. A NOTE ON THE UP-TO-DATE POSITION WITH REGARD TO THE USE OF SURKHI AS A POZZOLANA

# REPORT OF PANEL DISCUSSION

# ON

# CEMENT CONCRETE ROAD SURFACING

## INTRODUCTORY NOTE

With a view to obtain and exchange up-to-date information and experience on cement concrete road construction in India, a **Panel discussion** on the subject was arranged at the 16th, 17th, and the 18th Sessions of the Indian Roads Congress. The Council at their 43rd meeting held on the 9th February 1954 appointed a Subcommittee to examine the discussions and draft answers to the questions before their publication in the Journal of the Indian Roads Congress. The finalised answers as drafted by the Committee were circulated to the members of the Council for comments and advice regarding their publication in the Indian Roads Congress Journal. The comments received were passed on to the Committee to reconsider the answers before they could be considered for publication. This Committee at their sittings in May 1957, January 1958 and August 1958 considered the comments of the members of the Council and the answers as finalised by the Committee are given below:

Q. 1. **When do you adopt cement concrete surface in preference to other types of surfaces ?**

The selection of type of surface will, in general, depend on the nature of locally available materials and its cost, on the nature of the soil over which it is to be constructed, on the type and intensity of traffic it will be called upon to carry, and on the expected life of the surface under given conditions of traffic.

Concrete surface has been preferred over other types in the following situations:

(i) Where the traffic is heavy, i.e., the total daily traffic exceeding 2,000 tons per day, or the daily bullock cart traffic being not less than 750 tons.

(ii) Where suitable supplies of road stone for soling, metalling or pitching do not exist, or are costly due to the long distances they have to be transported from the quarries.

(iii) At hair-pin bends on hill roads.

(iv) On top of causeways and road dams where water would wash over during rains.

(v) Where it is necessary to render the road surface impermeable to water.

(vi) In narrow lanes and busy markets where the road surface is not open to the sun and so requires frequent cleansing to ensure proper sanitation.

(vii) In city streets where facilities for the drainage of storm water are poor or non-existent, and where such water is likely to run over the road surface.

(viii) In urban roads where it is desired to avoid frequent road repairs and the consequent interference with traffic in congested areas caused by stacked materials, road plant and the actual re-surfacing work. It may be pointed out that in such instances, by special arrangement, the service pipes and cables, etc., should be made easily accessible without the need for opening up the road at intervals.

(ix) For the outer lanes of carriageways with four or more lanes of traffic carrying both pneumatic and steel-tyred vehicles, the concrete surfacees tend to draw slow moving steel-tyred traffic, helping a freer movement.

Q. 2. **What types of base courses do you provide under cement concrete surfacing when the subgrade is: rock, gravel, sand, sandy clay, clay, silt or black cotton soil?**

(i) On rock: On rock the base should consist of a layer of lean mix concrete of 1:4:8 proportion, sufficiently thick to cover all protruding irregularities and thus provide a smooth and firm working surface.

(ii) On gravel and sand: If the gravel or sand is well-graded so that a high bulk density can be obtained, and if it can be compacted to a smooth and regular surface, a base course may not be necessary.

If the grading is poor so that a high bulk density cannot be obtained by compaction alone, it may be improved by adding imported material or by providing a base course of suitably graded granular material, water-bound macadam, stabilised soil or lean concrete.

(iii) On sandy clay: with a thoroughly stable soil the base may consist of a well compacted layer of suitable granular material, stabilized soil or water-bound macadam. On a soil of low stability the same



materials should be used, but laid to a greater thickness.

A layer or two of flat bricks or broad-based rubber soling, (limestone, laterite or granite stone 6 in. to 9 in. thick), with either a 4 in. to 6 in. thick layer of water-bound macadam of stone, or a 3 in. thick layer of jhama, laterite or kankar and a 3 in. thick layer of water-bound macadam of stone over it has been found satisfactory on sandy clay subgrades.

There are also instances where cement concrete slabs have been laid in the last few years directly on a 6 in. base of jhama or laterite metal and these are still functioning satisfactorily. These roads would need careful observation in the years to come.

(iv) On clay: It is of the utmost importance when laying concrete roads on cohesive soils, such as clay, to ensure that the clay is not too wet at the time it is covered and secondly, to cover the clay with a waterproof base such as stabilised soil (soil cement) or lean concrete, this is necessary to prevent softening of the soil by the ingress of water through cracks or poorly maintained joints in concrete. The provision of such a base of adequate thickness will reduce the stresses imposed on the soil to within safe limits. It is difficult to compact a base course when the soil consists of a heavy plastic clay, and it is generally desirable to cover the heavy clay with a sub-base. This would consist of granular material such as moorum 4 in. to 6 in. thick. If the clay is sufficiently dry and hard to enable the base to be properly compacted, the provision of this sub-base will not be necessary.

(v) On silt: The subgrade should not be allowed to become too wet during preparation. It should be thoroughly compacted to ensure adequate stability, and then covered with a waterproof base of stabilised soil as described for clay. Alternatively, plaited brushwood mattress weighted with rough timber corduroy raft may be laid on the subgrade and granular fill or sandy clay (whichever is available nearby) may be laid over it to the requisite depth as a thick sub-base; this may be covered with a suitable base as for gravel or sandy clay.

(vi) On black cotton soil: The subgrade in the box trench shall be treated with sand during the driest season when cracks and fissures characteristic of black cotton soil open out to their maximum depth and width. Sand shall be spread over the cracked subgrade and dry broomed and rammed into the cracks to the point of refusal. A blanket course of well compacted sand 4 in. to 6 in. thick shall next be laid on the surface. In case sand is not available within reasonable distance, a good depth of black cotton soil shall be replaced by granular fill of good quality.

If the cracks extend deep down into the soil, sand piles 6 in. to 12 in. dia., 30 in. apart, shall be driven into the ground reaching well below the depth of cracks before laying the blanket layer of sand. A layer of moorum or kankar 6 in. to 12 in. thick shall be placed over the sand, and on this, a base course of granular material or stabilised soil (soil cement) or macadam shall be laid.

Q. 3. **What methods of compaction do you specify for (a) subgrade, and (b) sub-base and what tests do you prescribe to show that compaction is complete?**

(a) Subgrades: Most of the concrete roads in this country have been laid on well consolidated water-bound macadam roads with or without bituminous surfaces and maintained for decades. The question of compaction does not therefore arise in their case. In cases where the concrete pavement is wider than the water-bound macadam surface, the consolidated formation itself serves as the subgrade and no further compaction is usually deemed necessary.

In the case of new formations, the soil in the subgrade should be compacted under controlled conditions to a maximum density, the aim being to reduce the air voids to a minimum and bring the soil to a condition in which there will be less tendency for subsequent changes in moisture content to take place. In specifying the required degree of compaction it would be convenient to state a dry density corresponding to a maximum permissible air content which should be 5 per cent for subgrades and bases.

*Note*: "Timing the construction of cement concrete slabs on prepared base courses would depend primarily upon whether such construction received full compaction during construction period or whether further consolidation under the traffic is considered necessary. Therefore, along freshly laid or re-constructed water-bound macadam construction, usually a time of 3 months to a year is allowed for compaction under traffic before concrete slabs are constructed."



Suitable compacting equipment is as follows:

(i) For cohesive soils: Sheepsfoot rollers, multi-wheeled pneumatic rollers, smooth-wheeled rollers and power rammers. The last mentioned are particularly suitable for small areas and confined spaces such as bridge abutments, etc.

(ii) For granular soils: Smooth-wheeled rollers, vibrating rollers and pneumatic tyred rollers.

On cohesive soils, compaction is best effected initially by a sheepsfoot roller or pneumatic tyred roller, followed by a smooth-wheeled roller, to give the final shape and finish.

Rolling should start at the sides of the road and work towards the centre, or where there is a straight cross-fall, from the low side towards the high side. If a smooth-wheeled roller of the heavier type is used alone, it will have a tendency to bed into the loose soil thereby causing ridges and waviness. This tendency can be counteracted by first going over the soil with a light roller, or with a vibrating roller in the case of granular soils, and then finishing off with the heavier smooth-wheeled roller. A tandem roller which gives uniform pressure produces the best results.

Rolling should continue until the processed soil no longer shows any yield under the roller and until an uniform, close-built surface is obtained.

The thickness of the layers in which the material is compacted is of great importance. No layer should have a greater loose thickness than 9 in. which can be compacted to a thickness of about 6 in.

(b) Sub-base: The equipment for and the method of compaction of sub-bases composed of soil or soil cement is the same as for subgrades of the same type of soil, described in the preceding paragraphs. The compaction of macadam sub-bases should be effected by using a smooth-wheeled roller with a loaded weight of not less than 10 tons. Loose thickness of stone to be compacted in one layer should not be more than 8 in.

For soils and stabilised soil (soil cement), the usual method of measuring compaction in the field is to determine the dry density of the compacted material in situ. There are many methods of making this determination but the core-cutter and sand-replacement methods are the simplest and the most favoured.

In the case of water-bound macadam where fairly rigid specifications for compaction under a heavy roller are usually practiced, no special test for compaction is normally necessary. The thoroughly compacted surface should be firm and even, and true, as judged by a ten-foot straight edge. Tests such as plate bearing and C.B.R. tests are used primarily in preliminary work for design of pavement and are of limited application for field tests of compaction of subgrade and sub-bases. Also preliminary tests for classification of soils usually indicate problems of compaction under field conditions.

Q. 4. **Do you insulate the cement concrete slab from the base course or do you bond it with the base course? What are the conditions in which either of the methods is prescribed as suitable?**

A very large extent of concrete roads constructed in the country is normally laid directly on the base which is usually of well consolidated water-bound macadam. Where traffic loads have not developed sufficiently to overstress such pavements, the bonded condition of the slab with the water-bound macadam has not caused any special defects. In urban areas, where thicker slabs have been adopted, they have been insulated from the subgrade.

Insulation is particularly desirable in the case of clay subgrades and soils which are subject to large volume changes due to variations in moisture and/or temperature.

Q. 5. **What materials have been used for insulation and with what results?**

Specially prepared waterproof papers and/or thin layers of sand ($\frac{1}{2}$ in. to 1 in.) have been used for insulation in concrete roads in India. Use of these materials has been for more than one purpose, following being the order of importance:

(i) Reduction of friction between the concrete slab and the base caused by temperature and/or moisture movements of the concrete.

(ii) Prevention of any dirt or loose material on the surface of the base from getting mixed with the lower layers of freshly placed concrete.

(iii) Prevention of the escape of cement paste into the bases which are permeable, such as macadam, gravel, sand, etc.



(iv) To reduce the risk of attack of the concrete by chemicals carried in the soil water.

Layer of sand alone, spread on the base, will not satisfy requirements (ii), (iii) and (iv) above and is not so satisfactory as a waterproof paper for the purpose.

Q. 6. **What are the thicknesses of concrete slab and base course prescribed for carrying normal traffic and heavy traffic on various classes of subgrade?**

Generally, as concrete roads have been built to cater to the requirements of heavy traffic after other types having been found inadequate, the consideration of a design for base course in conjunction with thickness of concrete has not come up. A minimum crust depth of 3 in. of macadam, in case of average subgrades, or 3 in. macadam with 6 in. soling in case of clayey or cohesive subgrades was insisted upon. Prior to World War II, the equivalent depths of uniform thickness of concrete roads which were confined to urban areas were based on tonnage of daily traffic per foot width of road and were as follows:

7 in. for mixed traffic of concentration 150 tons and over per day.

6 in. for 100 to 150 tons per day.

5 in. for 50 to 100 tons per day.

3 in. to 4 in. for private roads and driveways.

With the advent of the War, and due to reduced funds available for road construction, smaller thicknesses were adopted even on higher traffic intensities and the average experience with such construction was as follows:

For daily traffic upto 1,000 tons gross, 3 in. thick roads have satisfactorily withstood traffic but they are showing signs of distress as traffic on such lengths has gradually increased.

For traffic upto 1,500 tons per day, 4 in. thickness has proved quite satisfactory and is being increasingly adopted on most of the rural highways.

For heavier intensities of traffic, $4\frac{1}{2}$ in. and 5 in. thicknesses have been adopted.

Where there are indications of traffic intensities increasing beyond these limits and also where there is scope of wheel loads of 3 tons and over plying on such lengths, it would be desirable to adopt increased thicknesses depending on types of improved subgrade treatment and actual estimates of heavy wheel loads and their frequencies. Scope for improving the quality of concrete by better control methods and thereby obtaining better performance for mixed traffic even with the same thicknesses also exists in a few instances.

**Q. 7. To what extent do you reduce the thickness of the main slab by the provision of a base course? Is each designed independently of the other? What is the minimum thickness of cement concrete slab used and with what results?**

Generally, the thickness of concrete roads in India has been selected on an empirical basis, presupposing the presence or construction of a well consolidated macadam base, and the reduction or increase of thickness of slab with improved base courses has not come up.

As per recent practice, the minimum thickness of concrete capable of sustaining the worst combination of wheel loads and their frequency on a base treatment suited to the type of soil and the availability and cost of local materials should be the criteria. Base courses of macadam or their equivalent in bearing capacity have proved quite adequate and improving them beyond this limit, would not be of significant advantage to reduce the thickness of concrete.

With a good knowledge of the underlying soil, it is now possible to estimate fairly accurately the requirements of overall depths of pavements and bases and therefrom work out several alternative combinations of bases and pavements to determine the most economical.

The minimum thickness of plain concrete slab used fairly extensively is 3 in. and the behaviour of such slabs under medium traffic has been satisfactory where the base is unyielding and impermeable. In such cases, the slabs have not been usually insulated.

**Q. 8. Have you used the thickened edge section, and, if so, what is the section used and with what results?**

Slabs with thickened edge sections such as 9-6-9 in., 7-5-7 in., 6-4-6 in., 5-3½-5 in., and 4-3-4 in., have been used and have functioned satisfactorily in the past.

Theoretically, thickened edge construction gives a balanced design in which the maximnm tensile stress due to wheel loads



at the edge is approximately equal to the maximum tensile stress at the interior. The most severe stress normally occurs, however, when the stress due to wheel loading is combined with the stress produced by internal temperature gradients.

In practice, the construction of thickened edges involves additional labour in shaping the edges of the formation, and subgrades which have been carefully prepared and compacted would have to be disturbed. The edge of the slab will therefore be resting on a prepared subgrade of reduced thickness and one which may have been weakened by disturbance during reshaping. There is also a risk that water will collect in the depression in the subgrade or base formed by the thickened edge. The fairly satisfactory performance of the uniformly thick slabs of 4 in. to 5 in. used in the country indicates that, with adequate subgrade support, the edge stresses under worst combination of loads and stresses are still not so high for present traffic conditions.

**Q. 9. What is the least acute angle that you have permitted in slabs at intersections? Have any breakages of such corners been noticed and under what conditions?**

In the past acute corner angles of 30° and 60° were commonly permitted and wherever such angles were allowed, cracking and breakage of the slab have occurred.

Corner angles of less than 75° should be avoided. It would normally be possible to lay out slabs at junctions and corners without any acute angles by the judicious introduction of slabs with polygonal shapes.

**Q. 10. What is the maximum width of slab constructed without using a longitudinal joint?**

Slabs upto 22 ft in width have been laid without a longitudinal joint, but where the slabs are made more than about 15 ft wide they tend to crack approximately along the centre line, the tendency to crack increasing as the width increases.

The most suitable width of slab is usually determined by constructional requirements and practical conditions. Experience has shown that the maximum width of slab for hand compacted concrete should not exceed 15 ft. For greater widths the longer tamper required will be unwieldy and will have a tendency to warp and twist.

In view of the above factors, the most rational and safest practice would be: (a) to restrict the width of slab to 12 ft, whether the compaction is effected by hand tamping or vibration and (b) to provide central longitudinal butt joints for widths of carriageway greater than 12 ft by laying the concrete in two widths, one on either side of the centre line of the road.

The joints of the slab, such as the road intersections and road widenings, haunchings, etc., should be so arranged that widths less than 4 ft do not occur.

**Q. 11. What is the least and the greatest spacing of transverse expansion joints? Does this vary with slab thickness?**

Several factors affect the spacing of expansion joints, the most important of which are the prevailing atmospheric temperature at the time of construction, the daily and seasonal temperature changes, the thickness of the slab and the frictional resistance of the base.

If the road is constructed during the hot season of the year, its subsequent tendency will be to contract and shrink, so that at no future date is the length of the slab likely to be much greater than when first laid.

The practice in this country which has proved satisfactory by experience is to space all expansion joints at intervals of 90 ft to 120 ft and at the same time to provide construction joints of the butt type at every 20 to 40 ft. Intervals of 90 ft for expansion joints and 30 ft for contraction joints were most generally adopted; lately, contraction joint spacings are usually reduced to 25 ft or, alternatively, dummy joints are employed midway between contraction joints. For small slab thicknesses adopted in this country, the effect of thickness on the spacing of expansion joints is not significant.

**Q. 12. What types of joints and what spacings between these joints have been adopted by you and how have they behaved?**

There are three main types of transverse joints in concrete roads. They are as follows:

(i) Expansion joints: Expansion joints form a complete separation between adjoining slabs and permit the concrete to expand as the temperature increases. Such joints should extend the full width and depth of the slab. They should be at right angles to the centre line of the road, and, where the road is constructed in two or more widths, they should be continuous and not staggered. They should be filled with a non-extruding filler and should be sealed to prevent the entry of water and non-compressible material such as grit.

(ii) Contraction joints: Contraction joints are included in concrete roads to control any cracking which may take place due to contraction or shrinkage of concrete. They also relieve warping stresses in concrete. Contraction joints may be plain, vertical butt joints extending to the full depth of the slab, or may be dummy joints extending to about one-third of the depth of the slab and so forming a plane of weakness.

(iii) Construction joints: The primary purpose of construction joints is to facilitate construction. It is provided for convenience only when, for instance it is necessary to terminate the work of placing the concrete at any point other than at an expansion or contraction joint, or to suit the special requirements of formwork at road junctions. When constructed, it acts as a contraction joint.

Expansion, contraction and construction joints are the three types of joints ordinarily used in this country. The last of these functions as contraction joints as well.

The jointing practice described in question 11 has proved quite satisfactory in most cases except for increased transverse cracking in some locations, which has led to the adoption of smaller spacings of contraction joints as mentioned in question 11.

**Q. 13. Have you noticed any deformations or displacements of slabs which are directly attributable to the presence or absence of joints? If so, what is the range of movement? What steps do you take to rectify such slabs?**

Out of the limited number of miles of concrete roads laid in this country, there are few or none at all which have been constructed without expansion joints. There have been no known instances of deformations or displacements caused by the presence of expansion joints.

Some cases of buckling of concrete slabs (or "blow-ups" as they are called in America), have occurred in U. P. In the G. T. Road between Ghaziabad and Bulandshahr, these have been reported to be due to the failure of the expansion joints to function properly on account of the intrusion of incompressible material in the joint spaces. It may, however, be pointed out that in findings of main investigations abroad, certain types of coarse aggregate which cause expansion in concrete have been the principal cause of failures of this kind.

Repairs in such instances consist in cutting and removing the damaged portions of the slabs and laying fresh concrete in their place.

Q. 14. **What mixes do you prescribe for concrete for road slabs?**

A nominal mix of 1 : 2 : 4 by volume has been almost universally adopted except in very special cases where a 1 : 1½ : 3 proportion has been found necessary because of the need for a harder wearing surface under particularly exacting conditions of traffic. In order to avoid under-sanding due to the bulking of sand in the presence of moisture, the proportion of sand is generally increased if it is damp or moist. Two-course construction with mixes of 1 : 1½ : 3 or 1 : 2 : 4 for top courses and bottom courses of 1 : 2 : 4 or 1 : 3 : 6 respectively, have been tried and found to produce good results with consequent economy. The thickness of top courses in such construction has been varied from 1½ in. to 3 in.

The modern trend in the matter of mix proportions for concrete is to favour proportioning by weight and also to specify compressive and/or flexural strength required at twenty-eight days. Degree of workability is selected according to the compacting plant available and the mixes are designed for a selected w/c ratio according to the quality and grading of the aggregates obtained locally. This method has yet to be generally adopted in this country, since it would involve facilities for frequent testing of concrete specimens and qualified field staff to exercise accurate quality control at site during construction, both of which are not at present easily obtained.

Q. 15. **Do you grade the coarse aggregate or use the material as naturally graded and received from the quarry?**

Generally coarse aggregates whether hand-broken or crushed stone are collected at site in two or three separate sizes and broad gradings of aggregates are normally specified for blending them; for example, 66-2/3 per cent of 1-1/2 in. size and 33-1/3 per cent of 3/4 in. size. The material is rarely used without regrading as received from the quarry; as it is found



necessary that for obtaining a strong, dense concrete, the aggregates must be so graded that the voids are reduced to a minimum.

Q. 16. **What is the maximum slump or water used per bag?**

The slumps adopted vary from 1/2 in. to 1 in., if concrete is compacted by vibration and 1 in. to 2 in. if compacted by hand tamping.

The normal range of water content is four to five and a half gallons of water per cwt. bag of cement, due allowance being made for any moisture present in the aggregates.

The quantity of water to be used would also require adjustment for varying atmospheric conditions at the time of placing.

Q. 17. **Do you use mechanical equipment for finishing the surface?**

Mechanical vibrators attached to the tamper are quite commonly used. The finish obtained is found to be satisfactory. The surface of the wet concrete after vibration is also roughened by passing a light brush or wet hessian across the length of the slab.

Q. 18. **What methods of maintenance of concrete roads have been used and at what average cost?**

Concrete pavements, when properly constructed, have needed no maintenance, other than periodical sealing of joints and cracks and making up of the shoulders to ensure protection to the edges of the concrete. Hair cracks are usually ignored, while spalls and casual peeling off are made up with bitumen and small aggregate if the damage extends deeper than 1 in. Patches are done with cement concrete. In some instances, grooving or rutting of concrete slab caused by concentrated wear of the steel tyres of the bullock cart has also been patched up with bitumen or concrete.

Q. 19. **Have you done any cement macadam work or rolled concrete, and if you have, what has been your experience with it?**

Cement bound macadam roads by the sandwich method have been tried on small scales in U.P., Bombay (Municipality), Hyderabad and Madras. The results achieved, however, have not been particularly encouraging. Some successful experiments with cement bound macadam by the sandwich as well as the grouted methods have been carried out in Gwalior and at other places. Experience abroad indicates considerable success with cement bound macadam especially for light traffic roads on existing good foundations.

Lean mix rolled concrete such as 1 : 3 : 10 has been laid for short experimental stretches on the Calcutta-Madras National Highway in Madras State. Except for a few worn out patches here and there, such stretches have given satisfactory service for over ten years. The drawback of this process appears to be the difficulty of economically making the quantities of concrete required for laying them uniformly in a comparatively large area and then rolling and finishing it to required surface tolerances within the initial setting time. The savings that are possible from the adoption of rolled concrete suggest the need for under taking further experiments, at least on roads with moderat intensities of traffic.

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# "A NOTE ON THE UPTODATE POSITION WITH REGARD TO THE USE OF SURKHI AS A POZZOLANA"

*By*

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&

N. R. SRINIVASAN*

## CONTENTS



## SYNOPSIS

The Paper deals with the work so far done in the country on the use, manufacture and research on surkhi. It also outlines some of the problems that need further investigations so that after necessary studies it may be possible ultimately to produce surkhi as a standardised building material, the use of which, besides effecting economy, will improve several properties of concrete and mortars.

## 1. INTRODUCTION

Lime and surkhi were important building materials in this country till some fifty years ago. These have been used in our ancient historical structures which have stood for centuries. The use of cement as a construction material became popular since the end of the First World War, due to its availability as a standardised material and its early hardening properties, which helped in speedy construction. With the shortage of cement

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experienced in the country since the Second World War, various research organisations have been engaged in looking for alternative building materials, an obvious one being lime. Thus a considerable amount of work has been done on the use of surkhi in lime-surkhi mortars as well as a pozzolana in cement concrete.

Besides effecting economy in cost of construction, the use of surkhi, as part replacement of cement, improves certain properties of mortars and concrete, such as plasticity and workability, reduces bleeding and segregation, increases impermeability, lowers heat of hydration and affords increased resistance to sulphate attack and alkali aggregate reaction.

In recent years an attempt has been made to try and understand the basic reactions that take place when surkhi is processed for use as a pozzolana, which has led to certain original trends of thought. The fundamental aspects of surkhi, as a result, are much better understood now, and surkhi can consequently be manufactured on a more scientific basis than was hitherto possible.

Uptodate information on the use, manufacture and research on surkhi in India has been compiled in the hope that the information will prove to be useful for various construction agencies as well as research workers for formulating further programmes of investigation, so that it may be possible to make an intelligent use of the various advantages in future construction works in the country.

## 2. USE AND MANUFACTURE OF SURKHI

Surkhi has been extensivly used in some major engineering works in India. A brief information about the manufactnre and the results obtained at various works is given below :

**Vanivilas Sagar Dam:** Due to the difficulties involved in importing cement, the desirability of avoiding excessive heat of hydration and better workability and plasticity obtained with lime-surkhi mortar, the Mysore Engineers used 1 : 4 lime-surkhi (without sand) mortar for construction of Vanivilas Sagar Dam in 1899. The surkhi used was slightly underburnt. Against the allowable maximum stresses of 125 p.s.i. for this dam of 142 ft height, an average compressive strength of 670 p.s.i. was obtained at 14 days' age with this mortar [1, 2].

**Marikanava, Krishnaraja Sagar and Hirebhasgar Dams:** Based on the experience at Vanivilas Sagar Dam, lime-surkhi mortar was used in these three dams. Some of the strength results obtained in the investigations for Vanivilas Sagar and Krishnaraja Sagar Dams are given in Table 1.



**Nizam Sagar Dam:** In Hyderabad, the Nizam Sagar Dam and various other hydraulic works using lime-surkhi mortars were constructed. The construction of Nizam Sagar Dam was started in 1923. The bricks for surkhi making were hand-moulded and burnt in ordinary kilns[3]. Firewood was used as a fuel. The bricks were dried for 7 days and then clamped. Generally, 20,000 bricks were clamped for each flue and every kiln had five flues. The flues were $2\frac{1}{2}$ ft wide and the basement was 3 ft high. The average height of the pyramidal portion of the kiln was 9 ft. The walls of the basement were built with raw bricks in mud and, after the erection of the kiln, a casing of half a brick was given and plastered in order to conserve the heat. The kiln took 4 days for erection, 2 days to burn, 10 days to cool and 8 days to unload. The sound bricks were broken to required size for the preparation of the mortar. The cost of the powdered surkhi in those days worked out to be Rs 9 per 100 cu. ft.[3]

Lime and surkhi were ground together in mills to make mortar. The tensile strength of the lime-surkhi-sand mortars of different proportions was between 41 to 78 p.s.i. at 14 days age and 133 to 202 p.s.i. at one year's age. The minimum tensile strength prescribed at 14 days' age was 50 p.s.i. The compressive strength of these mortars was between 57 to 78 tons per sq. ft. at 3 week's age. [3]

**Mettur Dam:** Surkhi was also used in the construction of Mettur Dam where it was mixed with cement for making the red cement mortar. Since good quality lime was not available in adequate quantities nearby, lime-surkhi mortar was not used. Moreover, the use of cement was adopted to speed up construction [4]. The surkhi incorporated in these mortars was meant to reduce the leaching of lime and to decrease the heat of hydration of the dam. However, lime-surkhi mortar was also used in certain portions of the dam.

For the preparation of surkhi, about 50,000 raw bricks weighing about 80 tons were packed in each country type kiln. One ton of firewood was required for every 10 tons of packed bricks.

Attempts to burn in Bull's patent trench kilns were unsuccessful, resulting in bricks being sooty and either underburnt or overburnt.[4]

The bricks were broken to 1½ in. - 2 in. size and fed into disintegrators with a capacity of 1½ - 2 tons per hour. The following standard of fineness was prescribed for the surkhi :

| B. S. Sieve No. | Per cent retained |
|---|---|
| 40 | 12.5 |
| 76 | 27 |
| 100 | 35 |

Tests in the laboratory showed better strength results with finer surkhi [4]. The following results were obtained, using 1 : 4 : 8 concrete, in which 20 per cent of the cement was replaced with surkhi of different finenesses.

| Fineness of surkhi | Compressive strength (28 days) tons per sq. ft. |
|---|---|
| Passing B. S. Sieve No. 20 | 55.6 |
| ,, 50 | 68.0 |
| ,, 100 | 72.8 |

Practical considerations, however, led to the adoption of the coarser specifications of fineness.

Surkhi-lime-sand mortar of proportion 1 : 2 : 4 gave an average compressive strength of about 50 tons per sq. ft. in 28 days and 113 tons per sq. ft. in 6 months. Compressive strengths for cement mortar and red cement mortar obtained were as given below :

| Type of mortar | Compressive strength (tons per sq. ft.) of mortar cubes of proportions | | |
|---|---|---|---|
| | 1 : 2¾ | 1 : 3½ | 1 : 4 |
| Cement mortar | 242 | 199 | 143 |
| Red cement mortar (20 per cent cement replaced by surkhi) | 183 | 166 | 121 |

It was found that cement concrete increased in strength very rapidly in the early stages, but after two months the increase was very gradual. Lime-surkhi-sand mortar, however, continued to increase in strength for a much longer period, though its initial strength was much lower than that of cement concrete.



**Lower Bhawani Project**: Well-burnt surkhi was used in the cement mortar for the construction of Lower Bhavani Project.

**Tungabhadra Dam Project :** In the construction of Madras side of Tungabhadra Dam, a red clay rich in fines was selected for the manufacture of surkhi. Balls of clay were made and burnt in country type kilns.

**Bhakra Dam** : As a result of investigations carried out at Concrete Research Laboratory, Nangal, surkhi prepared out of raw shale, calcined at a temperature of 1400°F. is being used as a pozzolana in concrete for Bhakra Dam. In 1956, a modern plant to manufacture about 100 tons of surkhi per day from raw shale was installed at Bhakra. Calcination is being carried out in a rotary kiln, with necessary temperature control arrangements. All the stages of the process are fully mechanised.

### 3. RESEARCH WORK ON SURKHI

3.1. **Pre-war Research**: Upto about 1932, the cement industry was in its infancy. In 1915, only 85,000 tons of cement were produced which met only about 1/3rd of India's the then requirements[5]. In 1930, the production of cement was about 6 lakh tons. By 1940, it sharply rose to about 17 lakh tons. Between 1930 to 1940, the industry became well organised and greater publicity was given to the use of cement. The lime and surkhi industries were on the decline, as the products were inferior in quality.

In 1940, Dutt presented data to show how a 1 : 9 cement-sand mortar worked out cheaper and gave better strength than the normal lime surkhi mortars [6], [7]. By this time investigations for the use of surkhi as a building material were started. The work carried at various laboratories is briefly given below :

**Alipore Test House**: The first detailed investigation on surkhi was conducted by Khan and Verman at the Alipore Test House, using the bricks available around Calcutta area [8],[9]. Tensile strength determinations were made for various types of surkhis ground finer than B.S. 30 sieve. From these experiments, it was concluded that overburnt surkhi was better than well-burnt or underburnt surkhi. Replacement of cement with overburnt surkhi to the extent of 25 to 50 per cent was recommended.

### 3.2. Research Work during War Years

During the war, when cement was mainly used for military purposes, it was suggested that other substitutes should be tried. Dutta suggested the boosting up of cement production by producing 'high silica portland cement' [10,11,13]. He advocated the blending of 'jhama' powder of cement fineness with Portland cement to form the 'high silica portland cement'. From his experiments, he also showed that lime-jhama mortar with 5 per cent gypsum could develop even greater strength than a 1 : 3 cement-sand mortar in 90 days [12,14]. However, during the war, due to lack of laboratory facilities, no further progress in the investigation, pertaining to surkhi could be made.

### 3.3. Post-War Research

After the Second World War, a number of multi-purpose river valley projects were taken up by the Government. As this involved construction of complicated massive structures, a number of engineering laboratories were set up in many States and these carried out extensive investigations of the materials to be used in different projects. A careful perusal of the results of these investigations on lime and surkhi reveals that most of the materials tested were non-reactive. A large amount of data was collected, but it suffered from serious defects. In the absence of any standards in the choice of these materials, many of the laboratories fell a prey to conventions. Thus generally, only loamy soils, fit for brick making, were examined regarding their suitability for making surkhi and bricks from such soils were ground coarse for various tests. Often the problem was over-simplified, when general specifications for surkhi were attempted on the basis of the results of only a few local samples. This led to contradictory data from different laboratories, sometimes the specifications contradicting their own results. Some details of the work done in some of the laboratories are presented below :

**Krishnaraja Sagar Research Station:** Experience at Vanivilas Sagar and Krishnaraja Sagar had given the Mysore Engineers the idea that certain percentage of 'fines' were needed in the soil for surkhi making. The Krishnaraja Sagar research station specified that the soil should have 25 per cent to 50 per cent of materials below 0.05 mm. However, in their investigations of various soils for making surkhi for Tunga Anicut, the low reactivity of two soils, $D_1$ and $D_3$, which satisfied the above specification, was explained being due to the low clay content, which was about 5 per cent.

Besides the chemical analysis of the soils, strength tests have been reported for the lime surkhi mortars for different projects.



These generally compare unfavourably with the Vanivilas Sagar or Krishnaraja Sagar results. Some of the results are given below :

| | | Average tensile strength p.s.i. | Compressive strength p.s.i. |
|---|---|---|---|
| Nugu reservoir [16] | 1 : 4 | 157 (8 weeks) | 739 (8 weeks) |
| Badra dam [15] | 1 : 4 | — | 800 (12 weeks) |

**Hyderabad Engineering Research Laboratory**: Most of the surkhis tested for the various projects were derived from loamy soils and showed poor results. Some of the results are given in Table 2, [17], [18], [19].

**Irrigation and Power Research Institute Punjab:** Experiments with mixtures of surkhi, white lime and kankar lime showed that the addition of white lime did not increase the strength of surkhi-kankar lime mortars, which was probably due to inactive surkhis [2]. Tensile strengths, varying from 250 to 320 p.s.i. at 3 months age, were got with the various mixtures.

The institute tried to evaluate the pozzolanic activity of different types of surkhis through lime absorption test and found that underburnt surkhi had better tendency to combine with lime as compared with normally burnt or overburnt surkhis [21]. This test was also used to determine the required degree of burning of clays [12]. Later tests, however, showed that the lime absorption test was unreliable for indicating the pozzolanic activity of surkhis prepared from the Punjab soils [23,25].

The institute also reported that surkhi prepared from a clayey soil had better grindability [22,24].

Based on the work at the Punjab Irrigation Research Laboratory, Handa, Dhawan and Bahri suggested the following specifications for the soil for making surkhi [24] :

| | |
|---|---|
| Total soluble salts | 0.3 per cent max. |
| Calcium carbonate | 3 per cent max. |
| Per cent retained on B.S. 100 sieve | 10 per cent max. |
| ,, ,, 200 ,, | 25 per cent max. |
| Clay content | 20 per cent min. (relaxable in the case of silty soils) |

Kankar nodules to be separated before burning.

The specifications for surkhi, suggested by them, are given below:

| | |
|---|---|
| Loss on ignition | 5 per cent max. |
| Silicon dioxide | 50 per cent min. |
| Aluminium oxide | 10 per cent min. |
| Magnesium oxide | 3 per cent max. |
| Specific gravity | 2.65-2.75 |
| Unit weight | 70-90 lb per cu.ft. |

**Concrete Research Laboratory, Madras.** Work on Lower Bhavani Project showed that well-burnt surkhi was better than underburnt or overburnt surkhi [26].

Some important results were obtained during the investigations for Tungabhadra project. A notable departure from the usual practice of preparing surkhi from brick earth was adopted in the construction of the then Madras side of the Tungabhadra Dam, wherein a red clay, rich in fines, was selected after an extensive investigation of the soils for the manufacture of surkhi. After conducting comparative tests with some conventional surkhis, it was reported that the high reactivity of the Tungabhadra surkhi was due to its greater clay content. "Tungabhadra Surkhi", the report [27] said, "has greater amounts of iron and alumina and it has most of its silica in the combined form as silicates. The Madras surkhi has much of its silica as quartz. This suggests that the type of loamy or sandy soil, fit for brick manufacture, may not be the most suitable soil for good surkhi".

Rao and Venkataraman [28] reporting to the 4th Congress on Large Dams, presented the data on Tungabadra surkhi, collected from the works of the Madras Concrete Laboratory and the Tungabhadra Field Laboratory. The compressive strength of $1:1\frac{1}{2}:\frac{1}{2}$ lime-surkhi-sand mortar was about 85 tons per sq. ft. as against a compressive strength of 80 tons per sq. ft. for a 1 : 2 lime-surkhi mix. The permeability coefficient for lime-surkhi-sand mortars of proportions $1:1\frac{1}{2}:\frac{1}{2}$, after 60 hours of test, was about $2000 \times 10^{-12}$ ft/sec. Replacement of cement with surkhi upto 20 per cent was said to result in practically no reduction of mortar strengths of leaner mixes. Addition of 10 to 15 per cent of cement by weight of lime to lime-surkhi-sand mortars was said to increase the strength appreciably.



**Hirakud Research Station:** It was by now firmly established, as a result of extensive American experience, that burnt clays and shales could also be used in concrete with many resulting advantages, besides their use in mortars. The greater workability, lesser heat of hydration, prevention of the leaching of lime and the protection it gave to the concrete from harmful reactions, like the alkali aggregate reactivity and sulphate attack, encouraged the use of pozzolanas in many dams and road works in U. S. A.

The use of surkhi in India till 1950 was mainly confined to lime-surkhi or cement-surkhi mortars. In connection with the Hirakud project, an extensive investigation of the pozzolanic materials available near the dam site was undertaken by the Hirakud Research Station for use in concrete [29, 30, 31, 32, 33]. The materials investigated for Hirakud dam included some shales, surkhis, natural clays, phyllites and some conglomerates. Talabira shale was found to possess pozzolanic activity even in the unburnt state. Calcination did not improve its activity.

Work on different surkhis showed that these, when used as replacement of cement upto 25 per cent, generally increased the setting time somewhat and gave more than 90 per cent of the tensile and compressive strengths of the specimens made without pozzolanic replacement at three months' age. The water requirement for normal consistency was also raised by about 10 per cent in the case of 25 per cent cement replacement by an active surkhi. An appreciable reduction in the heat of hydration of mortars as well as concrete was reported as a result of replacing part of the cement with pozzolana.

**Krishnaraja Sagar Research Institution**: The work done in all the research stations was summarised by Doddiah and Gurushankariah [34] of the Krishnaraja Sagar Research Institution and certain standards were suggested for surkhi and its manufacture. A few extracts from these standards are presented below:

Preparation of surkhi involves the following operations:

(1) Preparation of soil

(2) Moulding

(3) Burning

(4) Grinding and screening, and

(5) Storing

1. **Preparation of the soil:** The soil must be well sieved to remove all the organic impurities like leaves, lumps, coarse

gravel, etc. It must be mixed with the necessary amount of water and made into a dough and well kneaded by kneader.

2. **Moulding**: The kneaded mass is moulded into bricks of 6 in. by $4\frac{1}{2}$ in. size. These bricks must be dried in the sun for 2 days and then spread over for drying on the other side also. Drying is continued for one more day.

3. **Burning**: The bricks may be burnt in a muffle furnace under controlled temperature.

4. **Grinding and Screening**: The surkhi bricks should be ground to a fine powder in a hammer mill or a disc mill. A suitable grinding mill has to be devised by investigation. The grinding may be done on close circuit system with a shaking screen of 100 mesh sieve.

5. **Storing**: The surkhi powder should be stored in such a way as to keep it dry.

"The equipment and technique adopted in the field for manufacture of surkhi mortar for large works requires improvement. The equipment used at present for burning lime and surkhi and grinding of mortar is intermittent in operation and wasteful. Therefore, a continuous kiln for burning lime and surkhi must be developed by investigations resulting in economy of fuel, greater control over temperature and degree of burning, maintaining the uniformity of the product and prevention of contamination by impurities. It may be added that the continuous Hoffman kiln may be suitable with some modifications. Grinding of surkhi mortar also requires a suitable continuous mill".

"The sequence of operations in the manufacture of surkhi mortar varies from place to place. The flow diagrams of the procedures, as adopted in Mysore, Sukkur and Tungabhadra are given below. From a study of these diagrams and other aspects, a flow diagram is suggested for adoption".

| | | | |
|---|---|---|---|
| 1. | SUKKUR METHOD | Kankar limestone—burnt in kiln Graded sand<br>Clayey soil—ground, wet, burnt in kiln | Ground wet in mortar mill |
| 2. | MYSORE METHOD | Kankar limestone - burnt in kiln. Surkhi soil moulded into bricks, burnt in kiln | Ground wet in mortar mill |



| | | | |
|---|---|---|---|
| 3. | TUNGA-BHADRA METHOD | Kankar limestone—burnt, ground slaked<br>Soil lumps—dried—burnt, graded sand. | Ground wet in mortar mill |
| 4. | SUGGESTED METHOD | Kankar from quarry—burnt in kiln. Soil made into bricks—burnt in kiln. | Ground wet in mortar mill |

### 3.4. Recent Research

The production of cement increased to about 4.5 million tons by 1955 and it was steadily increasing further. However, the pace of development due to the first and second five year plans was so brisk that it set engineers to think seriously about the use of alternative materials during the periods of cement shortage. Lime and surkhi were recognised to be good substitutes, but fear was expressed about their poor and variable qualities. Studies till then, based upon chemical analysis, some strength tests etc., as reported in the preceding pages, were not enough to understand the basic factors governing the pozzolanic activity of surkhi. Hence it was felt that the problem needed investigations in a more thorough and systematic manner with a view to evolve proper specifications.

### Work at the Central Road Research Institute

The Central Road Research Institute undertook extensive investigations on surkhi, with a view to use this material in road concrete. From this point of view, the approach was different from that of the previous works. The fundamental factors, viz., the proper selection and making of a highly reactive surkhi, however, remained common. To solve these problems and to understand the fundamental factors involved, an elaborate mineralogical study of different types of soils burnt at different temperatures and the pozzolanic activity of the surkhi derived from these was conducted [36,37]. Some of the findings are given below:

1. The type of loamy soil, fit for brick making, is not the suitable type for surkhi making. A loamy soil has a large percentage of primary minerals like quartz, felspar; etc., which are not reactive. Pozzolanic activity is mainly due to the clay fraction which undergoes certain thermal changes on heating, yielding the reactive products at certain optimum temperatures.

2. There is an optimum range of temperature for each type of clay, at which alone the maximum pozzolanic activity is exhibited. For a kaolin or montmorillonite type of clays, it is

usually between 600° – 800°C., while for illitic clays it is near about 1000°C. Burning, either below or above the optimum temperature, gives surkhi of reduced reactivity.

3. It is not to be supposed that all highly clayey soils could yield very good surkhi. For example, black cotton soils generally yield surkhis of low or medium reactivity even after burning at the optimum temperature. Actually the pozzolanic activity depends upon the mineralogical composition and certain crystalline characteristics of the final product. This to a great extent depends upon the composition of the parent clay and the presence of impurities, etc. Generally, the presence of iron oxide increases the pozzolanic activity of clays and often red clays and ochreous earths give surkhis of good reactivity even at 600°C.

The compressive strengths of a few lime-surkhi-sand mortars of proportions 1 : 2 : 9 are given in Table 3. The results show very high compressive strengths for some of these mortars.

To evaluate the pozzolanic activity of surkhis in a short period of ten days, an accelerated test known as Lime Reactivity Test was used. Results of this test for some surkhis are given in Table 4.

On the fundamental side, a theory was suggested explaining pozzolanic action [41]. On the applied side, the Rayerkeri surkhi, calcined at 600°C., which is one of the most reactive surkhis, was used in some experiments as part replacement of cement in concrete to study its effect on the compressive and flexural strengths and the abrasive resistance [38,40]. The results given in Tables 5 and 7 show that upto 20-25 per cent replacement of cement there is practically no reduction in compressive and flexural strengths [39].

Tables 5 and 6 show that a fine surkhi (90 per cent passing B.S. 200 sieve on wet sieving) gave better strength results than a coarse surkhi (56 per cent passing B.S. 200 sieve on wet sieving) [39].

Table 8 shows that abrasive resistance of cement mortar due to replacement of cement by surkhi upto 25 per cent was only slightly [40] lower than that of plain cement mortar.

Investigations were also conducted on the problem of the harmful alkali aggregate reaction in concrete and the remedial measures by using surkhi as part replacement of cement [41]. Some reactive aggregates were met with during the construction of Bannihal tunnel. Reactive aggregates were also found in a few other areas. Mortar bar tests showed that a number of surkhis, if not all, could reduce considerably the expansion due to alkali aggregate reaction. In India, high alkali cements are being manufactured in some factories. In certain areas, reactive aggregates are also present. Hence trouble due to alkali aggregate reaction is to be expected in some of the construction works in the country. American experience shows that one of the best methods of counteracting the alkali aggregate reaction is by the incorporation of pozzolana in concrete. Results of some mortar bar tests, conducted at the Central Road Research Institute, are given in Table 9.



Qualitative tests on concrete with and without surkhi replacements showed that the specimens with surkhi replacement withstood sulphate attack better than the plain concrete, i.e., concrete made without the use of surkhi.

**Concrete Research Laboratory, Nangal**: The material now being used at Bhakra Dam had been thoroughly investigated at the Concrete Research Laboratory, Nangal. Khanna and Puri [42] reported the optimum temperature of burning of the shale, as 1400°F. ± 50°F. and the optimum time of calcination as 2 hours. The fineness requirement of the surkhi was specified as 99 per cent to pass B.S. 100 sieve and the specific surface (Blaine's) to be 4300 sq./gm. minimum. Replacement of cement upto 25 per cent was said to have practically no effect on the water requirements of the concrete or its drying shrinkage. The temperature rise of concrete blocks, with and without surkhi replacement, under adiabatic conditions showed that while the temperature rise of plain concrete was 48.2°F., that of concrete with 20 per cent replacement was only 34°F. Permeability of concrete was reduced from .648-.757 cu. ft./sq. ft./year for unit hydraulic gradient for normal concretes to .216 – .302 cu. ft./sq. ft./year for unit hydraulic gradient for concrete with 20 per cent surkhi replacement.

## 4. STEPS BY VARIOUS ORGANISATIONS TO PROMOTE THE USE OF LIME AND SURKHI

4.1. The Central Water & Power Commission, in its seminar held at Hirakud in 1956, suggested positive measures to use lime pozzolana mortars in place of cement. After detailing the works in which such mortars could be used, the Central Water & Power Commission, suggested that a survey of the sources where suitable lime and pozzolanas are available should be made. The Indian Standards Institution was also requested to prepare a tentative standard on lime and surkhi.

The Indian Standards Institution brought out the specification for lime, while draft specification for surkhi, based mainly on the work at Central Road Research Institute, and draft methods of testing pozzolanas are being finalised.

The National Buildings Organisation's efforts to revive the lime industry has some bearing on the manufacture of surkhi and hence a few salient points will be mentioned. Macedo [44] writing about the use of cement in India said, " In foreign countries cement is not used indiscriminately as in India for all works without regard to its shortcomings under many conditions of use. Lime is an alternative to cement of equal status and is not considered as secondary substitute to be used if cement is not available. Lime is often preferred to cement in mortar, on account of its workability and its low shrinkage on wetting and drying, which makes for durability and watertight masonry and also because it is cheaper ". The same could be said of lime surkhi mortars. Regarding lime kilns in many areas, he said, " They are heat wasteful. The best possible step that could be taken by a progressive manufacturer would be to scrap them and start with new designs. The other alternative of improving the kilns will never yield satisfactory results. At the most these steps would be a stop-gap arrangement"[44].

Surkhi is at present a by-product of bricks, which are largely made in country kilns without any control of temperature. Since recent research has shown that this practice is wrong and a more clayey soil with its temperature of burning, varying between 600° - 1000°C is to be used for manufacturing surkhi, the problem of designing new types of kilns for this purpose presents many more difficulties than in the case of lime.

In the National Buildings Organisation symposium on the manufacture and the use of building lime [45], special emphasis was laid on the development of surkhi industry along the lines indicated by recent researches. It was pointed out by many that the development of lime and surkhi industries should be on their own merits, irrespective of the surplus or shortage of cement. Lime mortars and lime pozzolana mortars had definite advantages over cement mortar in certain types of construction.

## 5. FUTURE TRENDS OF INVESTIGATIONS

From the account given so far, utilization of surkhi along the following lines appears probable in the coming years :

1. The production of surkhi by itself, to be marketed separately either in bulk or in packages.



2. The production of pozzolanic cements in which the burnt clay is interground with cement clinker.
3. Marketing of lime pozzolana mortar cement in air-tight packages.

The first is generally applicable to all good, workable deposits of clays which could yield good surkhi, irrespective of the situation of a lime or cement plant nearby. The surkhi produced from these deposits, by controlled burning and proper grinding, could be marketed as such for use with lime or cement at work-site. This type of surkhi industry could fall in the range of either medium or small scale industry. In the case of the former, the plant could be on the model of the Bhakra pozzolana plant, which could be suitably modified to reduce its cost. This type of plant can give high quality surkhi, as it is easy to control the temperature of burning. On a small scale or village industry level, a lot of work is required to develop proper types of kilns to have a reasonable control on the temperature of burning and to economise fuel. It may even be necessary to partially machanise the process of manufacturing the materials. There is no need at all to make bricks first from the clay before firing. The raw material could be rolled into balls and fired in stationary vertical kilns or powdered and burnt in small rotary kilns.

The production of pozzolanic cement at cement factories, by intergrinding the cement clinker and pozzolana, is preferable to blending cement and pozzolana. Intergrinding is supposed to result in a greater homogeneity and reactivity. It avoids the use of a separate ball mill for surkhi. The production of pozzolanic cement requires the location of a suitable deposit near the cement factory. In such a case, it is advantageous to burn the material near the site itself and transport the burnt material to the cement factory for intergrinding.

Where a good lime factory exists near a good deposit of pozzolanic clay, it is preferable to produce lime-pozzolana mortar cement. The suggestion to market lime-pozzolana mixtures, in addition to pozzolana cement, was made to the American manufacturers by the ' Rock Products ' [46], while commenting on the work of the Central Road Research Institute. Since lime pozzolana has even a greater scope in this country than pozzolana cement, this proposition is worthy of consideration. The National Buildings Organization is already seized with the problem of developing the lime industry. While lime industry could be developed as an organized village industry, it almost calls for the total scrapping of the present day kilns and their replacement by better designed kilns which will prove economical in the long run. This aspect is common, both for the lime as well as surkhi industries at the small scale level and should be tackled simultaneously.

Before the surkhi industry can be developed on sound lines, it is necessary to locate the major deposits of materials, suitable for making surkhi throughout the country. This needs an all India survey under the control of a central organisation, having adequate laboratory facilities and trained personnel for carrying out the field work and laboratory testing. For this purpose it will be necessary to have a few survey teams, which would locate the deposits in the areas assigned to them, on the basis of information received from the Geological Survey of India, local State officials and other sources. In this connection, the results of the work already carried out in the Central Road Research Institute shall also provide some basis for the selection of suitable clays. For example, it has been found that highly clayey soils, preferably reddish in colour, with free hydrated iron oxides, impure ochreous clays, impure kaolins and kaolinitic clays are some of the types worth considering. The problem of controlled burning is another important factor requiring special attention. In today's country kilns, there is practically no control of temperature. New designs of kilns, including small rotary kilns suitable for various levels of production, using the different types of fuels should be evolved. In this connection, use of fuel oil, gas produced from a number of waste products, coke, etc., should be considered.

The effectiveness of a pozzolana can vary, depending upon the actual purpose for which it is to be used. While its reactivity in general, as indicated by the definition of a pozzolana, could be assessed to some extent by the lime reactivity test, it is desirable to develop quicker tests even for this purpose. Certain other characteristics of a pozzolana such as its effectiveness in reducing the harmful effects of alkali aggregate reaction and sulphate attack cannot be indicated by these general tests. The special tests called for are also time consuming. Work should, therefore, be carried out to develop quicker tests to evaluate the efficiency of pozzolanas for the different purposes for which it could be used.

For all these, as also for the selection or the manufacture of high quality pozzolana, it is necessary to understand the fundamental factors governing pozzolanic reaction and the extent to which it can be stimulated during the manufacturing process. Such a fundamental study may be time consuming and some may even consider it to be of mere academic interest. It is perhaps good to recall at this stage the words of Dr. Bogue[47] in this connection who, speaking about basic research on cement, said,



'In basic research of this character, it is not usually possible to predict just wherein the results will be applied to the problem of an industry. In journeying through these new regions of science, we do not know what will be our prize but we venture with complete conviction that some gems of great value will fall to our pack. All our past experience supports the justification of that assurance".

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Table 1

**Strength results at Vanivilas Sagar and Krishnaraja Sagar Dams**

| Lime : | Surkhi : | Sand : | Vanivilas Sagar Dam 14 days Tensile St. p.s.i. | Vanivilas Sagar Dam 14 days Compressive St. p.s.i. | Vanivilas Sagar Dam 3 months Tensile St. p.s.i. | Vanivilas Sagar Dam 3 months Compressive St. p.s.i. | Krishnaraja Sagar Dam 14 days Tensile St. p.s.i. | Krishnaraja Sagar Dam 14 days Compressive St. p.s.i. | Krishnaraja Sagar Dam 3 months Tensile St. p.s.i. | Krishnaraja Sagar Dam 3 months Compressive St. p.s.i. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | — | — | — | — | 50 | — | 129 | 482 |
| 1 | 0 | 1 | 10 | 336 | — | — | — | — | — | — |
| 1 | 0 | 4 | — | — | — | — | 34 | 98 | 75 | 324 |
| 1 | 1 | 0 | 66 | 1230 | 131 | 2390 | 109 | 907 | 256 | 2240 |
| 1 | 2 | 0 | 62 | 1372 | 123 | 2240 | 100 | 784 | 260 | 2262 |
| 1 | 3 | 0 | 90 | 1196 | 149 | 2632 | 133 | 1154 | 284 | 2363 |
| 1 | 4 | 0 | 76 | 1568 | 190 | 3248 | 122 | 896 | 240 | 1938 |
| 1 | 5 | 0 | 96 | 1288 | 191 | 3024 | 128 | 885 | 234 | 1882 |
| 1 | 2 | 1 | 93 | 1500 | 166 | 2744 | — | — | — | — |
| 1 | 2 | 2 | — | — | — | — | 66 | 364 | 152 | 1120 |
| 1 | 1 | 2 | 62 | 836 | 119 | 2184 | — | — | — | — |
| 1 | 1 | 3 | — | — | — | — | 56 | 336 | 156 | 1100 |

Table 2

**Results of tests on surkhis carried out at the Hyderabad Engineering Research Laboratory for various projects**

| Name of project | Rajulabunde[17] Project | Sarla Sagar[19] Project | Bendsura[19] Project | Tungabhadra[17] Project (Hyderabad portion) | Koil Sagar[18] Project |
|---|---|---|---|---|---|
| Fineness | passing ASTM 30 sieve | passing ASTM 50 sieve | 65% passing 100 sieve | 36% passing ASTM 200 sieve | passing ASTM 50 sieve |
| Optimum proportion of lime : surkhi : sand | 1 : 2 : $1\frac{1}{2}$ | 1 : $1\frac{1}{2}$ : 1 | 1 : $2\frac{1}{2}$ : $\frac{1}{2}$ | 1 : $1\frac{1}{2}$ : $\frac{1}{2}$ | 1 : 2 : $\frac{1}{2}$ |
| Average tensile strength p.s.i. | | | | | |
| 14 days | 56.6 | 23.8 | 29.7 | 56.0 | 20.6 |
| 28 days | 75.5 | 48.5 | 71.0 | 69.3 | 28.5 |
| Average compressive strength p.s.i. | | | | | |
| 14 days | | 146.2 | 155.6 | 354.1 | 142.6 |
| 28 days | | | 373 | 713 in 90 days | 190.0 |

TABLE 3

**Results of compressive strength tests for lime-surkhi mortars**

| Sl. No. | Name of Surkhi | Temp. of burning °C. | Compressive strength psi at the age of 1 month | 3 months | 6 months | 1 year |
|---|---|---|---|---|---|---|
| 1. | Jumna surkhi | 400 | 105 | 158 | 347 | 436 |
| 2. | ,, | 600 | 194 | 305 | 530 | 718 |
| 3. | ,, | 800 | 331 | 591 | 687 | 1030 |
| 4. | ,, | 1000 | 385 | 1392 | 2203 | 2346 |
| 5. | Rayorkeri surkhi | 600 | 944 | 1617 | 2370 | 2867 |
| 6. | ,, | 800 | 646 | 1790 | 2437 | 2608 |
| 7. | ,, | 1000 | 191 | 689 | 1422 | 1481 |

TABLE 4

**Results of lime reactivity test with accelerated curing for materials burnt at different temperatures**

| Sl. No. | Name of material | General type | Compressive strength p.s.i. with the material burnt at 400°C | 600°C | 800°C | 1000°C |
|---|---|---|---|---|---|---|
| 1. | Belgaum clay | Red clay | 488 | 682 | 366 | 248 |
| 2. | Rayerkeri clay | ,, | 453 | 1512 | 1444 | 822 |
| 3. | Karwar-Bellary clay | ,, | | 2067 | 1926 | 872 |
| 4. | Bombay clay | ,, | | 856 | 690 | 206 |
| 5. | Chana quarry clay Bombay | ,, | | 330 | 448 | 129 |
| 6. | Nagpur clay | Black cotton soil | 441 | 463 | 644 | 269 |
| 7. | Raichur clay | ,, | | 388 | 460 | 351 |
| 8. | Padegoon clay | ,, | | 324 | 348 | 163 |
| 9. | Raipura clay | ,, | | 587 | 517 | 272 |
| 10. | Madras clay | ,, | | 397 | 364 | 157 |
| 11. | Okhla clay-1 | Brick earth | | 162 | 200 | 171 |
| 12. | Rewa clay | ,, | | 197 | 385 | 249 |
| 13. | Manu Nagar clay | ,, | | 111 | 301 | 224 |
| 14. | Delhi clay-1 | ,, | | 119 | 227 | 121 |
| 15. | Delhi clay-2 | ,, | | 106 | 248 | 172 |



TABLE 5

**Effect of finer surkhi on compressive strength of concrete**

Mix proportion : 1 : 2 . 1 : 3 . 9 by weight

$$\frac{\text{Water}}{\text{Cement + surkhi}} = 0.50$$

| Cement replacement per cent | 1 month Comp. St. p. s. i. | 1 month Per cent blank | 3 months Comp. St. p. s. i. | 3 months Per cent blank | 6 months Comp. St. p. s. i. | 6 months Per cent blank |
|---|---|---|---|---|---|---|
| 0 per cent | 6561 | 100.0 | 7798 | 100.0 | 7812 | 100.0 |
| 5 ,, | 6454 | 98.4 | 7728 | 99.1 | 7868 | 100.7 |
| 10 ,, | 7070 | 107.7 | 7882 | 101.1 | 7798 | 99.8 |
| 15 ,, | 6711 | 102.3 | 7700 | 98.7 | 8022 | 102.7 |
| 20 ,, | 5816 | 90.2 | 7532 | 96.6 | 8022 | 102.7 |
| 25 ,, | 6202 | 94.5 | 7490 | 96.0 | 7042 | 90.2 |
| 30 ,, | 5366 | 81.8 | 6552 | 84.0 | 5600 | 71.7 |

TABLE 6

**Effect of coarser surkhi on compressive strength of surkhi**

Mix proportion : 1 : 2 . 1 : 3 . 9 by weight

$$\frac{\text{Water}}{\text{Cement + surkhi}} = 0.50$$

| Cement replacement per cent | 1 month Comp. St. p. s. i. | 1 month Per cent blank | 3 months Comp. St. p. s. i. | 3 months Per cent blank | 6 months Comp. St. p. s. i. | 6 months Per cent blank |
|---|---|---|---|---|---|---|
| 0 per cent | 6561 | 100.0 | 7798 | 100.0 | 7812 | 100.0 |
| 5 ,, | 6216 | 94.7 | 8162 | 104.7 | 8078 | 103.4 |
| 10 ,, | 5670 | 86.4 | 6552 | 84.0 | 7462 | 95.5 |
| 15 ,, | 6440 | 98.2 | 7266 | 93.0 | 7254 | 92.8 |
| 20 ,, | 5132 | 78.2 | 7322 | 93.9 | 6748 | 86.4 |
| 25 ,, | 5442 | 82.9 | 6286 | 80.6 | 6510 | 83.3 |
| 30 ,, | 4792 | 73.0 | 5376 | 68.9 | 5684 | 72.8 |

TABLE 7

**Effect of surkhi on flexural strength of concrete**

| Cement replacement per cent | 1 month | | 3 months | | 6 months | |
|---|---|---|---|---|---|---|
| | Modulus of rupture p. s. i. | Per cent blank | Modulus of rupture p. s. i. | Per cent blank | Modulus of rupture p. s. i. | Per cent blank |
| 0 per cent | 655 | 100.0 | 803 | 100.0 | 803 | 100.0 |
| 5 ,, | 724 | 110.6 | 785 | 97.7 | 803 | 100.0 |
| 10 ,, | 763 | 116.5 | 794 | 98.8 | 763 | 95.0 |
| 15 ,, | 736 | 112.4 | 747 | 93.0 | 770 | 95.9 |
| 20 ,, | 736 | 112.4 | 751 | 93.5 | 803 | 100.0 |
| 25 ,, | 675 | 103.0 | 821 | 102.2 | 830 | 103.3 |
| 30 ,, | 608 | 92.8 | 765 | 95.3 | 776 | 96.6 |

TABLE 8

**Abrasive resistance of mortars**

Mix proportion: cement : sand 1 : 2 $\frac{\text{Water}}{\text{Cement + surkhi}} = 0.40$

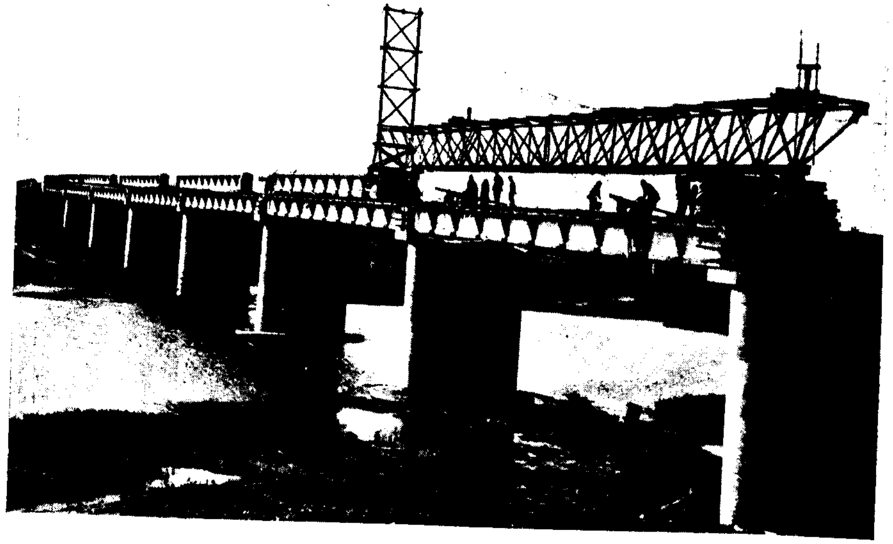
| Per cent cement replacement by surkhi. | Abrasion loss (gms.) |
|---|---|
| 0 | .96 |
| 5 | .84 |
| 10 | .90 |
| 15 | 1.02 |
| 20 | 1.06 |
| 25 | 1.04 |



TABLE 9

**Reduction in expansion of pyrex glass mortar bars using different surkhis**

| Sl. No. | Surkhi description | Temp. of burning | Per cent addition | Reduction in expansion per cent | |
|---|---|---|---|---|---|
| | | | | 14 days | 1½ months |
| 1. | Rayerkeri clay | 600°C | 10<br>15<br>20 | 35<br>86<br>96 | 29<br>85<br>94 |
| 2. | Delhi kaolin No. 1 | 600°C | 15<br>20 | 100<br>100 | 100<br>97 |
| | | 800°C | 15<br>20 | 86<br>92 | 86<br>95 |
| 3. | Delhi kaolin No. 2 | 600°C | 10<br>15<br>20 | 89<br>95<br>95 | 87<br>93<br>93 |
| | | 800°C | 15<br>20 | 97<br>92 | 98<br>93 |
| 4. | Kashmir clay | 600°C | 15<br>20 | 48<br>-37 | 43<br>-43 |
| | | 800°C | 15<br>20 | 59<br>69 | 49<br>57 |



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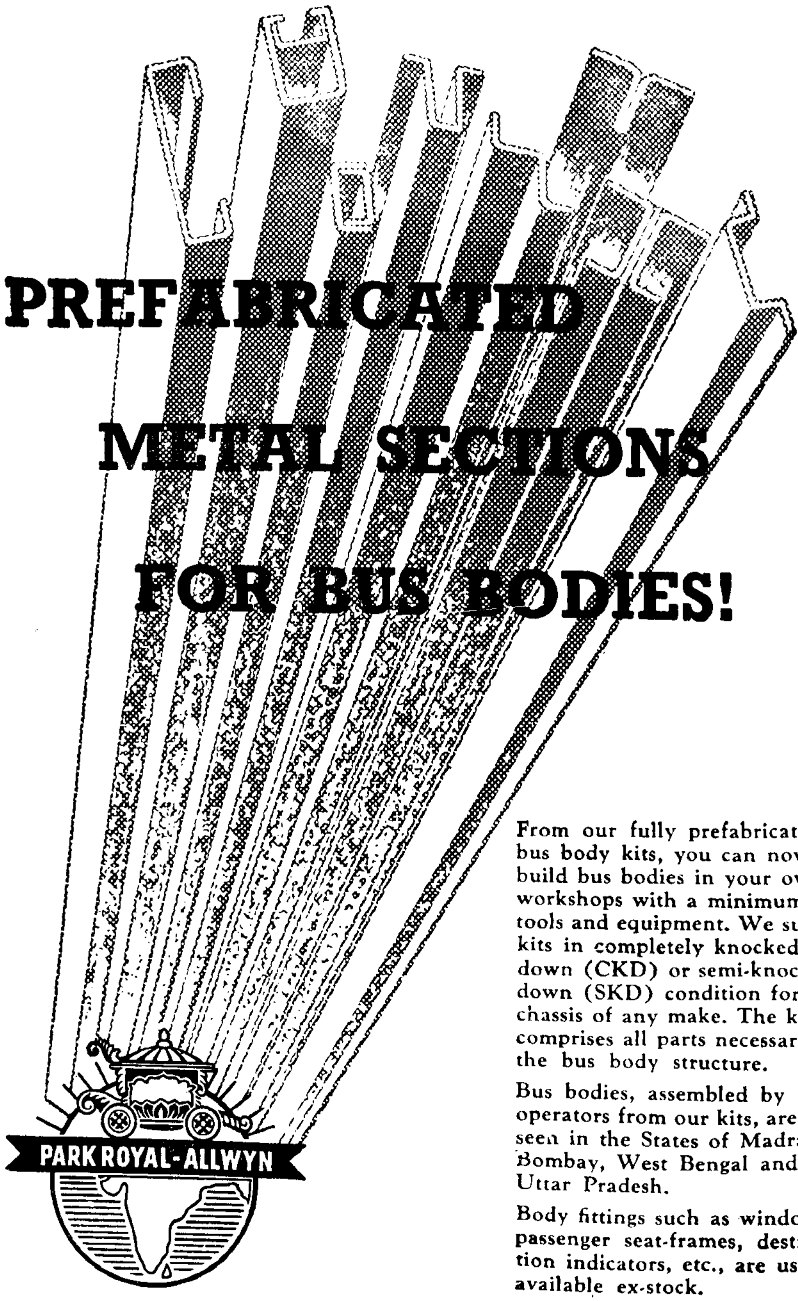


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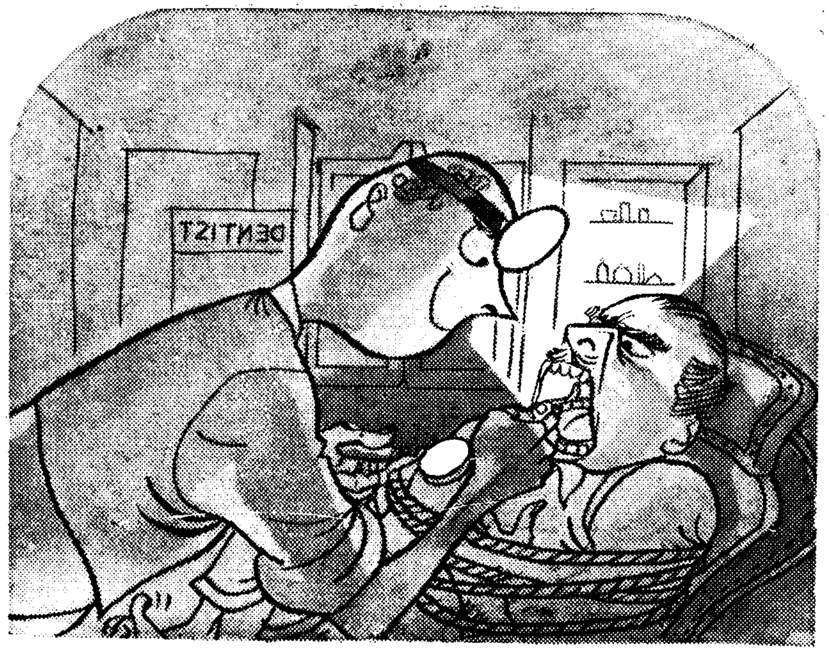

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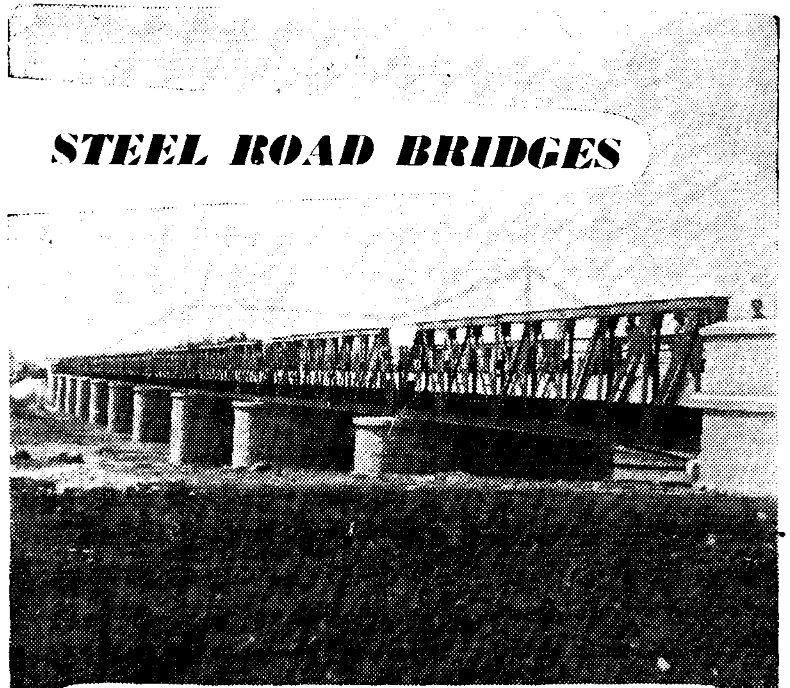

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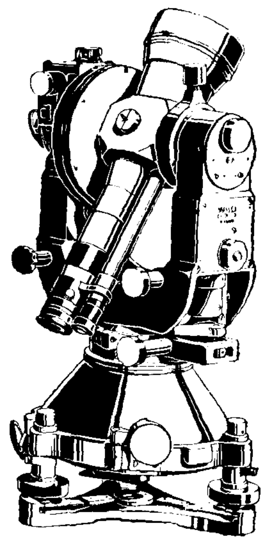

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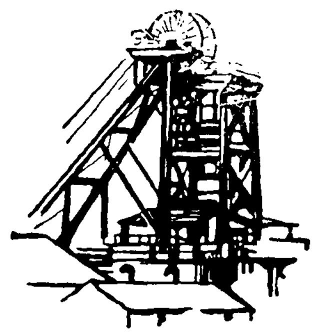

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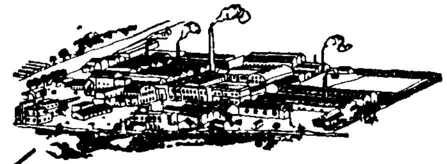

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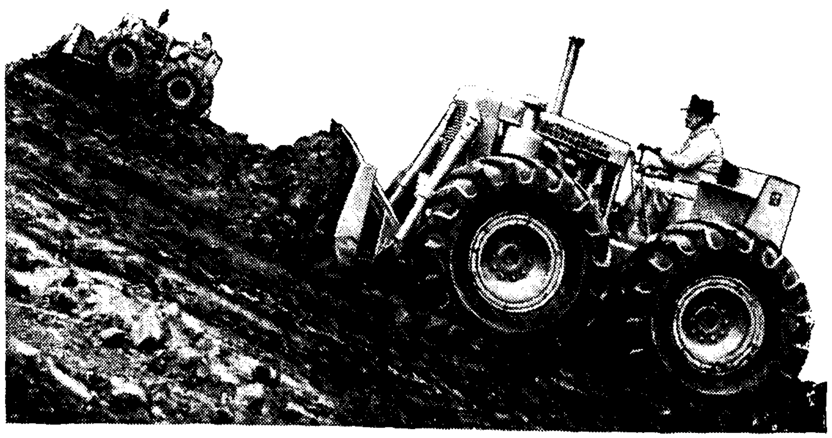

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