The

Indian Roads.

Congress

~~1951 52~~

Nov 1951

The Indian Roads Congress as a body does not hold itself responsible for statements made, or for opinions expressed, in the Papers or discussions in its Proceedings.

INDIAN ROADS CONGRESS

ESTABLISHED : 1934 REGISTERED : 1937

OFFICE-BEARERS AND COUNCIL 1951-52.

President :

G. M. McKelvie, C.I.E., O.B.E., I.S.E.,
Road Development Adviser & Joint Secretary to the Government of India, Ministry of Transport,
Roads Organization, New Delhi.

Vice-Presidents :

C. M. Bennett, I.S.E.,
Chief Engineer & Secretary to the Government of Orissa, P. W. D.,
Bhubaneswar.

T. Mitra, I.S.E.,
Chief Engineer,
Works & Buildings, West Bengal,
Calcutta.

E. A. Nadirshah,
Chief Engineer,
Concrete Association of India,
Fort, Bombay.

Honorary Treasurer :

H. P. Mathrani, I.S.E.,
Consulting Engineer to the Government of India (Roads),
Ministry of Transport,
Roads Organization, New Delhi.

Honorary Secretary :

J. M. Trehan,
Divisional Engineer (Consultant),
Ministry of Transport, Roads Organization,
New Delhi.

Members of Council

1. F. P. Antia.
2. R. N. Joshi.
3. C. J. Fielder.
4. L. R. Patel.

5. V. N. Rangaswami.
6. M. Meeran.
7. C. P. Misra.
8. R. C. Roy.
9. M. L. Bahl.
10. R. K. Batra.
11. S. N. Chakravarti.
12. A. C. Mukerjee.
13. E. Sivaraman Nair.
14. M. L. Saberi Yusuf.
15. Brig. Partap Narain.
16. W. B. Bakewell.
17. S. K. Ghosh.
18. S. B. Joshi.
19. N. K. Sinha.
20. K. G. Bhate.
21. K. K. Nambiar.
22. R. L. Varma.
23. M. S. Thirumale Iyengar.
24. M. L. Champhekar.
25. D. C. Sharma.
26. U. J. Bhatt.
27. Kishore Lal Mathur.
28. Raghbir Singh.
29. B. S. Puri.
30. H. S. Batliwala.
31. W. A. Griffiths.
32. K. S. Raghavachary.

WE ANNOUNCE WITH GREAT PLEASURE THAT THE PRESIDENT OF THE REPUBLIC OF INDIA HAS KINDLY AGREED TO ACCORD HIS PATRONAGE TO THE INDIAN ROADS CONGRESS.

LIST OF COMMITTEES AND SUBCOMMITTEES

1. *SPECIFICATIONS AND STANDARDS COMMITTEE:*

G. M. McKelvie — *Convenor*
H. Sunder Rao — *Member-Secretary*

(i) *Geometric Design Division:*

T. Mitra
N. V. Modak
Brijmohan Lal
K. K. Nambiar
Goverdhan Lal
H. P. Sinha

(ii) *Structural Design Division:*

(a) *Rigid Pavements:*

A. C. Mukerjee or nominee
One representative of E-in-C
C. V. Nazareth
H. P. Sinha
Goverdhan Lal

(b) *Flexible Pavements:*

Brig. Partap Narain
C. J. Fielder
H. P. Sinha
S. R. Mehra
G. Srirangachary
Sujan Singh
Goverdhan Lal

(iii) *Specifications and Costing Division:*

(For items other than (i) and (ii))
Goverdhan Lal
One Representative of E-in-C (Surveyor of works)
H. P. Sinha
Nominee of C. P. W. D.

2. *BRIDGES COMMITTEE:*

H. P. Mathrani — *Convenor*
S. L. Bazaz — *Member-Secretary*

(i) **Location, Layout and Hydraulics Division:**

Brig. Partap Narain
H. P. Sinha
Kanwar Sain
G. R. Nangea
J. Chambers
A representative of C.B.I. & Power

(ii) ***Substructure and Superstructure Division*** :

K. F. Antia
D. S. Desai
K. G. Bhate
S. K. Ghosh
V. Venkataramayya
H. P. Sinha
S. B. Joshi
E. P. Nicolaides
P. S. Subramaniam
M. V. Joglekar
K. C. Roy
M. Meeran

3. ***TECHNICAL SUBCOMMITTEE*** :

(i) ***Test Track Division*** :

T. Mitra (West Bengal) —*Convenor*

C. J. Fielder
H. Sunder Rao
S. N. Gupta
Dr. E. Zipkes
P. K. Chatterjee
G. Srirangachary
S. N. Chakravarti
G. M. McKelvie
W. B. Bakewell
Sujan Singh

(ii) ***Research Organization Division*** :

H. P. Sinha— *Convenor*

A representative of Engineer-in-Chief's Branch
Chief Engineer, Works & Buildings, West Bengal
Chief Engineer, Buildings & Roads, Uttar Pradesh
Chief Engineer (Highways), Madras
Chief Engineer, Buildings & Roads, Punjab
Dr. E. Zipkes

4. ***ROAD TRANSPORT SUBCOMMITTEE*** :

F. P. Antia — *Convenor*

K. M. Kantawala
V. N. Rangaswami
B. V. Vagh
E. A. Nadirshah
R. N. Dogra
N. V. Modak
M. L. Champhekar

5. ***SOIL RESEARCH SUBCOMMITTEE*** :

Dr. E. Zipkes — *Convenor*

{One representative of E-in-C.
U. J. Bhatt
C. J. Fielder
Sujan Singh
{One representative from Central Board of Irrigation & Power
S. R. Mehra
G. Srirangachary
H. Sunder Rao
H. L. Uppal

6. ***EDUCATION SUBCOMMITTEE*** :

E. A. Nadirshah — *Convenor*

N. V. Modak
Goverdhan Lal
K. F. Antia

7. ***BITUMINOUS TREATMENT OF WET AGGREGATES SUBCOMMITTEE*** :

W. A. Griffiths — *Convenor*

217

M. L. Bahl
R. N. Dogra
Dr. E. Zipkes
D. C. Dutta
Lakshman Swarup
T. Mitra
W. B. Bakewell

8. ***HIGHWAY LAYOUT SUBCOMMITTEE*** :

H. S. Batliwala — *Convenor*

T. Mitra
R. N. Dogra
M. Meeran
N. V. Modak
V. N. Rangaswami

9. ***PROVINCIALIZATION OF LOCAL BODIES ENGINEERING SERVICES SUBCOMMITTEE*** :

N. K. Sinha — *Convenor*

Y. K. Chaugule
G. S. Ram
M. P. Srivastava
S. K. Sinha
H. S. Sharma

10. ***PAPERS SUBCOMMITTEE*** :

G. M. McKelvie — *Convenor*

Brig. Partap Narain
B. S. Puri
A. C. Mukerjee.

11. ***MANUFACTURE OF ROAD-MAKING MACHINERY AND MECHANIZATION SUBCOMMITTEE*** :

H. P. Mathrani — *Convenor*
R. S. Bhalla — *Member-Secretary*

F. P. Antia
Brig. Partap Narain
B. S. Puri
M. L. Bahl
L. R. Patel
H. P. Sinha

12. ***ORGANIZATION COMMITTEE*** :*

G. M. McKelvie — *Convenor*

The Consulting Engineer to the Government of India (Roads) is an ex-officio member of all Committees and Subcommittees.

---

*Kept in abeyance.

INDIAN ROADS CONGRESS

NOTICES AND ANNOUNCEMENTS

1. CONTRIBUTION OF PAPERS FOR THE SIXTEENTH SESSION OF THE INDIAN ROADS CONGRESS.

The next General Session of the Indian Roads Congress is likely to be held sometime in April 1952. The exact date, place and programme of the Session will be communicated to Members in due course.

2. **Procedure**: Members who intend to contribute Papers on any subject connected with Highway Engineering are requested to intimate the fact to the Secretary, Indian Roads Congress, and to send a short synopsis of their proposed Papers as early as possible.

On receipt of acceptance of the subject matter of the Paper, the Member concerned should send his contribution to the Secretary, Indian Roads Congress, complete in all respects and with original drawings, photographs, etc., **as and when ready**. At least **three** copies of the typescript matter should be sent, typed (double space) on one side of good stout paper of foolscap size.

3. **The complete Paper, if intended to be read at the next Session, should preferably be submitted within the next four months, but not later than November 1951.**

From past experience it is observed that most of the Members send in their contributions at the last moment, when the Congress Office is busy on work connected with the Session. As it takes a long time to get Papers printed in the Journal and as it is desirable that Members should have time to study Papers well in advance of the date of the Session, it is hoped that Members will make an effort to send in their contributions **within the next four months**.

Members may please note that Papers received late in the year are likely to be carried over to the next year.

4. The younger engineers are particularly requested to contribute Papers which, if required, will be suitably edited by the Indian Roads Congress Office before publication.

5. **MEDALS**: The following Medals are available for award:

(i) **The Mitchell Medal**:

For exceptionally good Papers contributed to the Indian Roads Congress in any year. This has been instituted to perpetuate Sir Kenneth Mitchell's connection with the Congress.

(ii) **The Indian Roads Congress Medal**:

For Papers considered by the Council of the Indian Roads Congress to be of a decidedly more than average merit.

6. The Council have reserved the right to award more than one Medal in any year or to withhold the award of a Medal in any year without assigning any reason.

7. Rules and Regulations for the contribution of Technical Papers and the Award of Medals are published elsewhere in this issue.

II. RULES AND REGULATIONS FOR THE CONTRIBUTION OF TECHNICAL PAPERS AND THE AWARD OF MEDALS.

1. The following Medals are available for award:

(*i*) The Mitchell Medal:

This is a bronze medal to be awarded annually for exceptionally good Papers contributed to the Indian Roads Congress in any year. This has been instituted to perpetuate Sir Kenneth Mitchell's connection with the Indian Roads Congress.

(*ii*) The Indian Roads Congres Medal:

This is also a bronze medal to be awarded annually for Papers considered by the Council of the Indian Roads Congress to be of a decidedly more than average merit.

2. PROCEDURE ON CONTRIBUTION OF TECHNICAL PAPERS.

2.1. Our procedure in the past had been to invite Members to contribute Papers a few months before the holding of the General Sessions of the Indian Roads Congress. On receipt, the accepted Papers were circulated in advance to Members for prior study a month or so before the date fixed for discussion. This procedure resulted in the receipt of a large number of Papers all at one time and editing and printing had often to be done very hurriedly. Also Members often found that one month did not give them sufficient time to study all the Papers before the discussion at the Congress Session.

2.2. It has, therefore, been decided by the Council that Members should be invited, to contribute technical Papers through-out the year, as and when they are ready, and that the accepted Papers should be published in the Journals of the Society which, it is hoped, will be issued quarterly in future.

2.3. The Council considers that this will give Members more time to study the Papers and will also facilitate editing and printing. A record of the discussion and the comments received by correspondence will be published with the Author's replies in the Journal issued after the General Session.

2.4. It will be realized that it will only be possible to give effect to this new scheme if Members co-operate. The Council makes this special appeal to members to contribute Papers for discussion throughout the year at their convenience.

3. RULES FOR THE CONTRIBUTION OF TECHNICAL PAPERS.

3.1. The Standing Rules for guidance when contributing Papers, as now slightly amended, are reprinted below. It is requested that Members read these rules and observe them when submitting Papers to the Congress.

3.2. Members intending to contribute Papers to the Indian Roads Congress on any subject connected with Highway Engineering are requested to send their contributions to the Secretary as and when these are ready without waiting for a special invitation.

3.3. Final acceptance of the Papers rest with the Council. In order, however, to avoid disappointment through the Council having to reject Papers owing to an excessive number being written on any one subject or for any other reason, it is requested that any Member intending to write a Paper should intimate to the Secretary the subject on which he wishes to write and enclose a short synopsis of the proposed Paper. He will then be informed whether his offer can be accepted.

3.4. The Council reserve the right to publish any Paper in the form of an abstract. When a Paper is published in abstract form the manuscript copy of the Paper as sent by the Author will be added to the Indian Roads Congress Library and made available for inspection by interested Members.

3.5. The Council have decided that Papers from non-Members, who are experts or who have specialized knowledge will be welcome and acceptance of the Paper will carry honorary membership for the Author for the year provided there are good reasons that the contributor cannot join the Congress as an ordinary member.

3.6. The Council have expressed the opinion that Members, when choosing subjects for contributing Papers, should bear in mind the fact that there is often a good deal more to be learnt from failures than from success.

4. RULES REGARDING SCRIPT.

4.1. The following instructions are for the guidance of Authors of Papers:

a. **ALL CONTRIBUTIONS SHOULD BE DRAFTED IN THE THIRD PERSON.**

b. Papers should be typed on one side of good stout paper of foolscap size, double spacing being used and an ample margin (not less than 2 inches) should be left on the left hand side. **At least three copies of the typescript matter should be sent.**

c. The Author's full name, designation, academic qualifications and correct postal address should be given below the title of the Paper.

5. RULES REGARDING ILLUSTRATIONS.

5.1. Illustrations fall into two classes, *viz.*,

a. Line drawings.

b. Half-tones.

5.2. *Line drawings* should be made in black Indian ink on superior white drawing paper or tracing cloth. Blue prints are of no use for reproduction and black line prints are also unsatisfactory.

Line drawings are generally classified into two categories :

a. Diagrams which go into the body of the Paper.

b. Plates which are generally on separate large size sheets.

5.3. *Diagrams* :—The matter for the Journal is printed in 10 pt. size type (nearly 1/16 in. height) : therefore, the written matter in diagrams should be so made that the size of the letter when reduced for reproduction should be about 1/16 in. The printed area of a page measures 6¾ in. deep by 4¼ in. wide. Therefore, the ultimate size of such drawings will not generally be more than 5 in. × 4 in. Thus, if a diagram is to be reduced to one quarter of the size submitted by the Author, the lettering on it should not be less than ¼ inch in height.

5.4. *Plates* :—Plates should preferably be prepared in widths that are multiples of 7½ in. The size of letters used in the plate should be so chosen that after reduction no letter would be less than 1/16 in. in size. Thus if the width is 15 in. the minimum size of the letter should be ⅛ in. The thickness of the letter should also stand corresponding reduction. The title should be in the right hand bottom corner in letters of such size that when reduced the size will be at least ⅛ in. The name of the Author may be printed, if desired, at the bottom right hand side.

5.5. Scale should be drawn in the plate below the title to admit of reduction of drawings without altering the correct relation of the scale to the drawing. Mere mention of the scale thus "Scale 10 ft. = 1 inch" should be avoided as this would be incorrect when the size of the plate was reduced photographically.

5.6. Coloured inks should *not* be used. When it is desired to distinguish lines, dotted or chain dotted lines should be used instead of colours.

5.7.1. In drawing diagrams or graphs, the following points deserve the consideration of Authors.

5.7.2. From the standpoint of pleasing appearance, a rectangular graph or drawing with proportions between 3 by 5 and 3 by 4 is to be preferred to a square one.

5.7.3. The appearance and effectiveness of a graph depend in a large measure on the relative width of lines used in its component parts. The thickest line should be used for the principal curve. If several curves are presented on the same graph, the line width used for curves should be less than that used when a single curve is presented. Co-ordinate rulings should be the narrowest in thickness. Principal reference lines such as the axes should be wider than other rulings but narrower than curves. For the size of reduction that is usually adopted for the I. R. C. Journals, it is considered that the thickest line *when finally reduced* should not be more than 2½ points, *i.e.*, 0.035 inch in width.

5.8. Finished illustrations should not be folded for purposes of despatch. When mailed flat, they should be stiffened by using card boards or rolled with the drawing outside to prevent cracking of the Indian ink lines and securely packed.

5.9. "*Half-tones*" are ordinary photographs and it is necessary to see that prints are clear, slightly over printed and preferably glazed. Photographs which are dim or out of focus do not come out distinctly in reproduction and make a bad "half-tone". Negatives should accompany the photographs whenever possible, and will, if desired, be returned when done with. Captions should be written on the back of prints in soft pencil.

6. BRIDGE DETAILS.

6.1. Members contributing Papers on any bridgework actually carried out are requested to give *inter alia* the following details.

a. A site plan showing the road and river for two miles on either side of the bridge site :

b. A dimensioned cross-section of the roadway :

c. The loading on which the design is based :

d. The cost per square foot of the elevation area comprised by the formation level and the bottom of the foundations, and

e. The ratio of the total cost of the substructure to the cost of those parts of the superstructure as are subject to variation with variation of span.

7. UNITS.

7.1. Members are particularly requested to use the standard units of weight, measure, and cost given below:

STANDARD UNITS OF WEIGHT AND MEASURE

	Description of work	Units to be adopted.
1.	Road materials such as metal, gravel or moorum, sand.	100 cu. ft.
2.	Binder in surface dressing and grout.	lb per 100 sq. ft.
3.	Binder in premix, carpets, etc.	lb per cu. ft. of aggregate.
4.	Cement.	By weight and not by volume.
5.	Water Cement ratio.	...gallons of water per cu. ft. of cement (assumed as 90 lb)
6.	Cost and Rates.	In Indian standard currency (Rupees, etc.)

8. FORMULAE.

8.1. Mathematical formulae should be drawn carefully by hand and not set out with the typewriter.

9. ABBREVIATIONS.

9.1. The use of abbreviations should be avoided. For 6′-2″ × 3′-3″ should be written 6 feet 2 inches by 3 fee[t] 3 inches. Similary 225° C. should be written as 22[5] degrees centigrade, and so on.

10. ITALICS AND EMPHASIS.

10.1. Only those words and phrases which are to be printe[d] in italics should be underlined.

11. PARAGRAPHING.

11.1. When divisions and sub-divisions are designated by numbers and letters, the following symbols may be used in the arrangements indicated.

I.
II.
  1.
  2.
    a.
    b.
      (i)
      (ii)

12. ACKNOWLEDGMENTS.

12.1. Sources of quotations appearing in the Papers should be stated and acknowledgment should be made for all information culled from books, periodicals, and proceedings of sister societies, etc.

III. PROCEDURE REGARDING THE DISCUSSION OF PAPERS AT THE ANNUAL SESSIONS OF THE INDIAN ROADS CONGRESS.

1. The order in which Papers will be taken up for discussion will be decided by the Council and intimated to members attending the Session.

2. Every Chairman presiding at the discussion of a Paper will be introduced to the audience in appropriate terms. Similarly, the Chairman will introduce the Author and will call upon him to present his Paper for discussion. (The Paper will be taken as read). Introductory remarks shall not ordinarily take more than 10 minutes and, unless the Author had something new to say which came to his notice since the submission of his Paper, the introduction should be limited to 250 words. After the introduction, the Paper will be open to discussion.

3. To facilitate the conduct of business and the fixation of time for various sittings and individual Papers, those desirous of raising questions or offering comments at the meeting should inform the Secretary well in advance (*atleast 24 hours before the meeting*) about the Papers on which they would like to speak and the time they would take. Those who have not given the required intimation to the Secretary may, at the discretion of the Chairman be allowed to take part in the discussion if time permits and after those who have intimated their intention to speak in advance have spoken.

4. A copy of or the nature of the comments which a member intends to make should be sent in advance to the Author of the Paper and a copy endorsed to the Secretary.

5. If the comments are likely to take more than ten minutes or if they involve lengthy mathematical matter or diagrams, it would be desirable to send a copy of these to the Secretary at least 2 weeks before the date of the meeting so as to enable him to have them printed and circulated to all members attending the meeting before the discussion on the Paper takes place. These comments may, at the discretion of the Chairman, be taken as read and the members making them will thus only be required to explain generally the nature of his comments. The Author will, if possible, reply at the meeting as if the comments had been made orally.

6. Members who do not want to speak but want clarification of any issues arising out of the discussion or the introductory remarks of the Author should write out their queries on "Comment

Slips" which will be provided for the purpose while the discussions are in progress. Volunteers will be deputed to distribute and collect these slips at frequent intervals. The slips will be sorted out by the Secretary and at the end of the talk by the Speaker or Speakers, the Chairman will read out the queries and the Speaker or the Author will give a reply.

7. Members who are unable to attend the Session and who desire to comment on any Paper should send one copy of a note of their comments to the Author of the Paper and two typescript copies to the Secretary. A gist of the comments together with the Author's reply thereto will appear in the Proceedings.

8. After all members wishing to do so have spoken on a Paper, or when the Chairman considers that because of lack of time the discussion must be brought to a close, the Author will be called upon to reply.

9. If the Author of a Paper is unable to be present, he should depute another member to introduce his Paper and to reply to the discussion and should inform the Secretary accordingly.

IV. LIBRARY.

1. Information and books on loan from the libraries of the Consulting Engineer (Roads) and the Indian Roads Congress are available to **Members** of the Indian Roads Congress and can, on application, be had of the Secretary, Indian Roads Congress, New Delhi under the following arrangements :—

(a) **For Members of the Indian Roads Congress who are in the service of the Central or State Governments.**

Specifically named books or literature in res onse to enquiries on technical subjects will be sent to officers of the rank of Executive Engineer and above. Others should apply through their Executive Engineers or officers of equivalent rank.

(b) **For Members of the Indian Roads Congress who are not in the service of the Central or State Governments.**

Applications for specifically named books as well as enquiries for literature on technical subjects should clearly state the Member's roll number, his correct postal address, and the title and author of the book.

2. The library is intended primarily for reference. It is the source of information from which the Secretary, Indian Roads Congress, is enabled to answer enquiries addressed to him.

3. **Books are loaned for reference only and not for continuous use**. The library cannot be expected to relieve officers of the necessity of purchasing books required constantly or for long periods of time.

4. Ordinarily not more than two books will be issued at a time, but in special cases a larger number may be issued at the discretion of the Secretary.

5. The following rules will be strictly enforced :

(a) Books are issued for one month in the first instance. If a book is required for a longer period, an intimation should be sent to the Secretary, Indian Roads Congress for renewal before the due date of return. The book may then be re-issued for another month at a time at the discretion of the Secretary, but in no case will any book be issued for a total period exceeding three months.

(b) If a member does not return library books when the period of loan has expired or in any case within three months of the date of issue and thus deprives other members of their use, he will be liable for a fine at the rate of one anna a day for every day of retention up to three months and two annas a day thereafter up to six months. The Secretary will also have no power to issue any more books to the member until all the books already issued are returned. If all books are not returned within six months, twice the cost of the books will be debited to the borrower in addition to the fine referred to above.

(c) Current issues of Journals cannot be issued to members outside the Consulting Engineer (Roads)'s Office, but back issues of certain Journals may be sent on loan for a limited period.

(d) Books are issued strictly subject to the condition, in all cases, that they will be returned promptly if actually required and called for by the Secretary, Indian Roads Congress. Retention of a book after it had been recalled will render the member liable to the same penalties as if he had retained a book beyond the period of original loan.

(e) Borrowers are requested to take every care of books while in their possession, and particularly not to mark, underline, or note on the pages.

(f) If, during the period of issue to a borrower, any book is lost or so damaged as to be unserviceable for future use, the Secretary shall recover from the borrower a sum equal to the cost of obtaining another copy of the book.

6. **Instructions** :—

(a) No acknowledgment is required other than the postal acknowledgment card.

(b) While returning books, care should be taken to get them adequately packed to prevent damage in transit. They should be sent **"registered and acknowledgment due."**

7. **General :**

(a) Rare or specially valuable books and certain books of reference will not be sent out of the library.

(b) Any book may, however, be consulted in the library during office hours.

(c) Members who retain books for longer than a month after they have been called back or for longer than six months from the date of original issue and thus selfishly deprive other members of the use of the books, will be fined and/or charged subject to the penalties stated in these rules and deprived of all the privileges of membership until the dues are paid.

NOTE: All Members of the Indian Roads Congress, not in arrears of subscription for more than 90 days, are entitled to borrow books.

V. NEW ADMISSIONS.

LIST OF MEMBERS OF THE INDIAN ROADS CONGRESS ENROLLED FROM 19-3-1951 TO 11-9-1951.

Serial No.	*Roll No.*	*Name.*	*Address.*
1430	1574	Kashi Ram Kaushika.	Assistant Executive Engineer (Roads), N.D.A.P.C.II, Khadakwasla, North Camp, POONA-4.
1431	1575	G. S. Ghatpande.	Municipal Engineer, Indore City Municipality, INDORE, (Madhya Bharat.)
1432	1576	S. D. Vidyarthi.	Assistant Engineer, P. W. D., B/R, RANIKHET, (Almora, U. P.
1433	1577	R. I. Kapadia.	Assistant Engineer, P. W. D., WARANGAL (Hyderabad State).
1434	1578	Dina Nath Dhar,	Assistant Engineer, P. W. D., P. O. BARAMULLA, (Kashmir State).
1435	1579	Basant Lal.	Assistant Engineer, Rajasthan P.W.D., B/R., Udaipur South, UDAIPUR.
1436	1580	R. S. Grewal.	Divisional Engineer, Frontier Division, 2, Boulevard, SRINAGAR.
1437	1581	V. Govindaswami.	Assistant Engineer, Highways, Thallakullam Post, MADURAI, S. I.
1438	1582	T. S. Deo.	Assistant Engineer, C/o. Superintending Engineer, B/R, N Circle, GWALIOR, (Madhya Bharat).
1439	1583	P. N. Wanchoo.	Divisional Engineer, B/R Division, P.W.D., JAMMU (TAWI), (Kashmir).
1440	1584	S. S. Spencer.	Sub-Engineer, Bombay Port Trust, Mehta Mansion, 4, Alexandra Road, New Gamdevi, BOMBAY-7.
1441	1585	S. R. Shah.	Assistant Engineer, Right City Sub-Division, SRINAGAR (Kashmir).
1442	1586	H. J. Thakor.	Resident Engineer, Allied Construction Co., Ltd., Ramdaspeth, NAGPUR (Madhya Pradesh).
1443	1587	C. N. Jha.	Assistant Engineer, P. W. D., P. O. JAMUI, District Monghyr Bihar).

Serial No.	*Roll No.*	*Name.*	*Address.*
1444	1588	L. N. Gupta.	Assistant Engineer, P.W.D., PAURI (Garhwal).
1445	1589	S. N. Chattopadhyay.	Assistant Engineer, 13, Puddopukur Lane, CALCUTTA-20.
1446	1590	P. Massarik.	Civil Engineer, C/o. The Braithwaite Burn & Jessop Construction Co. Ltd., P-13, Mission Row Extension, CALCUTTA-1.
1447	1591	M. C. Abraham.	Professor of Civil Engineering, Bengal Engineering College, P. O. Botanic Gardens, HOWRAH, (West Bengal).
1448	1592	Balbir Singh Agrawal.	Overseer, P. W. D., PAURI-GARHWAL, (U. P).
1449	1593	Rajendra Kumar Berry.	Assistant Engineer, Punjab P. W. D., Buildings & Roads Branch, KARNAL.

VI. DEATHS.

The Council have received with regret, intimation of the following deaths :—

1	606	P. V. N. Sarma.	Assistant Engineer (Highways), Anakapalli, Visakapatnam District.
2	474	K. V. Chowdhury.	Divisional Engineer (Highways), Kakinada, East Godavari District.
3	432	H. J. Kothari.	C/o. Modern Construction Co., Mangal Bhuvan, Morvi (Saurashtra).
4	1458	S. G. Lakhani.	Assistant Brick and Sand Supply Officer, C/o. Office of the Assistant Housing Commissioner (West), Bombay.

VII. ADDRESSES OF MEMBERS WANTED.

Communications addressed to the following members have been returned unclaimed by the Post Office. Members able to give information regarding the present address of any of those concerned are requested to forward particulars to Secretary, I. R. C.

Serial No.	*Roll No.*	*Name of Member.*	*Address.*
1	125	Das Gupta, N.	C/o Shri K. R. Sen, Calcutta Insurance Co., Ltd., Connaught Circus, New Delhi.
2	700	Goswami, S. M.	159, Rashbehari Avenue, Calcutta-29.
3	24	Korni, M. A.	114, Regent Estate, Tolly Gunj, Calcutta.
4	1[illegible]3	Nawab Ahsan Yar Jung Bahadur (L.M.)	Afsar Manzil, Jubilee Hill, Hyderabad-Deccan.
5	417	Parang, Hari Ram (L.M.)	Retired Executive Engineer, Lal Chowk, Qila Gujar-Singh, Lahore. (Pakistan).
6	720	Shaw, M. (L.M.)	Executive Engineer, C. P. W. D., Indore.

Paper No. 156.

"Vertical Curves For Highways."

By

THE SPECIFICATIONS AND STANDARDS COMMITTEE
OF THE INDIAN ROADS CONGRESS

[Following precedent, the recommendations of the Specifications and Standards Committee on "Vertical Curves for Highways" are published in the Journal for discussion and comments of Members before finalization as an approved standard.]

TABLE OF CONTENTS

SYNOPSIS.

Visibility is a very important factor in road design. The Paper discusses the necessity for properly designed and laid out vertical curves to secure visibility and to avoid shock. Basing the investigations on published literature on the subject in other countries, the committee make recommendations to suit Indian conditions. Square-law parabolas for summits and cubic parabolas for valleys are advocated. Graphs showing the relation between the recommended lengths of curves, deviation angles, and the sight distances for design speeds are included.

Typical problem representing different conditions likely to be met with in the field are worked out. Tables helpful in field work are also included.

1. INTRODUCTION.

1.1. In the alignment of a highway, it is a generally accepted practice to follow, as closely as possible, the natural lie of the land. This practice, while satisfying the æsthetic principles of road location, lends itself to economical road construction. As the natural ground is rarely level, the road located therein according to these principles will also have a series of grades, often changing to suit the ground level. For the economical and safe operation of vehicular traffic, however, certain other important considerations set definite limits to the grades and also define the way the changes in grades are to be effected by the introduction of vertical curves in the longitudinal profile of the road.

1.2. Not so long ago, the average speed of motor vehicles on the main roads in this country was about 20 m.p.h. In recent years there has been a rapid advance in design. Motor vehicles, with low centres of gravity and equipped with powerful brakes, are now built to travel at high speeds. To take full advantage of these improved vehicles and thereby to increase the speed of road transport, it is necessary to improve the design of the road itself by applying proper geometric standards and by other means.

1.3. To attain the primary objectives of safety and comfort in travelling over different grades, the design of vertical curves has to be given due attention. This Paper gives a rational conception of the principles governing the design of vertical curves on roads. Mention is made of the recent contributions to the subject by expert investigators and recommendations have been developed to suit Indian conditions.

1.4. The design of vertical curves on highways is not entirely a matter of mathematical analysis. Factors such as the "personal equation" of the driver of the vehicle have to be taken into account and subjected to extensive research. On many such factors, research work and field observations carried out in other countries, particularly the United States of America, the United Kingdom, and Australia have supplied valuable material. Not all the data used in this Paper have been supported by adequate experimental observations. As further investigations are made some of the conclusions may need revision in the course of time.

2. GRADIENTS AND SPEED STANDARDS.

2.1. The rate of rise or fall with respect to the horizontal along the length of a road, expressed as a ratio or a percentage, is termed the "**Gradient**." It is customary to express a gradient in terms of the natural tangent of the angle of its inclination to the horizontal. This may also be stated as a ratio, e.g., 1 in 20, 1 in 25, etc. In the U. S. A. and some other countries the grade is more often expressed as a percentage as 5 per cent or 4 per cent etc.

2.2. When an angle is small, its tangent is approximately equal to its circular measure. For this purpose all angles within the practical range of gradients on roads may be treated as small.

2.3. In this Paper notations n_1 and n_2 are used to denote the natural tangents as well as circular measures of the angles of inclination to the horizontal of the two intersecting grade lines. Thus in Fig. 1, n_1 is the tangent (or circular measure) of the angle BAE and n_2 that of the angle BCF. Signs + and - are used to denote ascending and descending gradients respectively, in the line of travel, which, by convention, is generally left to right in figures.

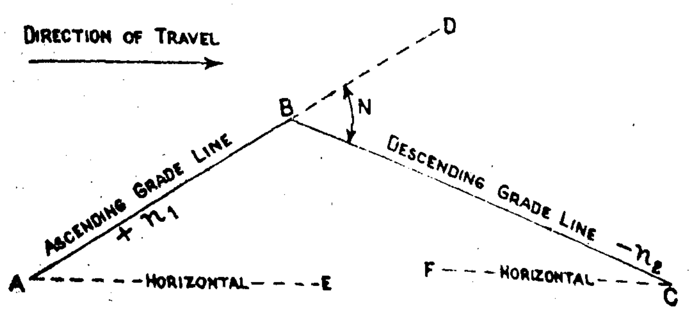


FIG. 1

2.4. The angle which measures the change of direction in the path of motion at the intersection of two grade lines is called the **deviation angle**. Thus in Fig. 1, angle DBC is the total deviation angle. In this Paper 'N' will denote the natural tangent or the circular measure of the deviation angle.

The deviation angle 'N' is given by the algebraic difference between the two grade angles.

Thus $N = n_1 - n_2$

Example :

$$\text{Let } n_1 = +\frac{1}{20} \text{ or } +\frac{5}{100} \text{ or} +5 \text{ per cent}$$

$$n_2 = -\frac{1}{25} \text{ or } -\frac{4}{100} \text{ or } -4 \text{ per cent}$$

$$\text{Then } N = \frac{1}{20} + \frac{1}{25}$$

$$= +0.09$$

2.5. Gradients must be fixed before a vertical curve can be designed. The designer has always to keep an eye on economy in selecting the alignment and suggesting the longitudinal profile of a road. The choice of the alignment of a projected road is influenced by many considerations, gradients being one of the most important. The necessity of securing easy grades sometimes compels a long and expensive alignment. On many an existing road grades can be improved only by abandoning the present alignment and re-locating it. Thus, for road projects it is necessary for the designer to know what gradients are to be aimed at. With this knowledge the designer is in a position to achieve a balance between the economy of design and its utility to the road user.

On motor roads in hilly country the gradients should be such that they can be negotiated with the least changing of gears by the heavier vehicles, (there is not much animal-drawn traffic on such roads). This saves time and operation costs. The problem is somewhat complicated in the plains where roads are used by the slow moving bullock cart on the one hand, and the fast modern motor vehicle on the other. For many years to come the bullock cart will remain a dominating element in the agricultural economy of this country. Gradients adopted on roads in the plains should, therefore, **not** be such as to have an adverse effect on bullock cart traffic. There are many varieties of bullock carts, differing in design and capacity, and in the strength, and number of bullocks used to pull. Obviously therefore the nature of the problem does not permit of laying down precise and rational standards applicable throughout the country. Experimental data are not yet available and, until such data are collected, the following standards based on experience are tentatively recommended (See Table I). These may be followed until a separate note on road grade standards is brought out.

Table 1—Gradients

	Ruling	Limiting	Exceptional*
Plains	1 in 30	1 in 20	1 in 15
Hills	1 in 20	1 in 15	1 in 12

* for short distances not exceeding 300 ft in a mile.

Gradients up to the **ruling gradient** can be used as a matter of course in road designs and quantities of cut and fill balanced as far as possible.

The **limiting gradients** may be used where the topography of a place compels this course or where the adoption of gentler gradients would add enormously to the cost. In such cases, the length of the continuous grade line at a grade steeper than the ruling gradient should be limited as far as possible. In hills where limiting gradients have to be used rather frequently it is important to separate such stretches by providing stretches of level road or easier grades.

In some very extraordinary situation **exceptional gradients** (see Table 1) may be unavoidable. For example, in a built-up area adherence to the grade of 1 in 20 may involve damage to expensive abutting property. Also in a hilly tract short stretches of grades, steeper than the maximum, may become essential to gain elevation to reach an obligatory point on a fixed route. In such exceptional cases gradients in excess of the maximum, and up to the exceptional, may be permitted. But each such case should be very critically examined and justified.

2.6. *Compensation in Grades for Horizontal Curves.*

2.6.1. When a vehicle driven by the rear wheels travels on a curve there is some loss in the tractive force as is explained below.

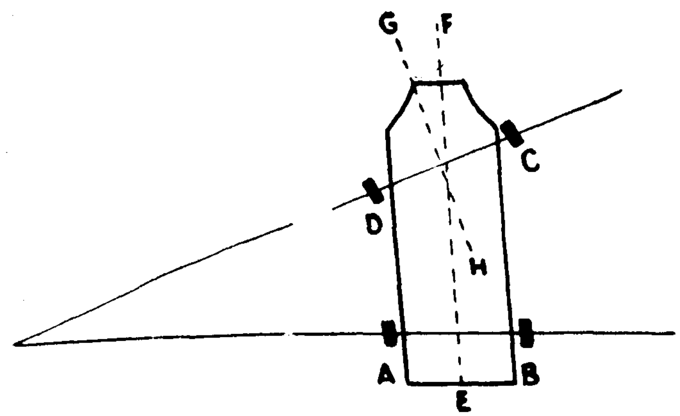


FIG. 2.

Let A and B be the rear driving wheels and C and D the front wheels of a motor vehicle in plan travelling on a curve (Fig. 2). It is seen that the tractive force acts in the direction EF while the front wheels should move in the direction GH so as to follow the curve. As GH is inclined to EF there will be a tendency for the vehicle to slide in the direction EF. This tendency is resisted by the friction between the wheels and the road surface, but in effect there **will** be a sliding movement when the curve is sharp. This action takes up some of the tractive force driving the vehicle forward. In the case of a vehicle with driving wheels in the front this action would be absent. To maintain the same speed on curve as on a straight more of the tractive effort of the vehicle has therefore to be mobilised in case of vehicles driven by rear wheels. The effect of the curve on the tractive effort is, therefore, the same as that of a grade. If, in addition to the curve, there occurs also a sharp grade the total effect of the curve and grade should not exceed that of the limiting gradient specified.

2.6.2. Very little scientific or experimental data are available to decide on the amount of reduction in the grade required to compensate for the loss of tractive effort on a curve but a number of empirical rules have been prescribed by different authorities.

L. I. Hewes recommends the following rule.

"Curves which are greater than 6 degrees or say of radii less than 1000 ft in length should always be compensated on grades of 5 per cent or over.

A simple rule is :

$$\text{Compensation in per cent grade} = \frac{250}{\text{Radius of Curve}}\text{"}$$

Example : If on a grade of 6 per cent there occur a horizontal curve of 250 ft radius the compensation to be given is 1 per cent. Thus the grade will have to be reduced to 5 per cent.

A rule of the Public Roads Administration of the United States of America is to reduce a 5 per cent ruling grade by 0.075 per cent for each degree of curvature in excess of 10 degrees. This rule gives reductions not much out of line with the results of the Hewes rule referred to above.

2.6.3. Australian practice follows more elaborate empirical tables in which the speed of the vehicle and the nature of the road surface are also taken into account. These rules are given in **Appendix II.**

2.6.4. It is considered that for all practical purposes the simple rule given by Hewes may be followed. It is not necessary to compensate grades where they are much below the maxima specified. It will be observed that curve compensation in grades becomes important when the road is in hilly country and takes sharp turnings as on hairpin bends or on curves approximating thereto.

2.7. *Design speeds of travel on various classes of Roads.*

2.7.1. As stated earlier in this Paper, the purpose of designing proper vertical curves is to achieve a safe sustained speed of travel on a road. Therefore we must know what maximum speed is to be sustained on each class of our roads. The analytical treatment of vertical curves centres round the one dominating factor "speed".

2.7.2. The Specifications and Standards Committee of the Indian Roads Congress recommended the undernoted (see Table 2) speed standards in their Paper on "Horizontal and Transition Curves." These speed standards will be applied in this Paper.

Table 2—Standard Design Speeds.

Design Speeds for different classes of roads.

Class of Road.	DESIGN SPEED.			
	Plains.		Hills.	
	m.p.h. V	Ft/Sec v	m.p.h. V	ft/Sec. v
National Highways	50	73	30*	44
Provincial Highways	50	73	30	44
Major District Roads	40	59	25	37
Other District Roads	30	44	20	29
Village Roads	20	29	15	22

3. THE PURPOSE OF VERTICAL CURVES.

3.1. It is a well known fact that considerable forces are involved when a change takes place in the direction of motion of

* Where practicable.

a body. When a motor vehicle travelling along one grade is to move on to another grade, a change of direction of motion in the vertical plane is involved. If this change is not effected gradually the vehicle will be subjected to shock and the occupants of the vehicle will experience discomfort. Therefore vertical curves are required to ease off the changes in gradients.

3.2. Vertical curves can be classed into two types viz., (1) Summit curves to ease off intersections convex upwards and (2) Valley curves to ease off intersections concave upwards.

3.3. In the Paper on standards for sight distances* recommendations are made for requirements of visibility from considerations of safety. When a motor vehicle approaches a summit curve the view of the road is cut off beyond the summit. Therefore to secure the required sight distance the intersection of the two grades should be flattened and eased off by interposing a properly designed vertical curve.

3.4. *Requirement of Sight Distance.*

For the purpose of determining the length ahead along the road that should be visible to the driver of a motor vehicle it is first necessary to define the position of the driver with reference to the road surface. Virtually it is the height of the eyes of the driver seated in the vehicle that defines the position. This height varies with the height of the seat above the road surface and with the height of the driver. Measurements taken with drivers seated on some of the popular modern makes of passenger cars in India showed a variation between 4 ft and 4 ft 6 in. The eyes of the drivers of some low-hung sports cars may be lower but these being relatively few in number may be neglected. The drivers of passenger buses and trucks are seated at a much higher level and therefore can see more of the road.

3.5. For purposes of road design the height of the driver's eye above the road surface is assumed in various countries as under :—

United Kingdom	...	3.75 ft
Australia	...	4.00 ,,
America	...	4.50 ,,
France	...	4.10 ,,
International Road system of Europe	...	4.48 ,,

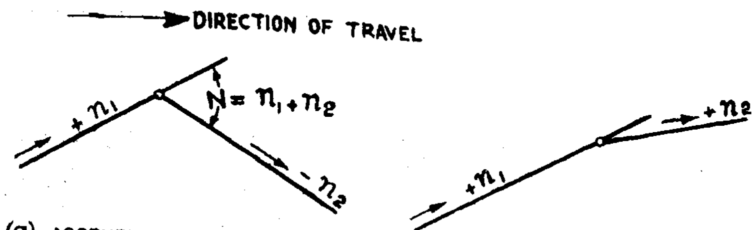
It is suggested that the height of the driver's eye for Indian conditions may be assumed as 4.00 ft.

* Paper No. 149, published in I.R.C. Journal Vol. XV-1, pages 155-183.

As explained in the Paper* on sight distances, two types o sight distance have to be considered. One is the absolute minimun and is equal to the safe stopping distance. The other is the mini mum overtaking distance, that is, the clear length of roadway a driver overtaking a slower vehicle has to look for between himsel and another approaching vehicle ahead travelling in the lane h proposes to use for the purposes of overtaking. The height o such vehicle ahead is also assumed as 4 ft which, while erring or the side of safety, simplifies design of the vertical curve.

4. SUMMIT CURVES.

4.1. A curve with convexity upwards is called a Summi Curve. Figure 3 illustrates cases where Summit Curves have to be used.



(a) ASCENDING GRADE MEETING A DESCENDING GRADE

(b) ASCENDING GRADE MEETING ANOTHER ASCENDING GRADE

FIG. 3 – SUMMIT CURVES

Fig. 3 (a) is the case of an ascending gradient intersecting a descending gradient; whereas in Fig. 3 (b) an ascending gradient intersects another ascending gradient. An intermediate case would be that of an ascending gradient meeting a horizontal.

4.2. *Type of Curve.*

The design of a summit curve is principally governed by considerations of sight distance unless the summit is so low as not to interfere with visibility. The dynamics of movement over an ordinary summit curve is of little consequence. This can be inferred from two considerations. (1) The centrifugal force generated by the movement of the vehicle along the curve acts practically in opposition to the force of gravity and is, therefore, beneficial in so far as it relieves the pressure on the tyres and

* Paper No. 149, I.R.C. Journal Vol. XV-1, pages 155-183.

springs of the vehicle. (2) Vertical deviation angles on roads are so small because the summit curves prescribed by the sight distance are so long and easy that "shock" is automatically rendered imperceptible to the travellers.

4.3. It, therefore, follows that on summit curves transitions are not essential and simple circular arcs are good enough. Since a circular arc has a constant radius of curvature throughout its length, it gives a constant sight distance all along. From this viewpoint the alternative of a curve fully transitional and symmetrical about the intersection is unsuitable, as the radius of the curve decreases towards its apex and the visibility on a vertical transition curve varies from point to point and is smallest across its apex. At a given intersection of gradients a transition curve will have to be much longer than a circular arc for equal visibility across the apex. Because of this disadvantage a transition curve is not recommended.

4.4. In actual practice a simple parabolic curve is used instead of the circular arc. The reasons are :—

(i) A simple parabola is nearly congruent with a circular arc between the same tangent points, because on road work the vertical deviation angles are very small and lengths of curves are very great.

and (ii) A parabola is very easy of arithmetical manipulation for computing ordinates.

4.5. There are, however, situations where the consideration of visibility or sight distances does not arise. When the road goes over a hump, such as one created by a culvert which rises two or three feet above the road level and does not obstruct the sight line, there is some advantage, however small, in using a transition curve instead of a simple parabola and there is no disadvantage. The advantage is that the transition curve is a perfectly shock-free curve. This course simplifies the design of curves over small humps as will be explained later on in this Paper (Para. 6.4).

4.6. *Summit Curve Formulae.*

4.6.1. In Fig. 4, let AD and DC be the two grade lines intersecting at D and inclined at $+n_1$ and $-n_2$ to the horizontal. Let ABC be a parabolic curve between the tangent points A and C. With A as origin, measure x horizontally and take y as the vertical intercept between the curve and the grade line ADE. Let the equation of the curve be

$$y = \frac{x^2}{a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

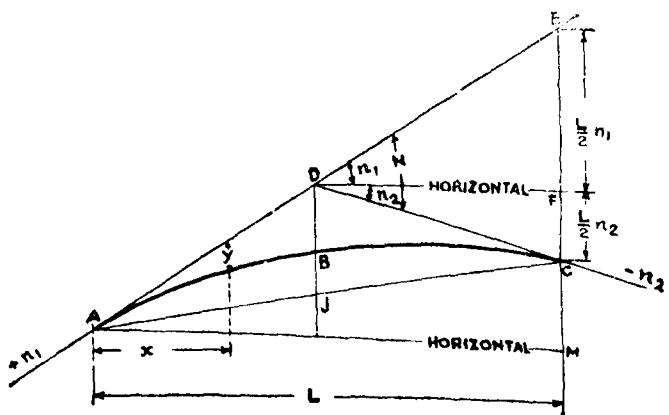


Fig. 4

From the geometry of the figure it is clear that

$$EC = EF + FC$$
$$= \frac{Ln_1}{2} + \frac{Ln_2}{2}$$
$$= \frac{L}{2}(n_1 + n_2)$$
$$= \frac{LN}{2}$$

Since summit curves are long and flat, the length of the curve ABC and its horizontal projection AM are for all practical purposes equal, each $= L$.

At the point C on the curve, $x = L$ and $y = EC = \frac{LN}{2}$.

Putting these values in the equation of the curve,

$$\frac{LN}{2} = \frac{L^2}{a}$$

Therefore $a = \frac{2L}{N}$ .... [2]

4.7. *Radius of Curvature of Summit Curve.*

Let (x, y) be the cartesian coordinates of any point on any curve. Let R be the radius of curvature at that point. If the curve is flat, $\frac{1}{R} = \frac{d^2y}{dx^2}$ .... [3]

The equation to the summit parabolic curve is $y = \frac{x^2}{a}$

Therefore $\frac{dy}{dx} = \frac{2x}{a}$

and $\frac{d^2y}{dx^2} = \frac{2}{a}$

that is $R = \frac{a}{2}$ .... [4]

But in equation (2), we have shown that

$$a = \frac{2L}{N}$$

Hence $R = \frac{L}{N}$ .... [5]

4.8. *Formulae for Length of Summit Curves.*

4.8.1. The length of a summit curve depends on (i) the deviation angle, (N), and (ii) the required sight distance (S), which may be either the overtaking sight distance or the minimum sight distance which is equal to the safe stopping distance (Ref. Paper No. 149, I.R.C. Journal, Vol. XV-1).

4.8.2. The gradients on both sides of the intersection are selected on the principles already discussed in para. 2.5. The deviation angle and the chainage of the point of intersection of the gradients can then be measured and recorded.

4.8.3. In calculating the length of the curve two cases have to be considered :—

For Overtaking Sight Distances

Case I : When the length of the curve exceeds the required sight distance, that is L is greater than S. In Fig. 5, ABC is a parabolic curve, A and C are tangent points, $E_1E_2 = S$, the required sight distance ; H, the height of the driver's eye above the road level ; N, the deviation angle ODC ; and L, the horizontal projection (AM) of the curve ABC.

From the geometry of the Figure it is obvious that

$$OC = OF + FC$$
$$= \frac{L}{2}(n_1 + n_2)$$
$$= \frac{L}{2} N.$$

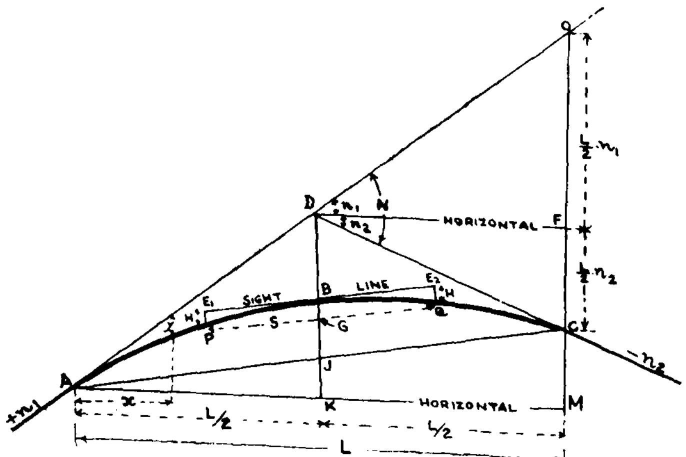


Fig. 5

Since grade angles are always small, the lengths of the curve *ABC* and the lines *AC* and *AM* can each be taken as very nearly equal to *L*.

From the properties of the parabola—

$$\frac{BG}{BJ} = \frac{(PQ)^2}{(AC)^2}$$

Putting $BG = H$

$$BJ = \tfrac{1}{4}DJ$$

$$= \tfrac{1}{4} \times \frac{LN}{2} = \frac{LN}{8}$$

$$PQ = S$$

and $AC = L,$

We get $\dfrac{8H}{LN} = \dfrac{(S)^2}{(L)^2}$

Or $L = \dfrac{N.S^2}{8H}$ .... [6]

As explained in para. 3.5, $H = 4$ ft.

Hence $L = \dfrac{N.S^2}{32}$ .... [7]

Case II: When the length of the curve is less than the required sight distance, that is, *L* is less than *S*. In Fig. 6, ABC is the parabolic curve and E_1E_2 is the sight distance *S*.

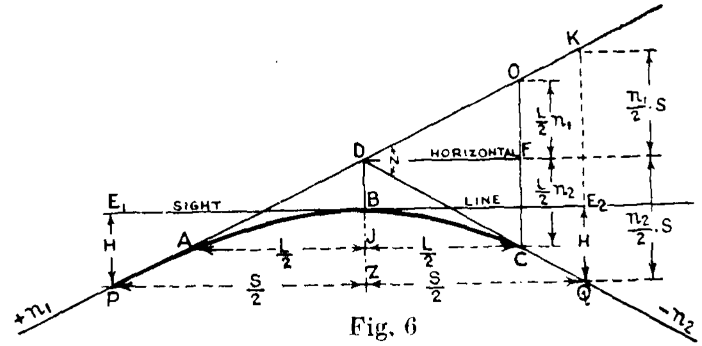


Fig. 6

Now $DB = \tfrac{1}{4} DJ$

$$= \tfrac{1}{4} \times \frac{L}{2}(n_1 + n_2)$$

$$= \tfrac{1}{8} LN$$

Also from the geometry of the figure,

$$BZ = H, \text{ and } DZ = DB + BZ$$

Therefore $DZ = \dfrac{LN}{8} + H$

but $DZ = \tfrac{1}{2} KQ$

$$= \tfrac{1}{2} S \frac{(n_1 + n_2)}{2}$$

$$= \frac{S.N}{4}$$

Equating the two values of *DZ*,

$$\frac{LN}{8} + H = \frac{SN}{4}$$

Hence $L = 2S - \dfrac{8H}{N}$ .... [8]

Putting $H = 4$ ft

$L = 2S - \dfrac{32}{N}$ .... [9]

4.8.4. ***For Non-Overtaking Sight Distances.***

In this case the situation corresponds to that shown in Fig. 7. The driver of the vehicle sights the top of an object lying beyond the apex of the curve. The formulae applicable to this condition are as below :—

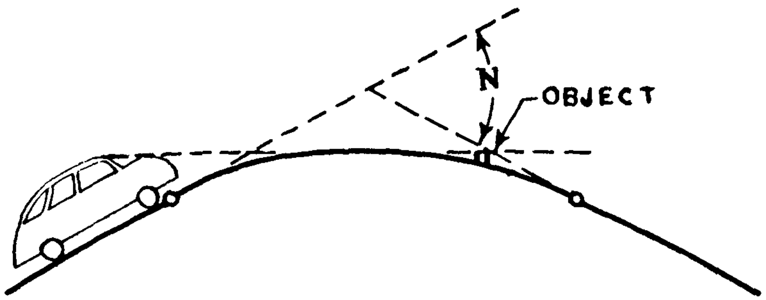


FIG. 7

Case I. When the length of the curve exceeds the required sight distance, that is L is greater than S.

$$S = 3.645\sqrt{\frac{L}{N}}$$

$$\text{or} \quad L = \frac{N}{13.286} S^2 \quad \ldots\ldots\ldots [10]$$

Case II. When the length of the curve is less than the required sight distance, that is L is less than S.

$$L = 2S - \frac{13{\cdot}286}{N} \quad \ldots\ldots\ldots [11]$$

4.9. ***Relation between L, R, N, and S.***

4.9.1. From equations [6] to [9] it is seen that the length, L, of a vertical curve decreases as N and/or S decreases. Therefore, in some cases the length of the curve required for providing the required sight distance would be very small. Further, in very flat grades no vertical curve is necessary for visibility but, for comfort in driving and to avoid shock and consequent strain on the springs of the vehicle, it is necessary to introduce a vertical curve. In both the above cases it is sufficient if a minimum length of curve be prescribed.

4.9.2. It is generally accepted that the ratio of the centrifugal force generated while negotiating a curve to the weight of the vehicle—known as the "centrifugal ratio"—is a measure of the smooth riding qualities of a curve. For vertical curves it has been assumed that this value should not be more than 20 per cent.

4.9.3. Taking the case where the sight distance is 200 ft that is, the minimum overtaking sight distance for a speed of 20 m.p.h., the 20 per cent centrifugal ratio would occur when the radius of curvature is 133 ft. However, allowing 100 per cent increase in the centrifugal ratio for shock at entry, a radius of curvature of 266 or 300 ft would be necessary to limit the centrifugal ratio to 20 per cent. The comfortable radius of curvature would therefore be 300 ft. Assuming, for the worst conditions, a total change of grade equal to 1/6 (i.e. twice the exceptional grades in hill sections) and substituting these values of R (300 ft) and N (1/6) in the equation,

$$R = \frac{L}{N}$$

We get $L = 50$ ft.

Hence, it is recommended that a minimum length of curve of 50 ft may be adopted.

4.9.4. In setting out and in plotting curves the length of the curve has to be divided into a suitable number of equal chords. The length of the chord is so chosen that the number of stations should not exceed about 50 (a workable limit) and also the length of the chord should not exceed $\frac{R}{200}$. In order that the length of the curve should be a multiple of the chosen length of the chord, the computed length of the curve is suitably rounded off while designing curves.

From the adopted value of L, modified as explained above, and the known value of N, are calculated the other characteristics of the curve such as "a" and "R" from the equations [2] and [5] respectively.

4.9.5. Plates I and II, included in **Appendix I** exhibit curves connecting the various elements N, L, S, R, etc. The use of these curves is explained by solving some practical design problems in Section 6 of this Paper.

4.10. ***Some observations on the minimum length and radius of summit curves.***

4.10.1. The most important objective in the design of summit vertical curves is to secure the sight distance corresponding to the design speed of the road. Hence, when S has been selected in a particular problem, the characteristics of the curve (L, R, etc.) can be read from Plates I and II.

4.10.2. Another consideration to which Western authorities attach varying importance, is to ensure that the radial acceleration over the curve does not exceed a certain limit so that it is comfortable to ride over the curve. The criterion of comfort introduces the personal element and makes it difficult to specify a correct limit for the radial acceleration. This may be illustrated by quoting Aitken and Boyd—"The Authors drove over a vertical curve of 400 ft radius at 30 m.p.h. and the sensation was hardly perceptible; the acceleration being 4.85 ft per second per second whilst a police patrol car was driven at 35 m.p.h. over a curve of 140 ft radius giving an acceleration of 18.9 ft per second per second and the journey was pronounced not uncomfortable." It is, therefore, clear that whatever specifications exist on the limiting value of radial acceleration are essentially arbitrary. The consensus of opinion appears to be that for comfortable riding the radial acceleration should not exceed 2.5 ft per second per second. This would mean that the radius of curvature should not be less than the values given in Table 3, calculated from the formula :

$(1.47\ V)^2/R = 2.5$ ft per sec. per sec.

Table 3

Minimum Radius of Curvature for Summit Vertical Curves.

Speed MPH	15	20	25	30	40	50	60
Min. radius R in ft	195	350	540	780	1380	2160	3110

Curves designed for the minimum sight distances prescribed will have radii greater than the minimum given above.

4.10.3. Another method of design was adopted at one time to secure good riding qualities of a curve. This method specified the maximum rate of change of slope on the curve per 100 ft length of the curve. Here again all specifications were arbitrary. The following rule appears to have been generally favoured :—

Speed MPH	30	40	50	60
Max. change of slope per 100 ft length as percentage grade	4.00	2.25	1.44	1.00

4.10.4. In other words, this rule means that the radial acceleration at any speed should not exceed 0.8 ft per sec. per sec minimum radii of curvature calculated to give this acceleration for various speeds are as below :—

Speed MPH	30	40	50	60
Min. R. Ft	2,500	4,440	6,940	10,000

It has been verified that curves designed as recommended in this Paper for overtaking sight distance do not give smaller radii of curvature than the above stated minima.

4.11. *Calculating Ordinates of Summit Curves.*

For the purposes of plotting and laying out a curve, its length is divided into a number of equal chords and the ordinates to the curve calculated at the ends of these chords.

Ordinates $y_1, y_2, y_3, \ldots\ldots y_r$ at stations 1, 2, 3........r (Fig .8) are calculated as under :

Since $y = \dfrac{x^2}{x}$

$y_1 = \dfrac{u^2}{a}$, (where u is the chosen length of the chord)

$y_2 = \dfrac{(2u)^2}{a}$ or $y_1 \times 2^2$

$y_3 = y_1 \times 3^2$

....

$y_r = y_1 \times r^2$

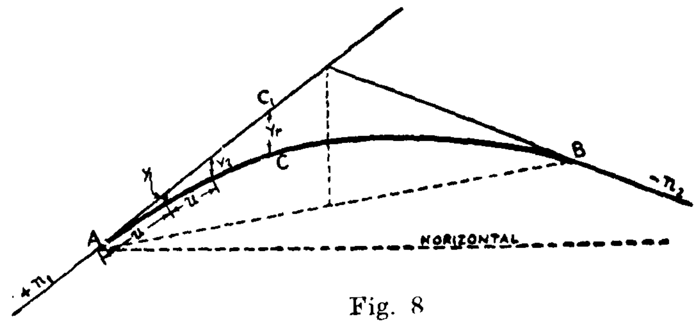


Fig. 8

Let C be the point on the road surface curve at the end of the r^{th} sub-chord. Let C_1 be the point on the grade line vertically above C. Let the reduced level of the tangent point A be 100.00.

Then R. L. of $C_1 = 100.00 + r\,(u \times n_1)$

R. L. of C = R. L. of $C_1 - y_r$

Similarly, the *R. Ls.* of other points on the curve are worked out and the design chart drawn as illustrated at the end of this Paper. *Vide Appendix I*

4.12. *Highest Point on Summit Curve.*

It is sometimes important to know the position of the highest point on a vertical curve for the purpose of layout of drainage appurtenances and for ascertaining vertical clearances in restricted locations as road under bridges etc.

When the two grades are equal the curve would be symmetrical about the vertical bisector of the intersecting angle and the highest point would also lie on this bisector. When the two grades are unequal the curve would be tilted and the highest point of the curve would lie on the side of the flatter gradient.

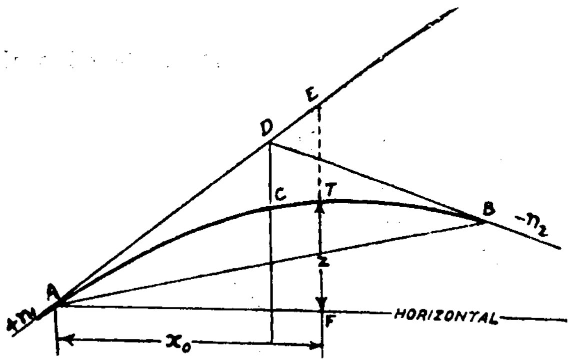


Fig. 9

In Fig. 9 let T be the highest point distant x_0 from the origin A.

The equation of the curve is $y = \frac{x^2}{a}$

Therefore $ET = \frac{x_0^{\,2}}{a}$

Also $EF = n_1 x_0$

Hence $Z = FT = EF - ET = n_1 x_0 - \frac{x_0^{\,2}}{a}$

T will be the highest point when Z is maximum.

i.e., when $\frac{dz}{dx} = 0$

That is, when $n_1 - \frac{2x_0}{a} = 0$.

Or $x_0 = \frac{a}{2} n_1$

But $a = \frac{2L}{N} = \frac{2L}{n_1 + n_2}$

Hence $x_0 = \frac{n_1}{n_1 + n_2} L.$

5. VALLEY CURVES.

5.1. A vertical curve concave upwards is known as a valley curve, dip or sag. Figures 10 and 11 illustrate two cases where valley curves have to be used.

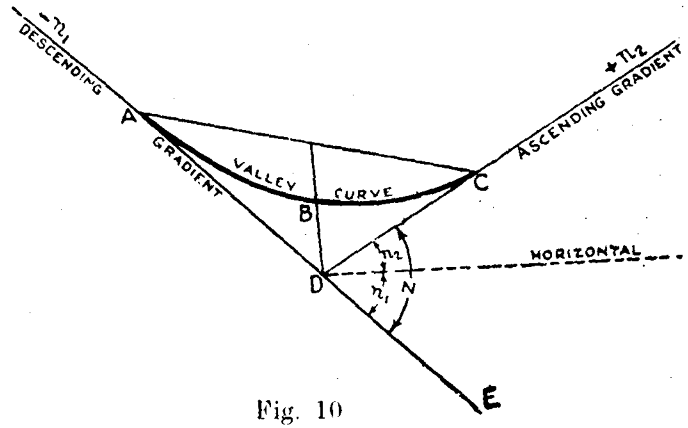


Fig. 10

Fig. 10 is the case of a descending gradient intersecting an ascending gradient, whereas in Fig. 11 a descending gradient intersects another descending gradient. In between these two cases would be the case of a descending gradient meeting a horizontal.

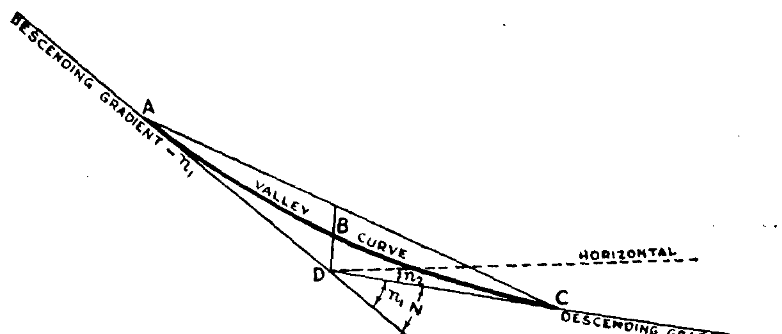


FIG. 11

5.2. ***Deviation angle on Valley Curves.***

According to the general rule already stated, the deviation angle is the algebraic difference of the two grade angles. Thus, in Fig. 10 –

N = angle $CDE = (-n_1)-(+n_2) = -(n_1+n_2)$ and in Fig. 11 –

N = angle $CDE = (-n_1)-(-n_2) = -(n_1-n_2)$

5.3. ***Shape of Valley Curves.***

5.3.1. On a valley curve a large component of this centrifugal force will act vertically downwards and will exert extra pressure on the tyres and springs of the vehicle in motion on the curve. If the entry to the curve is sudden, centrifugal force will develop suddenly and cause greater strain on the vehicle than that would be caused by a gradual increase in the curvature for a constant speed. The sudden jerky motion also would set up vertical oscillations which may prove very uncomfortable to the passengers and detrimental to the vehicle because of the alternating stresses produced. The latter wouldbe particularly important in the case of heavily loaded lorries and trucks.

5.3.2. Main roads of the future must be planned for high speed traffic. Centrifugal force which varies as the square of the speed has therefore to be adequately provided for. A transition curve is more important on a vertical curve than on a horizontal one. In the latter case the motorist has some freedom to make his own transition curve but on vertical curves he is tied down to the profile of the road.

5.3.3. As has been discussed in the Paper* on Horizontal curves, the reduction of the effect of the centrifugal force is brought about by the interposition of transition curves. It has also been shown there that three types of transition curves answer the purpose, viz., the spiral, the lemniscate, and the cubic parabola; and also that, when the polar deflections do not exceed 4 degrees, there is practically no difference between these three curves. The range or deviation angles met with, in actual practice, in the design of vertical curves is so small that there is practically no difference between these three curves and what finally decides the choice is the case of computation of data for setting out. While the spiral is suitable for setting out horizontal transition curves in the field by transverse angles of deviation, it has been found that the cubic parabola satisfies this condition in the case of vertical curves.

* Paper No. 119, Indian Roads Congress Journal Volume XI-3.

5.4. ***Radius of Curvature of the Valley Curve.***

5.4.1. Since the cubic parabola and the spiral are practically congruent for the small angles met within the design of valley curves, the properties of the spiral are used for easy determination of some of the characteristics of the curve and those of the cubic parabola for the other characteristics.

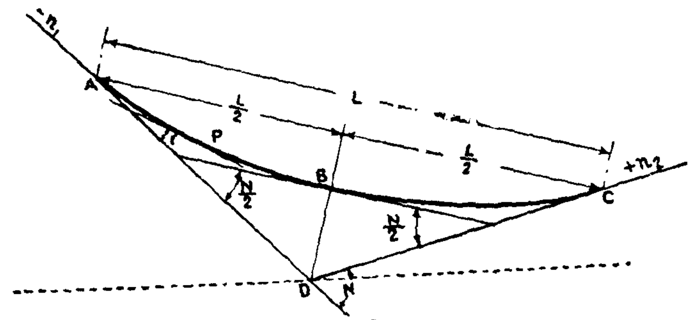


Fig. 12

In Fig. 12, n_1 and n_2 are two grades meeting at D and ABC is the complete transition curve made up of two equal spirals AB and BC.

5.4.2. Consider the spiral AB; let r be the radius of curvature and l the length of the curve (measured from A) at any point P on the curve. Let i be the change of slope from A to P.

From the definition of the spiral, $r \times l = m$, a constant, but

$$r = \frac{dl}{di} \quad \ldots\ldots [12]$$

Therefore, $\dfrac{dl}{di} = \dfrac{m}{l}$

or $l.dl = m.di$

Integrating $\dfrac{l^2}{2} = mi + a$ constant which can be shown to be 0.

$$\therefore \quad l = \sqrt{2mi} = \sqrt{2rl} \quad \ldots\ldots [13]$$

$$\therefore \quad r = \frac{l}{2i} \quad \ldots\ldots [14]$$

As the cubic parabola and spiral are practically congruent, this equation would hold good for the former too.

5.5. *Limiting Value of the Rate of Growth of Radial Acceleration.*

5.5.1. Imagine a body moving on a curved path with a uniform speed of v ft per sec. If r (feet) is the radius of curvature of the path at a given point and a the radial acceleration in ft per sec per sec at the given point

$$a = \frac{v^2}{r} \text{ ft per sec per sec.}$$

In Fig. 12 the radius of curvature changes on the transition curve from infinity at the origin A to a value, say R ft, at end B of the curve. Therefore a increases from naught at A to $\frac{v^2}{R}$ at B. If the length of the curve AB is $L/2$ ft, the time taken to cover AB is $\frac{L}{2v}$ seconds. Hence the rate of increase in radial acceleration C is given by

$$C = \frac{v^2}{R} \div \frac{L}{2v} = \frac{2v^3}{LR} \text{ ft per sec}^3 \ldots\ldots\ldots\ldots[15]$$

For comfort C should not exceed a certain permissible limit. This limiting value for C recommended by various authorities is as under :—

Country	Value of C	Authority
U.K.	1.0	Royal Dawson & Criswell
U.S.A.	2.0	Public Roads Administration
Australia	2.0	For speeds upto 50 mph
New South Wales	1.54	For speeds over 50 ,,

For the purposes of standards in India the value of C for design of vertical curves may be taken equal to 2.0 ft per sec^3. In the design of horizontal curves a sliding value changing with speed is adopted. It can be demonstrated easily that centrifugal acceleration in horizontal curves gives different sensations from those experienced on vertical curves. While the latter merely add to or deduct from the force of gravity, horizontal movements cause more discomfort.

5.6. *Length and other Characteristics of the Transition Curve.*

5.6.1. In Fig. 12, let L ft denote the length on the straight between the tangent points A and C. For all intents and purposes the length of each of the curves AB and BC may be taken as $L/2$, because the grade angles n_1 and n_2 are small.

The length L of the curve from the tangent point A to any point P is given by equation [13] viz., $l = \sqrt{2r\,li}$

At the end B of the curve AB, we have $r = R$,

$$l = \frac{L}{2} \quad \text{and } i = \frac{N}{2}$$

Substituting these values in the above equation we have

$$\tfrac{1}{2} L = \left(2 \times R \times \frac{L}{2} \times \frac{N}{2}\right)^{\frac{1}{2}}$$

$$\text{or } L = (2RLN)^{\frac{1}{2}}$$

From equation [15], $LR = \frac{2v^3}{C}$

but $v = 1.47V$ and $C = 2$

$$\text{Therefore } LR = \frac{6.3}{C} V^3 = 3.15\, V^3 \ldots\ldots\ldots\ldots[16]$$

Substituting for L, R,

$$L = 2.5 \quad (N.V^3)^{\frac{1}{2}} \ldots\ldots\ldots\ldots[17$$

Also the radius of curvature at any point P on the curve is given by the equation

$$r = \frac{L}{2i}$$

Substituting values for point B, we get

$$R = \frac{L}{2N} \quad \ldots\ldots\ldots\ldots[1$$

The cartesian equation to the cubic parabola is

$$y = \frac{x^3}{b} \quad \text{where } b = 6\,rl$$

Particular values for r and l at the point B may be substituted get

$$b = 6 \times R \times \frac{L}{2} = 3RL$$

$$\text{but } R = \frac{L}{2N} \text{ hence } b = \frac{3}{2} \cdot \frac{L^2}{N} \quad \ldots\ldots\ldots\ldots[$$

5.7. *Plate III V,N,L,R.*

When a curve has to be designed we must know n_1 and and the design speed V (M.P.H.).

From these data the length of curve, L, can be calculated from equation [17] above. In actual practice, the length of the curve so calculated is adjusted to the nearest multiple of 20 ft so that it can be divided into an equal number of chords 20 ft or 10 ft long for setting out.

Plate III included in the appendix exhibits the relation between V, N, L, and R. The use of this diagram will be explained later when solving practical problems in Part 6 of this Paper.

5.8. ***Finding the Lowest Point on a Valley Curve.***

It is essential to know the lowest point on a valley curve for fixing the position of scuppers etc. When the two gradients are unequal, the lowest point occurs on the side of the flatter gradient. In Fig. 13, let P be the lowest point distant x_1 from. C.

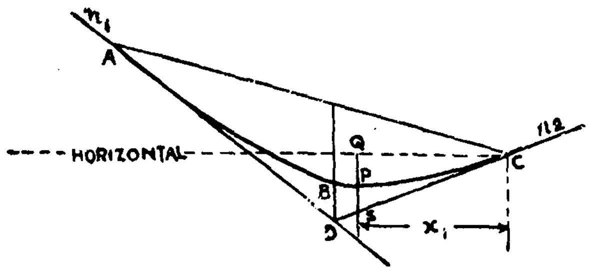


Fig. 13

Assume DC to be the flatter gradient of the two—

Let z_1 be the depth of P below the horizontal through C;

then $z_1 = QP = QS - PS = n_2 x_1 - \frac{x_1^3}{b}$

P will be the lowest point, if z_1 is maximum, i.e., when

$$\frac{dz_1}{dx_1} = 0. \text{ i.e. } n_2 - \frac{3x_1^2}{b} = 0.$$

$$\text{or } x_1 = \sqrt{\frac{b.n_2}{3}} \qquad \text{.............................[20]}$$

Substituting for b from equation [19],

$$x_1 = L \times \left(\frac{n_2}{2N}\right)^{\frac{1}{2}} \qquad \text{...............................[21]}$$

This fixes the position of the lowest point on the curve,

5.9. ***Computing Ordinates of Valley Curves.***

The Valley curve is made up of two transition curves—cubic parabolas—equal and reversed. Consider one of the curves viz., AC in Fig. 14. Let this be divided into a number of equal

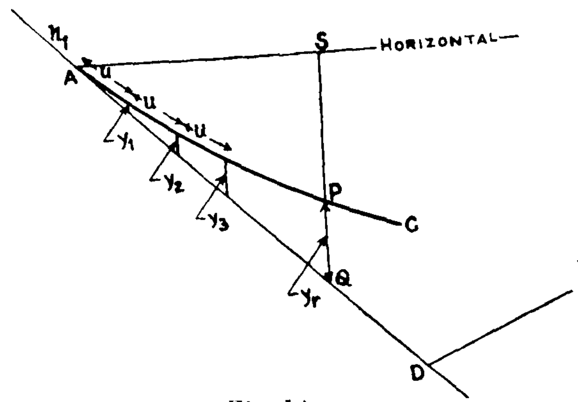


Fig. 14

chords, each of length u ft. In practice u is taken as 20 ft or 10 ft for convenience. Ordinates at the ends of successive chords can be calculated as below :—

The equation to the curve is

$$y = \frac{x^3}{b}$$

First ordinate $y_1 = \frac{u^3}{b}$

Second ,, $y_2 = \frac{(2u)^3}{b} = y_1 \times 2^3$

Third ,, $y_3 = \frac{(3u)^3}{b} = y_1 \times 3^3$

....

rth ,, $y_r = \qquad y_1 \times r^3$

If the level of the tangent point A is 100.00 the level of point P on the curve at the end of rth chord is $(100.00 - SQ + PQ) = 100.00 - r.u.n_1 + yr$

5.10. *Impact Factor.*

The centrifugal force, F, due to motion on the curve is given by—

$$F = \frac{W}{g} \times \frac{v^2}{r} \text{ lb.}$$

Where W = weight of the vehicle in lb.

v = speed in ft per sec.

r = radius of curvature in ft at the point under consideration.

F is maximum where r is minimum. This occurs at the end B of the transition curve (Fig. 12) where $r = R$. Hence the maximum value of F,

$$F \text{ max.} = \frac{W}{g} \times \frac{v^2}{R}$$

The impact factor, I, may be defined as the percentage which F max. is of the weight W of the vehicle.

$$\text{Hence, } I \text{ max.} = \frac{F \text{ max.}}{W} \times 100 \text{ per cent} = \frac{v^2}{gR} \times 100 \text{ percent}$$

Putting $R = \dfrac{L}{2N}$,

$v = 1.47\ V$,

and $g = 32$ ft per sec per sec

We get,

$$I \text{ max.} = 13.4\ \frac{V^2 N}{L} \text{ per cent} \quad \ldots\ldots[22]$$

Impact imposes additional strain on the tyres and framework of the vehicle as also on the road structure. Besides, it causes discomfort to the passengers. Impact factors are, therefore, kept as low as economically possible. The limit is taken as 25 per cent for vertical curves on roads, though in railway practice it is kept as low as 12.5 per cent.

5.10.1. In the analysis of the impact factor it was tacitly assumed that the centrifugal force would be built up gradually on the transition curves and has nothing of a live force in its nature. That is actually so, but then there are many factors, such as, undulations of the road surface, imperfections in the actual execution of designed curves, etc., which, though not ascertainable, add appreciably to impact.

To allow for these, the maximum permissible impact factor is reduced from 25 per cent to 17 per cent. The impact factor should be calculated along with the design of the curve and stated on the curve sheets to ensure that the limit of 17 per cent is not exceeded.

6. PRACTICAL DESIGN OF VERTICAL CURVES ON HIGHWAYS.

6.1. *General.*

In the application, to actual problems of the principles enunciated in the previous Sections, the following points deserve to be borne in mind.

The vertical curvature of roads should be bold in design and long easy curves should take in all *minor* changes in ground levels. As far as possible, numerous changes in gradients joined together with a short vertical curves should be avoided, except in mountainous country where the adoption of long and easy curves might become very costly. The economic aspect of vehicle operation is very important in the choice of grades since the greater consumption of fuel and the heavier wear and tear of tyres and brakes of vehicles in traversing a wide range of vertical rises and falls would add heavily to operation costs. For reasons of aesthetic appearance also, where horizontal and vertical curves occur together, the two curves should begin and end together as far as possible, otherwise, if *possible*, the length of the horizontal curve should be greater than that of the vertical. It is often desirable in such cases, and particularly where a permanent type of surfacing such as cement concrete makes subsequent changes difficult, to examine all proposals by making scale models.

6.2. *Design of Summit Curves.*

The design of summit curves follows the procedure given below.

6.2.1. On a longitudinal section of the road drawn to scale are fixed the economical gradients, selected by taking into consideration the amount of earthwork and other incidental works involved. The value of two gradients meeting at a point being known, the deviation angle N is known (see para. 2.4).

6.2.2. The sight distance applicable to the section of the road is selected, taking into account the classification of the road, the topography of the country and whether the section lies in an overtaking zone or *non*-overtaking zone (see Paper No. 149—"Sight Distances for Highways", I.R.C. Journal Vol. XV-I).

6.2.3. The value of N and S being thus known, the appropriate length of the summit curve, L, corresponding to those values is read off from Plate I or II, as applicable. The radius of curvature, R, of the curve at the apex can also be obtained from the same Plate.

6.2.4. The value of L as read from the graph is then rounded off so that the modified value is divisible into a number of equal chords of a reasonable length not exceeding $R/200$.

6.2.5. By reading the value of M (see Plates I & II), for the length designed from the graphs in Plate I or II, as applicable, the depth of cutting required for constructing the curve is obtained. This depth may be checked to see if the cutting would be excessive.

6.2.6. The constant "a" is calculated from equation [2] and the first ordinate y_1, obtained. The other ordinates and reduced levels of the various station points on the curve are then calculated and tabulated for facility in setting out in the field.

6.3. *Design of Valley Curves.*

6.3.1. The gradient lines are marked on the longitudinal section of the road and the deviation angle, N, calculated as explained in para 6.2.1.

6.3.2. The design speed, V, appropriate to the class of road and the topography of the country, is noted down.

6.3.3. By using the graphs in Plate III are obtained the length, L, and the minimum radius, R, of the curve for the corresponding values of N and V. This length, L, is rounded off so as to be divisible into a number of equal chords of a convenient length not exceeding $R/200$.

6.3.4. From equation [19] the constant "b" and the first ordinate y_1 (para. 5.9) are obtained and the other ordinates and reduced levels of the station points are calculated from these and tabulated for setting out in the field.

6.4. *Shock-free Curves at Humps and Dips.*

Very often in the vertical alignment of a road there occur humps over culverts, where the total height of the hump is less than the height of eye and the sight line is not obstructed. In such cases, in order to make the hump shock-free it is necessary to employ transition curves—Plate IV exhibits graphs from which the important functions such as the length, L, and the radius, R, as well as ordinates at various points on the curve can be read from known values of the deviation angle, N, and the design speed, V. Also the ordinates y_1, y_2, y_3, etc., can be read from the graphs correct up to 0·05 ft.

The procedure for design is clear from Plate IV which is self-explanatory. In this Plate, the figure illustrating the curve over a hump shows deviation angles as N_1, N_2, N_3 and N_4. In actual practice these deviation angles will be equal in most cases, and therefore, the design of the curve in its various parts will be very simple.

The Plate provides a simple method of designing shock-free vertical curves on unimportant dips or short shallow crossings also.

Plates V and VI exhibit an alternative chart and a nomogram for the design of Shock-free Vertical Curves for Dips and Humps. The procedure for using the graph and the nomogram is explained in the Plates.

PROBLEM No. 1

Design of a Vertical Summit Curve on a National Highway in plain Country.

Data (i) Gradients : $n_1 = +\ 1/25$ or 4 per cent

and $n_2 = -\ 1/30$ or 3.33 per cent

(ii) Class of Road - National Highway

(iii) The existing features near the locality permit the adoption of only the minimum sight distances. Case I will show the design for a curve providing non-overtaking, sight distance and case II that for overtaking, sight distance.

Solution

(a) Deviation angle $N = +\frac{1}{25} - (-\frac{1}{30})$

$= 0.040 + 0.033$

$= 0.073$

(b) Sight distance

Referring to Paper No. 149—"Sight Distances for Highways" the minimum non-overtaking sight distance for a speed of 50 m. p. h. is 400 ft and the corresponding overtaking sight distance is 1,450 ft for an undivided carriageway.

Case I: **Non-overtaking, sight distanee.**

(c) Length of curve

From Plate II corresponding to $N = 0.073$ and $S = 400$ ft, the length of the curve is 880 ft.

The radius of curvature read from Plate II is 12,000 ft.

Round off L to 900 ft.

With L equal to 900 ft and $N = 0.073$ the sight distance secured will be greater than 400 ft.

(d) Calculation of the design chart:

$$a = \frac{2L}{N} \text{......Equation [2] (Para. 4.6.1)}$$

$$= \frac{2 \times 900}{0.073} \quad = 24{,}658.$$

From equation $y_1 = \frac{u^2}{a}$ (Para. 4.11)

First ordinate $y_1 = \frac{100 \times 100}{24{,}658} = 0.4055$

The design is then worked out assuming the beginning of the vertical curve (B. V. C.) to be RL 100.00 as in table on p. 53.

(e) Highest point on the curve

From equation in para. 4.12

$$x_0 = \frac{n_1}{n_1 + n_2} \times L$$

$$= \frac{0.04 \times 900}{0.04 + 0{\cdot}033} = \frac{36}{0{\cdot}073} = 493.2 \text{ ft.}$$

The reduced level of this point is worked as under:

$$y \text{ max.} = (4.932)^2 \times y_1$$

$$= 9.93 \text{ ft.}$$

R.L. of the point along the 1/25 gradient corresponding to the highest point on the curve

$$= 100 + \frac{493.2}{100} \times 4.00$$

$$= 119.73$$

$\therefore$ *R.L.* of the highest point $= 119.73 - 9.93$

$= 109.80$

PROBLEM NO. 1 : CASE 1

Design Chart

for a non-overtaking sight distance of 400 ft speed :—50 m. p. h.

First half of the curve (1 in 25)					Second half of the curve (1 in 30)				
No. of station from B. V. C.	Chainage from B. V. C.	R. L. of points on first grade line	Ordinates between curve and first grade line	R. L. of station on curve	No. of station from B. V. C.	Chainage from B. V. C.	R. L. of points on 2nd grade Line	Ordinates between curve and 2nd grade line	R. L. of station on curve
Read down-wards		Rise per station 4.00 ft							
0 (BVC)	0	100.00	0.000	100.00	10 (EVC)	900	103.003	0.000 As in opposite station of first half of the curve	103.00
1	100	104.00	$y_1 = 0{\cdot}4055$	103.60	9	800	106.336	0.4055	105.93
2	200	108.00	$2^2 y_1 = 1.622$	106.38	8	700	109.669	1.622	108.05
3	300	112.00	$3^2 y_1 = 3.650$	108.35	7	600	113.002	3.650	109.35
4	400	116.00	$4^2 y_1 = 6.488$	109.51	6	500	116.335	6.488	105.85
5	450	118.00	$(4.5)^2 y_1 = 8.212$	109.79	5 Read up wards	450	118.00 Fall per station 3.33 ft	8.212	109.79

B. V. C. = Beginning of the Vertical Curve
E. V. C. = End of the Vertical Curve

In the field it is essential to mark the highest point also. The solution is indicated diagrammatically in Fig. 15.

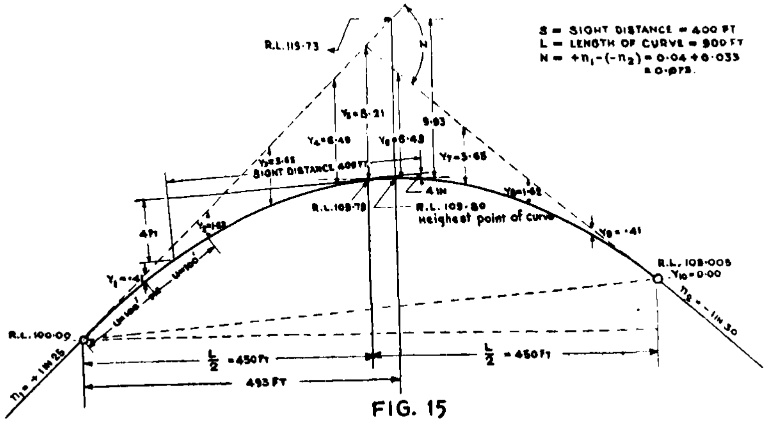


FIG. 15

Case II : **Overtaking sight distance.**

(i) From Plate I corresponding to $N = 0{\cdot}073$ and $S = 1{,}450$ the intersection point giving the length of the curve for the given conditions is outside the charts. Therefore using equation [7], (Para. 4.8.3) –

$$L = \frac{NS^2}{32} = \frac{0{\cdot}73 \times 1450 \times 1450}{32} = 4{,}796 \text{ ft}$$

Round off the length to 4,800. The radius of curvature of the curve is 65,000 ft (Plate I). Divide the curve into 24 stations of 200 ft each.

(ii) Calculation of the design chart : Table on p. 56

From equation [2] para. 4.6.1

$$a = \frac{2L}{N}$$

$$= \frac{4800 \times 2}{0{\cdot}073}$$

$$= 1{,}31{,}507$$

$\therefore$ From equation $y_1 = \dfrac{u^2}{a}$ para. 4.11

$$y_1 = \frac{200 \times 200}{1{,}31{,}507}$$

$$= 0{\cdot}3042$$

(iii) Highest point of the curve occurs at x_0. From equation (vide para. 4.12)

$$x_0 = \frac{n_1}{n_1 + n_2} \times L$$

$$= \frac{.04}{.073} \times 4800$$

$$= 2630{\cdot}1$$

$$= 2630$$

$$y \text{ max.} = (26{\cdot}30)^2 \times \frac{100 \times 100}{1{,}31{,}507}$$

$$= 52{\cdot}60 \text{ ft.}$$

R. L. along the 4 per cent grade $= 100{\cdot}00 + 26{\cdot}30 \times 4$

$= 205{\cdot}20$

$\therefore$ R. L. of the highest point $= 205{\cdot}20 - 52{\cdot}60$

$= 152{\cdot}60$

The solution is diagrammatically indicated in Fig. 16.

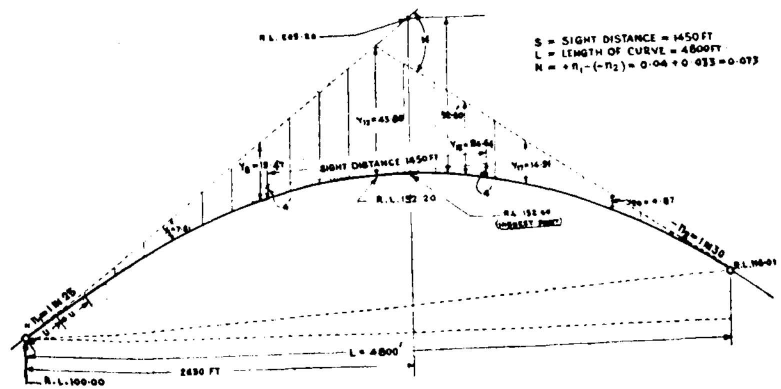


FIG. 16

PROBLEM No. 1 : CASE II

Design Chart for an overtaking sight distance of 1450 ft ; speed 50 m. p. h.

First half of the curve (1 in 25)					Second half of the curve (1 in 30)				
No. of station from B. V. C.	Chainage from B. V. C.	R. L. of point on 1st grade line	Ordinates between curve and first grade line	R. L. of station on curve	No. of station from B. V. C.	Chainage from B. V. C.	R. L. of points on 2nd grade line	Ordinates between curve and 2nd grade line	R. L. of station on curve
Read downwards	0	Rise per Stn = 8.0							
0 (BVC)	0	100.00	0.000	100.00	24	4800	116.008	0.0000	116.01
1	200	108.00	$y_1 = 0.3042$	107.70	23	4600	122.674	0.3042	122.37
2	400	116.00	$2^2 y_1 = 1.21168$	114.78	22	4400	129.340	1.2168	128.12
3	600	124.00	$3^2 y_1 = 2.7378$	121.26	21	4200	136.006	2.7378	133.27
4	800	132.00	$4^2 y_1 = 4.8672$	127.13	20	4000	142.672	4.8672	137.80
5	1000	140.00	$5^2 y_1 = 7.6050$	132.40	19	3800	149.338	7.6050	141.73
6	1200	148.00	$6^2 y_1 = 10.9512$	137.05	18	3600	156.004	10.9512	145.05
7	1400	156.00	$7^2 y_1 = 14.9058$	141.09	17	3400	162.670	14.9058	147.76
8	1600	164.00	$8^2 y_1 = 19.4688$	144.53	16	3200	169.336	19.4688	149.87
9	1800	172.00	$9^2 y_1 = 24.6402$	147.36	15	3000	176.002	24.6402	151.36
10	2000	180.00	$10^2 y_1 = 30.4200$	149.58	14	2800	182.668	30.4200	152.25
11	2200	188.00	$11^2 y_1 = 36.8082$	151.19	13	2600	189.334	36.8082	152.53
12	2400	196.00	$12^2 y_1 = 43.8048$	152.20	12	2400	196.000	43.8048	152.20
					Read upwards		Fall per station 6.66 ft		

Note :—The table is worked out for chord lengths of 200 ft ; a similar procedure may be adopted if length of 100 ft is chosen.

PROBLEM No. 2

Design the curve in Problem No. 1 with the condition that the length of the curve is not to exceed 1,000 ft.

In problem No. 1 it was seen that for a non-overtaking sight distance for a speed of 50 m.p.h. viz., 400 ft the length of the curve was 900 ft. Whereas for an overtaking sight distance of 1,450 ft the length was 4,800 ft.

Limiting the length of curve to 1,000 ft is possible in one of the following two ways :—

(i) Reducing the total grade change or deviation angle N by re-adjusting the approach gradients.

(ii) Reducing the sight distance.

The former is preferable and may be possible in many locations. In certain situations it may not be possible to adjust the gradients as, for example, between a high level bridge and a causeway which have their formation levels fixed and are situated a specified distance apart. The grade line joining the two will not, therefore, permit flattening beyond a certain point. In such a case the sight distance, and therefore the speed over the curve, must be stepped down.

Solution I. Adjusting the approach gradients.

Referring to Plate I the deviation angle for a sight distance of 1,450 ft and length of curve 1,000 is 0.017. The gradients may be adjusted to suit this.

Other characteristics of the curve can now be calculated and the design chart drawn up as in problem 1.

Solution II. With a deviation angle (N) of 0·073 and length of curve of 1,000 ft the sight distance would be of the order of 650 ft (from Plate I). Calculating from equation [7] $L = \frac{NS^2}{32}$

$$\therefore\ 1000 = \frac{0.073.S^2}{32}$$

$$S^2 = \frac{32000}{0.073}$$

$$\therefore\ S = 662 \text{ ft}$$

The safe speed will be 32 m.p.h. (vide Table 6, Paper No. 149, Indian Roads Congress Journal Vol. XV-1).

PROBLEM NO. 3

Design of a valley curve on a Provincial Highway in plain country.

Data : A falling gradient of 1/35 meeting a rising gradient of 1/20.

Solution :

(i) Deviation angle $N = \frac{1}{20} - (-\frac{1}{35})$

$= 0.05 + 0.028$

$= 0.078$

(ii) Design speed $= 50$ m.p.h.

(iii) Length of curve : From Plate III corresponding to $N = 0{\cdot}078$ and $V = 50$, $L = 245$ ft.

Round it off to 240, and divide it into 24 stations 10 ft apart.

(iv) Design chart :

$$\text{From equation [19]},\ b = \frac{3L^2}{2N}$$

$$= \frac{3 \times 240 \times 240}{2 \times 0.078}$$

$$= 11{,}07{,}700.$$

$$\text{First ordinate } y_1 = \frac{u^3}{b} = \frac{10 \times 10 \times 10}{11{,}07{,}700}$$

$$= 0.000903$$

The design chart is then worked out as on p. 59.

(v) Lowest point on the curve. It is very important to fix this point in the field as the siting of drainage works depends on this.

$$\text{From equation [21]},\ x_1 = L \times \left(\frac{n_2}{2N}\right)^{\frac{1}{2}}$$

$$= 240 \times \left(\frac{0.028}{2 \times 0.078}\right)^{\frac{1}{2}}$$

= 95.76 ft from the beginning of the curve on the flatter side.

PROBLEM NO. 3

Valley Curve Design Chart

No. of station from B.V.C.	Chainage from B.V.C.	R. L. of point on 1st grade line	Ordinates between curves and 1st grade line	R. L. of station on curve	No. of station from B.V.C.	Chainage from B.V.C.	R. L. of point on 2nd grade line	Ordinate between curve and 2nd grade line	R. L. of station on curve
Read downwards		Fall 0.286 ft per station							
0 (BVC)	0	100.00	0.000	100.00	24 (EVC)	240	102.568	0.000	102.58
1	10	99.714	$y_1 = 0.000903$	99.71	23	230	102.068	0.001	102.08
2	20	99.428	$2^3y_1 = 0.007$	99.44	22	220	101.568	0.007	101.57
3	30	99.142	$3^3y_1 = 0.024$	99.17	21	210	101.068	0.024	101.09
4	40	98.856	$4^3y_1 = 0.058$	98.91	20	200	100.568	0.058	100.63
5	50	98.570	$5^3y_1 = 0.113$	98.68	19	190	100.068	0.113	100.18
6	60	98.284	$6^3y_1 = 0.195$	98.48	18	180	99.568	0.195	99.76
7	70	97.798	$7^3y_1 = 0.310$	98.31	17	170	99.068	0.310	99.38
8	80	97.712	$8^3y_1 = 0.462$	98.17	16	160	98.568	0.462	99.03
9	90	97.426	$9^3y_1 = 0.658$	98.08	15	150	98.068.	0.658	98.73
9.576	95.76	97.210	$(9.576)^3y_1 = 0.793$	98.00	Lowest point on curve.				
10	100	97.140	$(10)^3y_1 = 0.903$	98.04	14	140	97.568	0.903	98.47
11	110	96.854	$(11)^3y_1 = 1.202$	98.06	13	130	97.068	1.202	98.27
12	120	96.568	$(12)^3y_1 = 1.560$	98.13	12	120	96.568	1.560	98.13
					Read upwards		Rise per station = 0.500 ft		

Intercept between curve aud tangent $= (9.576)^3 \times 0{\cdot}000903$

$= 0.793$

Level along the tangent at 95.76 from the beginning of the curve is $100.00 - 0.2886 \times 9.576$

$= 100.00 - 2.79$

$= 97.21$

$\therefore$ Level of the lowest point $= 97.21 + 0.793$

$= 98.003$ or 98.00

It is necessary to consider the valley curve to be composed of two cubic parabolas but of identical parts. The reason is that the cubic parabolas has a variable rate of change of slope and the radius diminishes and then continues to increase again.

PROBLEM No. 4

Data: Design suitable curves for the approaches of a long causeway, on a National Highway. The floor of the causeway is 8.5 ft below the approach roads, which are level on either side.

Solution: Since the causeway is on a National Highway the design speed is 50 m.p.h., non-overtaking sight distance is 400 ft, overtaking sight distance is 1450.

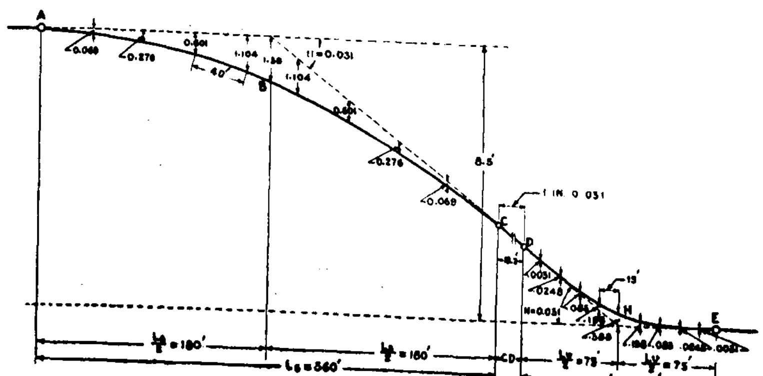


FIG. 17

From Fig. 17 ignoring the straight bit CD,

$$\tfrac{1}{2}(Ls + Lv) \times N = 8.5 \text{ ft.}$$

where Ls = length of summit vertical curve ABC

and Lv = length of the valley curve DHE.

Here N is not fixed and has to be chosen so that

(i) Ls (corresponding to the value of N chosen and $S = 400$ ft.)

and (iii) Lv (corresponding to the value of N chosen and design speed 50 m.p.h.)

satisfy the above relationship.

Try $N = 0.031$

From Plate II $Ls = 360$ ft.

From Plate III $Lv = 155$ ft.

Rounding the values to 360 and 150

$$\tfrac{1}{2}(360 + 150) \times 0.031 = 7.905 \text{ ft.}$$

This is near enough and the balance of fall $(8.50 - 7.905)$ or 0.595 will be covered by the straight portion CD.

The length of the straight portion CD would be

$$\frac{0.595}{0.031} = 19.2 \text{ ft.}$$

The detailed design of the curves is then made as shown below. Fig. 17 shows the curve with the ordinates to the curve from the tangent.

(i) Design of the summit curve.

Ls = length of summit curve = 360 ft.

S = sight distance with obstruction 4 in. height and height of eye 4 ft = 400 ft.

$N = 0.031$

Divide the length of the curve in chords of 40 ft each.

The design chart may be calculated now.

$$\text{Constant } a = \frac{2 \times L}{N} = \frac{2 \times 360}{0.031} = 23{,}226$$

$$\text{First ordinate } y_1 = \frac{40 \times 40}{23{,}226} = 0.069$$

Design Chart for Summit Curve (Problem 4)

First half of curve			Second half of curve		
No. of station from B.V.C.	Chainage from B.V.C.	Ordinate between curve and first grade line	No. of station from B.V.C.	Chainage from B.V.C.	Ordinate between curve and second grade line
Read downwards					
0 (BVC)	0	0.00	10 (BVC)	360	0.00
1	40	$y_1 = 0.069$	9	320	0.069
2	80	$2^2 y_1 = 0.276$	8	280	0.276
3	120	$3^2 y_1 = 0.601$	7	240	0.601
4	160	$4^2 y_1 = 1.104$	6	200	1.104
5	180	$4.5^2 y_1 = 1.39$	5	180	1.39
			Read upwards		

(ii) Design of the valley curve:

Deviation angle = 0.031

Design speed = 50 m.p.h.

Lv = length of the valley curve 150 ft.

Divide the curve into 10 equal parts of 15 ft each.

$$b = \frac{3.L^2}{2\ N} = \frac{3}{2} \times \frac{150 \times 150}{0.031} = 10,88,710.$$

$$\text{First ordinate } y_1 = \frac{x^3}{b} = \frac{15 \times 15 \times 15}{1088710} = 0.0031$$

Design Chart for the Valley Curve (Problem 4)

First half of the curve			Second half of the curve		
No. of station from B.V.C.	Chainage from B.V.C.	Ordinate between curve and first grade line	No. of station from B.V.C.	Chainage from B.V.C.	Ordinate between curve and second grade line
Read downwards					
0 (BVC)	0	0.00	10 (BVC)	150	0.00
1	15	$y_1 = 0.003$	9	135	0.003
2	30	$2^3 y_1 = 0.248$	8	120	0.0248
3	45	$3^3 y_1 = 0.0837$	7	105	0.0837
4	60	$4^3 y_1 = 0.1984$	6	90	0.1984
5	75	$5^3 y_1 = 0.388$	5	75	0.388
			Read upwards		

There are many solutions to the problem, that given above being one.

In case it is desired to provide an overtaking sight distance a value of $N = 0.016$ would suit.

Then *Ls* from Plate I = 880 ft.

Lv from Plate III = 160 ft.

$\frac{1}{2}(Ls + Lv) \times 0.016$ = 8.32 ft.

The balance of 0.18 could be negotiated in a straight gradient of 0.016 in 11 ft.

PROBLEM No. 5.

Data: Design the approach curves to a bridge which is 17.00 ft above the road level on either side on a National Highway in plain country.

Solution: $V = 50$ m.p.h.

Sight distance : Case I non-overtaking = 400 ft.

Case II overtaking = 1450 ft.

Case I :

$$\tfrac{1}{2}(Ls + Lv)N = 17.00$$

The value of N to satisfy the above relationship is to be chosen

Try $N = 0.047$

$Ls = 560$ from Plate II

$Lv = 192$ from Plate III

Rounding the values to 560 and 200

$$\tfrac{1}{2}(500 + 200) \times 0.47 = 17.86 \text{ ft.}$$

This is in excess of the available 17.00 ft. Therefore, try

$N = 0.04$

$Ls = 480$

$Lv = 176$ or 180

$$\tfrac{1}{2}(Ls + Lv) \times 0.04 = \tfrac{1}{2}(480 + 180) \times 0.04 = 13.2 \text{ ft.}$$

This would suit the balance of 3.8 ft being made up in the straight length of $\frac{3.8 \times 1}{0.04} = 95$ ft. The curves are worked out as in problem 1 and 3.

Case II :

Try $N = 0.022$

$$\tfrac{1}{2}(Ls + Lv)N = \tfrac{1}{2}(1300 + 130) \times 0.019$$
$$= 15.73 \text{ ft from Plates I and III}$$

This would suit when a straight portion of 58 ft in length is introduced to make up the height of $(17.00 - 15.73) = 1.27$ ft.

The details of the summit and valley curves are then worked out as in problems 1 and 3.

PLATE I

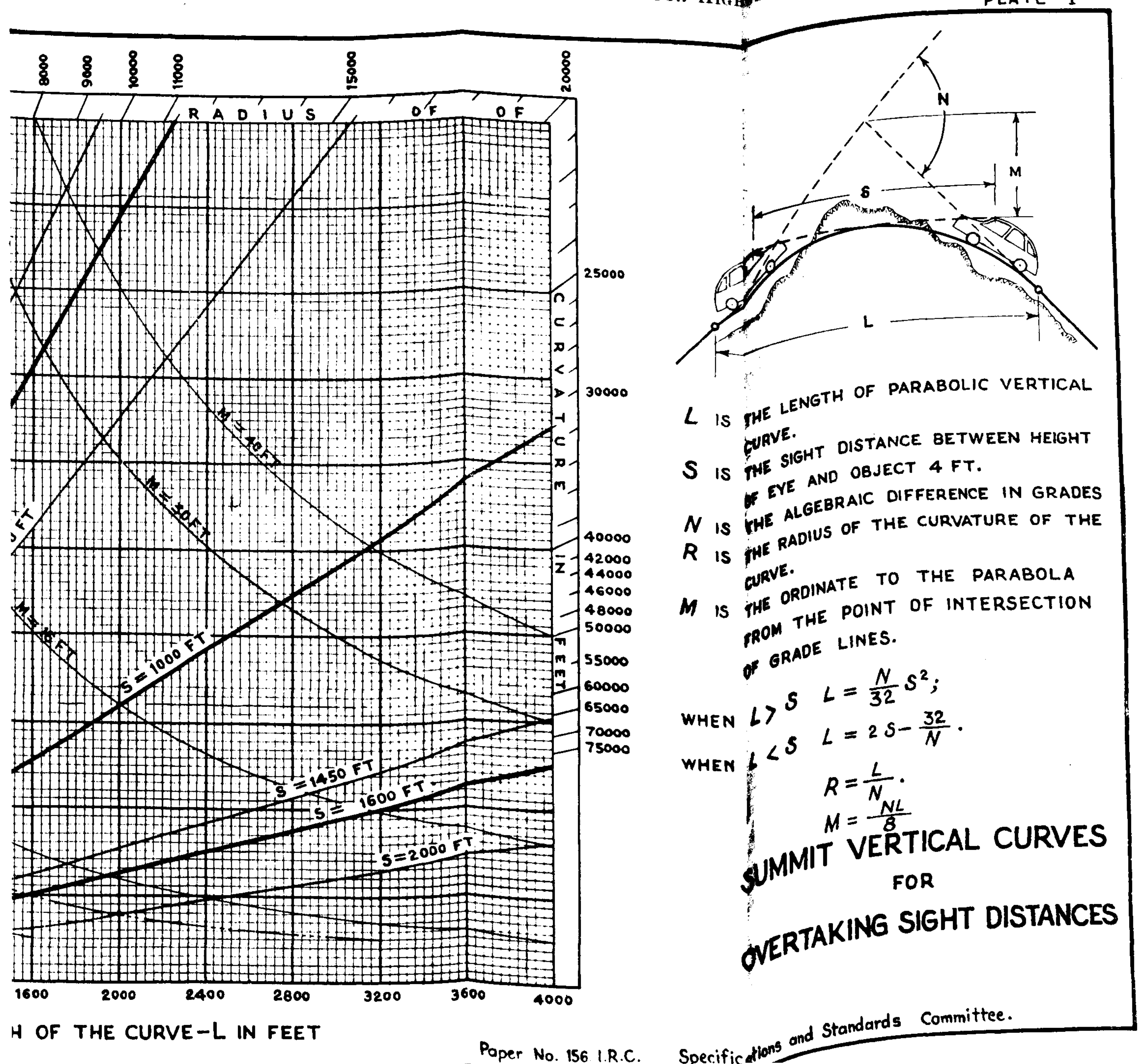
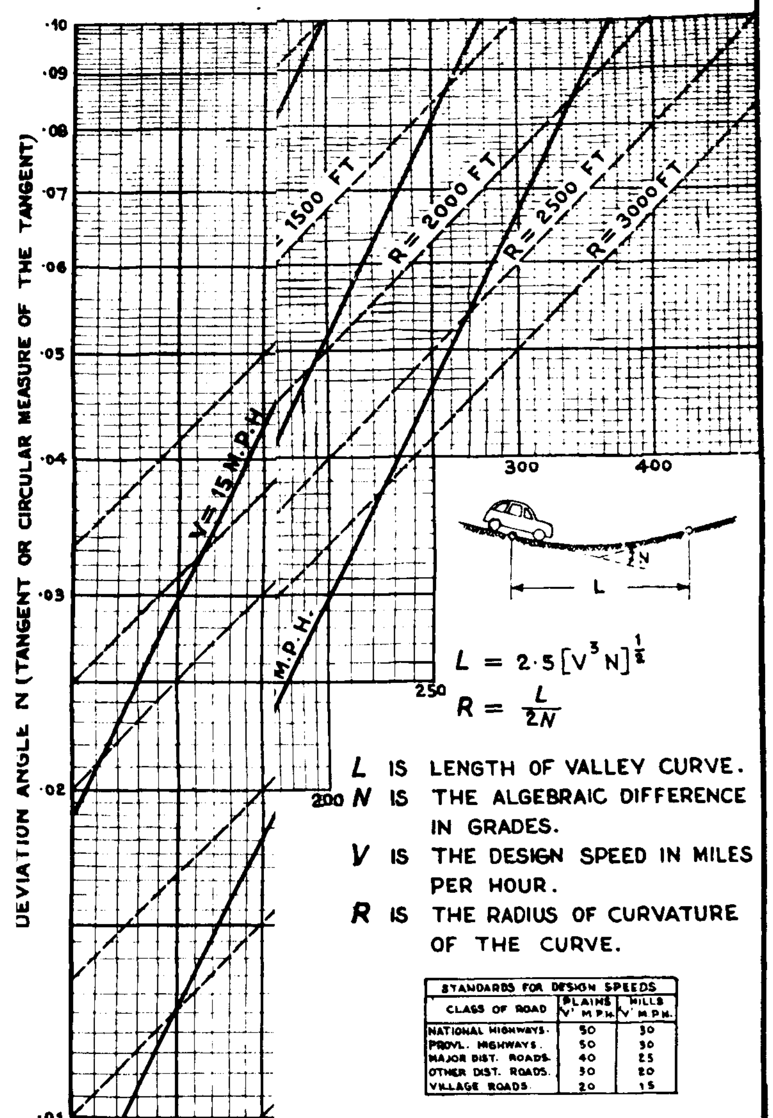


PLATE III



$$L = 2\cdot5\,[V^3 N]^{\frac{1}{2}}$$

$$R = \frac{L}{2N}$$

L IS LENGTH OF VALLEY CURVE.

N IS THE ALGEBRAIC DIFFERENCE IN GRADES.

V IS THE DESIGN SPEED IN MILES PER HOUR.

R IS THE RADIUS OF CURVATURE OF THE CURVE.

STANDARDS FOR DESIGN SPEEDS		
CLASS OF ROAD	PLAINS 'V' M.P.H.	HILLS 'V' M.P.H.
NATIONAL HIGHWAYS.	50	30
PROVL. HIGHWAYS.	50	30
MAJOR DIST. ROADS.	40	25
OTHER DIST. ROADS.	30	20
VILLAGE ROADS.	20	15

VALLEY VERTICAL CURVES

Specifications and Standards Committee.

APPENDIX II*

Australian Standards on Curve Compensation.

Combination of Horizontal Curves with grades and Vertical Curves.

(a) *Grade Compensation.*

Grades shall be compensated for curvature in accordance with the following table:—

Radius of Horizontal Curve in Feet.	Equivalent Additional Grade due to Curvature at Design Speed - miles per hour.			
	30	40	50	60
2,500 or more	Nil	Nil	Nil	Nil
1,600 - 2,000	Nil	Nil	Nil	¼%
1,300 - 1,500	Nil	Nil	¼%	¼%
1,000 - 1,200	Nil	Nil	¼%	½%
800 - 900	Nil	¼%	½%	...
650 - 750	Nil	½%	½%	...
500 - 600	¼%	½%	...	...
400 - 450	½%	¾%	...	...
300 - 350	¾%	...	...	...
220 - 250	1%	...	...	...

The above additions shall be made to the grades along the nominal centre line for the full length of curve and transitions in computing the grading of hills.

(b) *Minimum Curves on Steep Grades.*

The normal minimum horizontal curves are permitted on level sections or on sections with light grades only. For steep grades the minimum curves shall be increased as follows:—

* From "Main Roads"—Vol. 9, No. 2, February 1938, p. 68-9.

(i) **Earth, Gravel or Stone Surfaces.**

Grade in per cent	Minimum Radius in feet for Design Speed in miles per hour.			
	30	40	50	60
1	250	500	800	1,200
2	250	500	800	1,200
3	250	500	800	1,300
4	300	550	850	1,300
5	300	550	850	...
6	300	550	900	...
7	300	550	...	...
	300	550	...	...
9	350	...	...	...
10	350	...	...	...

(ii) **Bitumen, Tar or Concrete Surfaces**

Grade in per cent	Minimum Radius in feet for Design Speed in miles per hour.			
	30	40	50	60
1	220	400	650	1,000
2	220	400	650	1,000
3	220	400	700	1,100
4	220	400	700	1,100
5	250	450	750	1,200
6	250	450	750	1,200
7	250	500	800	...
8	250	500	800	...
9	250	500	...	...
10	300	550	...	...
11	300	...	...	...
12	300	...	...	...

(c) *Combined Horizontal and Vertical Curves.*

Combinations of horizontal and vertical curvature are undesirable, and shall be avoided if practicable.

Where such combinations are unavoidable, the normal minimum radius of horizontal curves shall be increased as follows :—

(i) **Earth, Gravel or Stone Surfaces.**

Value of R/W.	Minimum Radius (feet) for Design Speed in miles per hour of			
	30	40	50	60
5% or less	250	500	800	1,200
Over 5% to 10%	300	550	850	1,300
Over 10% to 15%	300	650	900	2,000
Over 15% to 20%	Not allowed in combination with any horizontal curve			

(ii) **Bitumen, Tar or Concrete Surfaces.**

Value of R/W.	Minimum Radius (feet) for design speed in miles per hour of			
	30	40	50	60
5% or less	220	400	650	1,000
Over 5% to 10%	250	450	700	1,100
Over 10% to 15%	250	500	800	1,200
Over 15% to 20%	300	550	900	1,300

R = Variation in the reaction of the vehicle on the road surface (expressed as percentage of the weight).

W = Weight of the vehicle (including 100 per cent addition over the steady value on a long vertical curve of the same radius to cover the impact shock at entry).

$\frac{R}{W}$ is a measure of the shock-free nature of the curve.

Where such combinations occur at summits and sight distance is a controlling factor attention is drawn to the following points :-

1. The line of sight is inside the path of the car and usually off the pavement altogether, frequently therefore the level of the pavement near the centre of the combined curves does not affect the sight distance and the longitudinal grading can be designed for riding qualities and economy irrespective of sight distance.

2. Where benching is used, the level of the bench required will be fixed by the road levels some distance from the bench and the bench will not be horizontal.

Such combinations are unusual and very variable and each will require separate treatment.

BIBLIOGRAPHY

1. American Association of State Highway Officials, " A policy on Sight Distance for Highways " - 1940 : A.A.S.H.O. 1220, National Press Building, Washington, D.C. 1.

2. Aitkens J., " A consolidation of Vertical curves design ", *Journal of the Institution of Civil Engineers*, December 1945.

3. Bruce A.G., " Highway design and construction " - 1937; International Text Book Co., Scranton, Pennsylvania.

4. Collins and Hart. The Road makers library, Volume VI " Principles of Road Engineering ": Edward Arnold and Company (1946).

5. H. Criswell, " Highway spirals, superelevation and vertical curves " - 1937, The Carriers Publishing Company Ltd., 66, Victoria Street, London, S.W.1.

6. H. Criswell, " Vertical curves for two-way and one-way Roads " Roads and Road Construction, January, May, August, September, October, November and December 1942. The Carriers Publishing Co., Ltd.

7. Elgar, W.H., " The Elementry Dynamics of vertical curves on Highways ", The Surveyor and Municipal & County Engineer, October, 3, 1941.

8. Laurance Ilsley Hewes, " American Highway Practice " Volume I. New York: John Willey & Sons, Inc. (1945)

9. Specifications and Standards Committee of the Indian Roads Congress " Width of Highway Pavements " Paper No. 113, Volume XI-1. *Journal of the Indian Roads Congress*, November 1946.

10. Specifications and Standards Committee of the Indian Roads Congres " Horizontal and Transition Curves for Highways " Paper No. 119. *Journal of the Indian Roads Congress*, Volume XI-3, January 1947.

11. Specifications and Standards Committee of the Indian Roads Congress, " Standards for Sight Distances for Highways " Paper No. 149. *Journal of the Indian Roads Congress*, Vol. XV-1 August, 1950.

12. Jenning, R.D. "Highway Vertical Curve Design" *Civil Engineering*, London, February, 1946.

13. Road Design Standards - 1937, *Main Roads*, November 1937 and February, 1938.

14. Richard E.W.W., "Vertical curves", *Roads and Road Construction*, April, May, June, August, September, 1939. The Carriers Publishing Co., Ltd.

15. Royal Dawson, F. G, "Vertical Curves for Roads," 1946; E. & F.N. Spon Limited, 57, Haymarket, London, S.W.I.

16. Royal Dawson, F. G., "Road Curves," 1936; E. & F. N. Spon.

17. Royal Dawson F. G., "Curve Design," 1932, E. & F. N. Spon.

18. Smith, D. W. M. "General Properties of Parabolic Vertical Curves, with special reference to Road Design," *Journal of the Institution of Civil Engineers*, February, 1941.

19. Ministry of Transport Momorandum No. 575, (1943) "Layout and Construction of Roads," His Majesty's Stationery Office, London.

Paper No. 157.

"Grouted Concrete Roads."

By

E. A. NADIRSHAH, B.A., B.E., B.SC. (ENG.), M. INST. C.E., M.I.E. (IND.), F.I.S.E. (LOND.)

CONTENTS.

SYNOPSIS.

The Paper gives specifications for the construction of concrete roads by a process of grouting coarse aggregate already laid in position. The comparative costs of this method and the conventional method are discussed. Details are given of three sets of experiments carried out in Bombay, Madras, and the Punjab. The Author makes a plea for co-ordinated research on the subject so that the high cost of concrete road construction may be brought down.

1. INTRODUCTION.

1.1. Origin of Cement Grouted Roads.

The construction of cement grouted roads is not a new thing. As every engineer knows, the initial cost of the normal type of premixed cement concrete road is rather high. Its construction, therefore, is undertaken only where the traffic conditions are severe and the maintenance costs of other types of surfaces run high. The possibilities of a cheaper, and yet efficient, substitute for the normal type of concrete road were therefore under investigation by many road engineers. As a result of persistent research, the process of grouting the coarse aggregate with Portland cement mortar was evolved and tried in England, Australia, and America. This type of road consisted of rolled coarse aggregate held together by cement mortar or cement bound macadam.

1.2. General Description.

In brief, the construction consisted of laying over the subgrade, between side forms of appropriate depth, a 4 to 6 inches thick layer of road metal and rolling it dry as for an ordinary waterbound macadam road. Cement grout of the consistency of thick cream was spread on the metal in such a way that it penetrated the voids in the metal and filled them completely. The grouted metal was then consolidated by rolling again. When rolling was complete, the surface was finished properly by means of a canvas belt. The object of rolling after spreading the mortar was to facilitate complete penetration of the mortar. Expansion joints 3/8 inch wide were provided at intervals of 50 to 60 feet by inserting strips in the aggregates.

1 3. Cost.

The cost of construction of this type of road in the City of Bombay is estimated at Rs 51 per 100 sq. ft as given in Table 1 of **Appendix I**. No overhead charges and profits are included in this figure.

It will be seen that the cost works out to as much as 30 per cent less than that of a 4 inch premixed concrete slab which may cost Rs 73-4-0 according to present costs of labour and material in Bombay. Details are given in Table 2 of **Appendix I**.

1.4. Practical Difficulties.

The Author is not aware of any roadwork successfully carried out in India to these specifications. Such small trial lengths as have been constructed have shown that making these roads is not as simple as it looks at first sight. The first difficulty usually experienced is the incomplete penetration of the grout. It is well known that if Portland cement, sand, and water in the form of a grout are poured over a previously laid layer of stones with the object of filling the voids so as to make a solid mass, the sand, cement, and water segregate partially. This leaves the voids only partly filled and the resultant concrete is honeycombed and, therefore, deficient in strength. As stated in para 1.2, the grouted coarse aggregate is required to be re-rolled. This disturbs the top layer of the aggregate and it becomes very difficult to get a properly finished and even surface.

Another difficulty experienced is the "setting" of the grout before rolling can be completed. It is not possible to roll very short lengths and, before a length suitable for the run of the roller can be completely grouted, the grout which is laid first starts setting. On account of these difficulties, this type of construction has not made much headway in this country in spite of its comparative economy.

2. ATTEMPTS TO FACILITATE GROUTED ROAD CONSTRUCTION

2.1. The question of overcoming these handicaps in the construction of concrete roads by the grouting process has attracted the attention of several engineers and scientists.

Treated Cements.—One approach to the problem has been by the use of treated cements. In this type of road work, as already explained, some time elapses before the rolling of the surface is completed. The cement to be used must therefore be slow-setting. Also, it is desirable to have very few joints so that there may be no obstruction to rolling. The cement should therefore be capable of resisting volume changes. In Germany, ordinary cement was at one time blended with a small quantity of bitumen (about 4 per cent) by blowing fine particles of cement through bitumen vapour by means of compressed air. The microscopic coating of bitumen over the cement particles gave the cement the required properties of slow setting and low volume change. Roads constructed in Germany by the grouting process with this cement were reported to be quite successful

2.2. Colloidal Grouting.

Another approach to the subject has been from a mechanical point of view. When ordinary machinery is used, the mixture of cement, sand, and water obtained is not as intimate as it should be for this type of work. But, by using a special type of mixer, it is possible to have a thoroughly intimate mixture so that the grout is more or less in a colloidal state. This grout fills in all the voids in the coarse aggregate because of its great fluidity and it is not necessary to roll after the grouting operation. By tamping in the ordinary way, the surface is finished to proper camber as in the case of an ordinary concrete road. The Author has seen a few trial lengths constructed by this method. Probably, on account of the large quantity of water used for making the grout fluid, the wearing qualities of the slabs were not found satisfactory.

2.3. Use of Chemicals.

For a long time suggestions have been made on the addition of wetting or dispersing agents to the cement or concrete. This may be done in various ways. One method is to add a dispersing agent to the cement clinker. In another method, albuminous material (tending to induce frothing) and a high fatty acid is added either during the manufacture of cement or afterwards.

The function of a dispersing agent is to reduce the surface tension of the mixing water. Surface tension is nothing but a force exerted by the molecules of a liquid for maintaining a continuous surface when the liquid is in contact with air. It makes the liquid behave as if it were covered by an elastic film, thus making it to resist intimate association with any solid with which it comes into contact. In the case of cement, which is a finely ground powder and has a large specific surface, resistance to intimate contact exerted by the molecules of the mixing water is very great. The dispersing agents reduce this tendency and consequently the cement particles get thoroughly wetted.

The thorough wetting of the cement particles helps in producing an intimate mixture of cement, sand, and water so that by using the grout so prepared, it becomes possible to make concrete practically without any voids, by pouring the grout on pre packed aggregates. No special machinery is required for making this grout. The use of an ordinary cement mixer or even mixing by hand is quite sufficient. The addition of this wetting agent to the cement grout makes it so fluid that it is even possible to pump this grout over a long distance without any segregation of the constituents in the grout.

Of the different methods of preparing grouts for road construction mentioned here this method is the simplest.

This method is described at length in this Paper and details of experimental stretches of road built by this method are given.

3. CONSTRUCTION OF CEMENT GROUTED ROADS.

3.1. General Description.

A detailed method of constructing concrete roads and pavements by cement grouting is described further on in this Paper. In brief, the pavement consists of a mixture of clean coarse aggregate consisting of crushed stone or gravel (preferably the former) laid between side forms, with suitable and adequate provision for expansion joints, and bound together with a cement-sand grout poured on to the surface of the aggregate (already partially compacted by light rolling) until all the voids in the mass are filled in. The fluidity of the grout is increased by the addition of a wetting agent. The slab thus laid is then tamped,

struck off, floated and finished to produce an even surface. After curing, the surface is ready for use.

3.2. Principle Involved.

Chemical grouting is a simple and cheap method of making concrete by pouring cement slurry or grout into the interstices between the coarse aggregate already placed in position. On setting the product becomes a uniform concrete of good quality.

A simple experiment will illustrate the principle. A vertical cylindrical mould of 12 in. diameter and 3 ft height is packed to a height of 30 inches with coarse aggregate consisting of crushed stone or gravel of $\frac{1}{2}$ to $\frac{3}{4}$ inch size. A mixture consisting of 6 pounds of cement, 9 pounds of sand, and 0.3 grams of the wetting agent mixed with 1,633 cc of water (corresponding to a water-cement ratio of 0.6) is poured into the cylinder. After the cement is set, the mould can be opened and on examination it will be found that the cement mortar has penetrated uniformly to a depth of about 18 inches into the aggregate to form a solid column of concrete of good quality, free from cavities. The same experiment can then be repeated without using the wetting agent. It will be found that the penetration of the grout will be quite irregular and that it will extend only to a small depth, say 2 to 3 inches. The interior of the column will be found to contain a number of cavities resulting in a low grade concrete of low strength. This is obviously due to the low fluidity of the grout made without a wetting agent and the time taken by the grout to gravitate into the aggregate. In the meantime, the cement starts setting and the penetration is thereby interrupted.

3.3. Composition of the Dispersing Agent Used.

The dispersing agent used in carrying out the experiments described in this Paper consisted of alkali salts of the higher sulphonated alcohols. These chemicals are eminently satisfactory for wetting purposes and the wetting or dispersing effect of the agent is stable. The wetting agent is not rendered ineffective, nor is it precipitated, or destroyed by the alkali nor by any of the calcium or magnesium compounds present in the cement or liberated by the agent. Every wetting agent must remain stable for that much duration of time as is required for preparing the grout and pouring it into the coarse aggregate and its penetration to the required depth. The dispersing agent used appeared to answer this requirement. It does not cause any chemical action and appears to have had no harmful effect on the cement, the aggregates, or the reinforcement used in the road work.

3.4. Design.

A concete pavement, whether made of normal premixed concrete or grouted concrete, is designed for a given load by the usual 'corner formulae'. The Sheets' formula for unprotected corners, ($d = \sqrt{\frac{1.2\ WIC}{S}}$), can also be used for these pavements,

Where d = average slab thickness (in inches),
W = static wheel load in pounds,
I = impact factor,
S = allowable concrete stress in flexure (pounds per sq. in.), and
C = subgrade constant.

The value of S will have to be determined by actual laboratory tests. Tests on cores removed from a pavement in the United Kingdom showed an average cube strength of 3,400 lb per sq. in. The pavement was laid in grouted cement concrete in which a wetting agent had been employed.

3.5. Subgrade

The subgrade should be prepared in the same way as for a conventional concrete road by slightly scarifying the existing road surface and re-rolling it uniformly. It must be noted that under no circumstances should the consolidated crust of the subgrade be disturbed unnecessarily. Scarifying should be done just at the surface to remove loose patches of rubbish sticking to the old road surface. In the case of new roads on virgin soil, the top crust of 6 to 8 inches should be removed and the soil consolidated properly.

One point worth mentioning is that the grouted concrete slab is not insulated from the subgrade like the premixed concrete slab which used to be laid on an insulation layer of either sand or waterproof paper. As the concrete mix in a grouted road is not as rich as that in a premixed concrete road, the expansion and contraction of a grouted concrete slab is comparatively much less.

3.6. Forms.

Wooden or steel forms of the required depth are fixed on both sides of the road as shown in Fig. 1.

Figure 1.
Fixing Form-Work.

3.7. Coarse Aggregate—Size, Grading, and Spreading.

Any coarse aggregate, even when unsuitable for concrete mixed by normal methods on account of defective grading, can be used. A coarse aggregate passing a one inch sieve should not, however, be used. The maximum size would be governed by the thickness of the concrete to be laid, and should not be more than half the thickness of the slab.

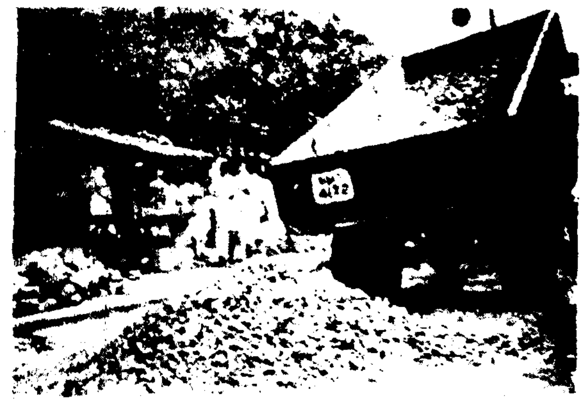


Figure 2.
Coarse aggregate being dumped on the subgrade.

As grading is of no importance in this type of construction, the coarse aggregate is dumped directly from the trucks on to the road (Fig. 2) and is levelled properly by hand (Fig. 3). It should then be rolled slightly in order to reduce the voids in the layer (Fig. 4).

Figure 3.
Spreading coarse aggregate.

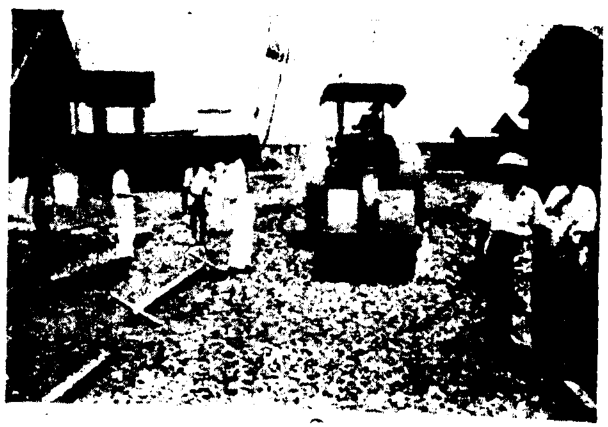


Figure 4.
Rolling coarse aggregate.

As metal is still broken by hand in most places in India, it is not always easy to procure the small size of metal usually

specified for concrete road construction. This problem does not arise in the type of construction described in this Paper. Another consideration is that in congested localities in busy towns, the public are usually much inconvenienced whenever a concrete road is to be built, because a great deal of space is occupied by stacks of metal and sand before actual mixing operations start. In grouted construction, however, coarse aggregate is placed in position straightaway, and no stacking space is required. This facilitates the work considerably besides being economical.

3.8. Joints.

As already explained (vide para 3.5) the expansion and contraction in a grouted road is expected to be much less than that in a premixed concrete road. The spacing of expansion joints should, therefore, be greater than that provided in the usual premixed concrete road. These joints should be put at the end of the day's work. In between the expansion joints dummy joints should be formed at smaller intervals by placing quarter inch thick steel flats, $1\frac{1}{2}$ to 2 inches deep (i.e., about 1/3 the thickness of the slab).

3.9. Grouting.

The grout consists of clean river sand or crushed stone screenings 1/8 inch to 1/100 inch in size, cement, water, and an approved wetting agent in specified proportions depending on the expected traffic. **Appendix II** gives the recommended proportions.

An ordinary concrete mixer can be used for making the grout (Fig. 5). After starting the mixer the required quantity of

Figure 5.
Preparing Grout.

water is poured into the drum, and the dispersing agent added. Cement is then added and lastly sand. After proper mixing the grout is emptied into a tank (Fig. 6), and kept agitated all the time.

If an ordinary concrete mixer is not available, hand mixing will give quite good results.

Figure 6.
Grout being emptied into a tub.

From the tank the grout is taken to the pre-packed coarse aggregate in buckets or wheelbarrows (Fig. 7). The dispersing agent renders the grout so fluid and homogeneous that it can be pumped or gravitated over some distance without segregation.

For large works a special pump worked by a petrol engine is suitable. The special feature of the pump is its non-clogging ball valves in the suction and delivery lines. The pump illustrated in Fig. 8 can grout 600 to 800 sq. yd of a 6-inch pavement in eight hours. It can supply grout to a length of 180 feet on both sides.

The grout is poured over and into the coarse aggregate until it fills in all the voids and just overflows and completely covers the aggregate. The grout sinks to the bottom of the aggregate at the point of pouring, runs along the under surface of the coarse aggregate, and eventually rises to the surface. All the air in the voids is thus displaced and driven out in the grouting process. This makes the concrete homogeneous and strong.

In order to remove any obstruction to the free flow of the grout into the slab that is likely to be caused by dirt deposited

Figure 7.
Grout, conveyed in buckets from the mixer, being poured over the metal.

between the stones, the stone may be hosed if necessary. This will not appreciably affect the strength of the concrete in any way as the grout made with a good wetting agent does not mix easily with water. Hosing the coarse aggregate will not, therefore, raise the water-cement ratio and thereby reduce the strength.

While grouting, certain precautions are required. Continuity of the process should be maintained and unnecessary spilling of grout here and there should be avoided. The grout shoud be broomed ahead (Fig. 9). It is also necessary to avoid the possibility of the formation of those air or water pockets that are formed if the aggregate which has already been grouted is disturbed after the concrete has partially set.

3.10 Compaction

Compaction is done with a tamper similar to that used for premixed concrete roads. (Fig. 10). In some of the experimental stretches described elsewhere, light rolling for consolidation proved useful. A vibrating tamper, however, did not prove helpful.

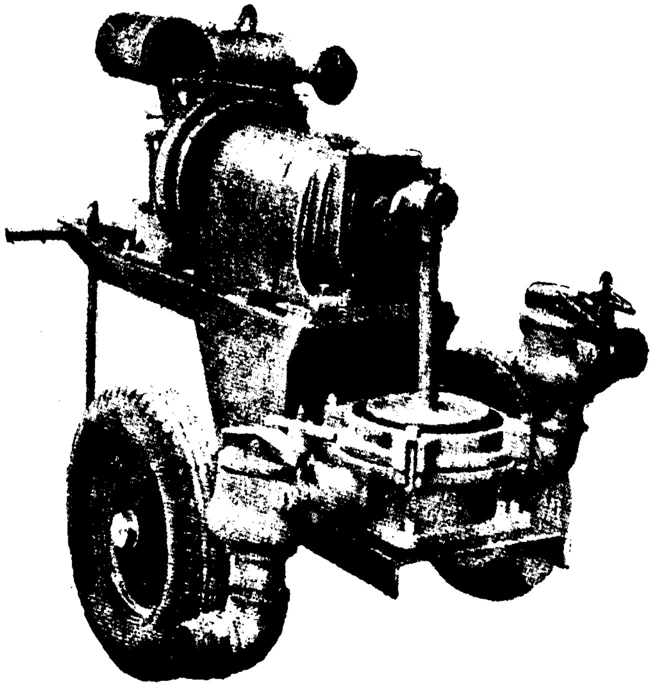


Figure 8.
Grout Pump.

Figure 9.
Grout being brushed for better penetration.

Figure 10.
Tamping the grouted surface.

3.11. Finishing.

The surface is finished by means of a wooden float as in the case of premixed concrete roads (Fig. 11).

Figure 11.
Finishing with wooden float.

Sometimes, in order to impart better wearing qualities or to provide a non-skid surface to the road, small stone chips are sprinkled on the surface, either along with the grout or after grouting is completed. These chips are worked in by means of the tamper before finishing with a float.

4. ECONOMIC ASPECTS OF CEMENT GROUTED ROADS

4.1. Labour.

For this type of construction only water, sand, cement and a dispersing agent are required to be mixed together. Thus the material which forms the bulk of premixed concrete, *viz.*, the coarse aggregate, is left out of the mixer. Consequently the mixing, handling and transport charges are reduced considerably. The coarse aggregate, as it comes from the quarries, is dumped on the subgrade straight from the trucks.

From the details of actual costs maintained while the experimental stretches were built in Bombay, (vide **Appendix IV**, Tables 1 to 8), it will be seen that the cost of labour varied from Rs 11 to Rs 12 per 100 sq. ft of the pavement. On a premixed concrete pavement of the same thickness, these expenses would range from Rs 15 to Rs 16 per 100 sq. ft.

It should be noted that the experimental stretches being of short lengths, the labour charges were bound to be on the high side and that the grout was transported by manual labour. Pumping of the grout is expected to give still lower costs. Unfortunately, this could not be tried as no pump was available at the time the experimental lengths were built. On the basis of experience abroad, it may be stated that the cost of grouting could easily be reduced further by the use of a pump.

4.2. Material.

It need not be repeated here that, other things being equal, the strength of concrete depends upon the water/cement ratio adopted. For the sake of comparison the quantities of materials required for the same quality of concrete made both by the conventional premixing method and the grouting method is worked out in detail in section 6. It will be seen that there is a saving of about 20 per cent in the quantity of cement required in the grouting method as compared to the conventional method.

5. QUANTITIES OF MATERIALS REQUIRED.

5.1. Premixed Concrete.

Taking a unit of one cubic yard of finished concrete, the quantity of cement, sand, and aggregate for premixed concrete of 1 : 2 : 4 mix by volume and a water/cement ratio of 0·70 is calculated here.

The voids in coarse aggregate are taken to be 38 per cent and in sand, 36 per cent.

The absolute volume of one cu. ft of cement

$$= \frac{1 \times 90}{3.15 \times 62.4} = 0.458 \text{ cu. ft}$$

(3.15 is the specific gravity of cement.)

Assuming the weight of the solid rock from which the aggregates, both fine and coarse, are obtained as 165 lb per cu. ft., the unit weight of sand, *i.e.*, the weight per cu. ft would be $165 \times \frac{(100-36)}{100} = 106$ lb and that of the coarse aggregate would be $165 \times \frac{(100-38)}{100} = 102$ lb approximately. Therefore, the absolute volume of 2 cu. ft of sand would be $\frac{2 \times 106}{165} = 1.29$ cu. ft and the absolute volume of 4 cu. ft of coarse aggregate $\frac{4 \times 102}{165} = 2.47$ cu. ft. The volume of $90 \times 0.7 = 63$ lb of water

$$= \frac{63}{62.4}$$

$$= 1.01 \text{ cu. ft.}$$

Therefore, the total volume of concrete produced by mixing one cu. ft cement, two cu. ft sand, 4 cu. ft coarse aggregate, and 1.01 cu. ft water is $0.458 + 1.29 + 2.47 + 1.01 = 5.23$ cu. ft. Hence, for one cubic yard of concrete, the quantity of materials required in this case is

$\frac{27}{5.23} = 5.16$ cu. ft = 4.30 cwt. of cement

10,3 cu. ft of sand

and 20.6 cu. ft of coarse aggregate.

5.2. Grouted Concrete.

The quantity of coarse aggregate may be assumed to be equal to the quantity of finished concrete, i.e., 27 cu. ft though, when measured loose, it will be slightly more. This is bound by the cement grout, the quantity of which equals the voids in the coarse aggregate (assumed 38 per cent). Therefore, the cement grout required = 0.38 cubic yard or 10.26 cu. ft

It is easy to find out how much grout is obtained by using one cu. ft of cement, $1\frac{1}{2}$ cu. ft of sand, and 63 lb of water (corresponding to a water-cement ratio of 0.7).

Absolute volume of 1.5 cu. ft of sand	$= 1.5 \times \frac{100-36}{100}$
	$= 0.96$
Absolute volume of one cu. ft cement	$= 0.46$
Absolute volume of 63 lb water	$= 1.01$
Total	2.43 cu. ft

which is the volume of the grout obtained.

Therefore for getting 10.26 cu. ft of grout required for one cubic yard of concrete, we require.

$\frac{10.26 \times 1.5}{2.43}$ = 6.33 cu. ft of sand per cu. yd. of concrete

$\frac{10.26 \times 1}{2.43}$ = 4.22 cu. ft of cement -do- -do-

$= \frac{4.22}{1.20}$ cu. ft

= 3.51 cwt of cement per cu. yd. of concrete,

as against 4.30 cwt of cement calculated for 1 : 2 : 4 premix concrete. Thus the percentage saving in cement is approximately 20.

6. NECESSITY FOR EXPERIMENTAL INVESTIGATION.

The Author saw this type of construction for the first time during his stay in the United Kingdom in the summer of 1948. The behaviour of the pavement under modern traffic and the economical possibilities appealed to him considerably. In order to investigate the feasibility of adopting this type of concrete road construction under Indian conditions, experimental lengths were constructed at Bombay, Coimbatore, and Kalka, the first one by the Bombay Municipal Corporation and the other two by the State P.W.D.s of Madras and Punjab.

Before these experiments were taken in hand a small stretch was laid in June 1949 by the Military Engineering Service on their estate at Colaba, Bombay. Being a private road, this is not described in this Paper.

All these experiments were carried out in close co-operation with the Concrete Association of India. It is needless to state that these experiments, described in detail in the following paragraphs, are only on a moderate scale and further research on a larger scale is necessary to arrive at definite conclusions as regards the status of this type of construction in the country's road building programme.

7. EXPERIMENTS AT BOMBAY.

7.1. General Description.

Early in 1950 a number of short experimental lengths were laid in Bombay along the Victoria Garden Road by the Bombay Municipal Corporation. The traffic along this road consists of about 1,500 heavy vehicles per day. The width of the slab is about 11 ft and the length 266 ft. Figure 12 shows the completed road.

Figure 12.

Grouted concrete pavement opposite Victoria Gardens, Bombay.

7.2. Subgrade.

The base consisted of 1 : 3 : 6 concrete over which an asphalt avement had been laid. This asphalt pavement was completely emoved and the old concrete slab was cleaned thoroughly.

7.3. Materials.

Local trap stone, broken to 1½ in. to 3 in. size, was used as oarse aggregate.

Three types of sand from different sources viz., from Mumbra, Bhyandar, and Juhu were used, the last named being very fine. Full details of grading, etc., of the aggregates used are given in **Appendix III**, Tables 1 and 2. For the topping ½ in. chips vere used.

7.4. Details of Slabs, Thickness, Grout, etc.

In all eight slabs of different thickness and specification were aid. In experiment No. 1 the proportion of grout was 1 : 1½ and he thickness of slab was 4½ inches. In experiment No. 2, a 1 : 2 nix grout was used and two slabs 5 in. and 4⅜ in. thick vere laid.

In the third experiment the proportions of the grout were 1 : 2½ and the experiment consisted of three lengths of composite slab, the base course being grouted and the wearing course ordinary 1 : 2 : 3 premixed concrete.

The fourth experiment consisted of a composite slab 4⅞ in. hick (total) with a base grouted with a 1 : 3 mix grout and a 1 : 2 : 3 premixed concrete topping (0.63 in. thick).

The fifth and last experiment had the grout and premix opping of the same specification as in experiment 4, but the otal thickness was reduced to 4½ in., the wearing coarse being 0.75 inch.

An outline of the experiments is given in the table below. Full details may be seen in **Appendix IV**.

An Outline of the experiments at Bombay

Experiment No.	Slab No.	Proportion of grout	Thickness (inches) Grouted	Pre-* mixed wearing course	Total	Remarks
I	1	1 : 1½	4½	—	4½	Grouted Concrete used as wearing course
II	2	1 : 2	5	—	5	
	3		4⅜	—	4⅜	
III	4	1 : 2½	4.2	0.75	4.95	Grouted Concrete used as base course
	5		4.85	0.9	5.75	
	6		4.20	0.63	4.83	
IV	7	1 : 3	4.20	0.68	4.88	
V	8	1 : 3	3.72	0.75	4.47	

7.5. Construction.

No forms were necessary as the permanent stone edges of the asphalted portion served the purpose. The coarse aggregate was dumped directly from the trucks, spread, and rolled by a ten-ton power roller. Before starting the grouting, pre-moulded expansion joints, 3/8 in. thick and 6 in. deep, were provided at every 33 ft 4 in. and were kept in position by wooden bulkheads. No dummy joints or construction joints were put in.

The grout was mixed in a rotary type concrete mixer of 10/7 cu. ft capacity. The quantity of wetting agent used was ¼ pint per cwt. of cement.

The metal was watered before pouring the grout. Ordinary buckets were used for grouting. Immediately after grouting, the surface was tamped with a wooden tamper and ½ in. stone

* Wherever used the wearing course was of 1 : 2 : 3 premixed concrete.

screenings were sprinkled on the top at a rate of 5 cu. ft per 100 sq. ft. The surface was finished by hand floating. Photos of cores taken from the slab (two months after laying) show full penetration of the mortar (Figure 13).

8. EXPERIMENTS AT COIMBATORE.

8.1. General Description.

A trial length of 1,940 ft of cement grouted road was constructed early in 1950 by the Department of Highways, Madras, for widening an existing 10 ft wide premixed concrete road to 18 ft by adding a 4 ft strip on either side. In addition to this, eight bays each 33 ft long and 12 ft wide were constructed in the central strip.

8.2. Subgrade.

The existing 4 in. thick layer of metal from the side berms was removed down to the soling in order to have the level of the new strips at the level of the existing road. The surface of the soling was cleared of all the loose particles.

8.3. Materials.

The coarse aggregate varied from $1\frac{1}{2}$ in. to 1 in. size. About 8 to 10 per cent of the particles were below one inch size. For making up the unevenness of the surface, $\frac{3}{4}$ in. to 3/16 in. size stone chips were used. Ordinary local sand was used for making the grout.

8.4. Details of Slab, Thickness, Grout, etc.

The slab was of a uniform section 4 inches thick. The grout consisted of $1:1\frac{1}{2}$ mix with $7\frac{1}{2}$ gallons of water per bag of cement in one strip. In the case of the other strip the proportion of the water used was $6\frac{3}{4}$ gallons per bag.

In a part of the 12 ft wide extension slab 1 : 2 grout was used (see **Appendix VII**).

8.5. Construction.

Channel irons were used as side forms. The coarse aggregate was spread and rolled down level with the adjoining concrete slab by means of a 10-ton three-wheeled road roller.

The grout was prepared in a non-tilting type of mixer. This proved very inconvenient as much of it was spilt while mixing. The grout was unloaded from the mixer into a big drum which was constantly agitated. From this drum the grout was conveyed

Figure 13.
Cores taken from the pavement opposite Victoria Gardens, Bombay.

by means of ordinary buckets to the site and spread over the consolidated coarse aggregate in a continuous operation.

It was observed that although the coarse aggregate had been well consolidated by a roller, some of the stone particles got dislodged on account of the grout being poured from a height and because coolies walked over the surface. The grouted surface was rolled again and it was possible to get only a tolerably even surface with light rolling. It is expected that a tandem roller would have given better results.

During rolling any depressions noticed were made good with fresh aggregate of 1½ in. to 1 in. size and a small quantity of grout.

Before floating the surface with a hand float, rough finishing had to be done with a tamper on account of the uneven surface produced by the three wheel roller.

The daily progress, including details of the quantities of cement consumed, etc., is given in **Appendix V**. It will be seen in that Appendix that the consumption of cement for the road averaged 4½ bags per 100 sq ft against 6¼ bags for an ordinary concrete road.

8.6. Joints.

Expansion joints were used mostly at the end of each day's work. Whenever this length was great, expansion joints were provided in between. In addition, dummy joints were provided at intervals of 66 ft. Details of the spacing of joints are given in **Appendix V.**

9. EXPERIMENTS ON THE KALKA-SIMLA ROAD.

9.1. General Description.

In the summer of 1950 the Punjab P.W.D. constructed a short length of 300 ft grouted concrete road on a portion of the Kalka-Simla road which is subject to heavy traffic consisting of lorries and steel-tyred hand carts, the intensity of traffic being about 600 tons per day.

9.2. Subgrade.

The subgrade was prepared properly in the usual way.

9.3. Materials.

The size of metal varied from 1½ in. to 1 in. on the first half width of the road. On the second half width the size was changed to 2½ in. maximum graded down to one inch in order to decrease

he voids. Ordinary local sand was used for making the grout. n some portions 60 per cent stone screenings were mixed with the ocal sand.

9.4. Details of Slabs, Grout, etc.

The slab was 4½ in. thick. The proportions of the grout were :1½ with 6½ gallons of water per bag of cement. On three bays he grout consisted of a 1 : 2 mix with 7½ gallons of water per bag of cement.

9.5. Construction.

First half width.—After fixing the forms metal was placed between them to a depth of 4½ inches. This was rolled twice vith a two-ton hand roller and lightly watered. The grout and he wetting agent, at the rate of ¼ pint per bag of cement, were nixed in a mechanical mixer and poured into a trough. The grout was carried in iron pans and spread over the rolled surface vhich was then tamped with a hand tamper weighing about 7 lb per lineal foot. The low spots noticed were made up with 3/8 in. grit grouted again, and finished with a brush. In some bays, a hand float was used instead of a brush.

Curing was done in the usual way, first with wet bags and afterwards by ponding.

Second half width.—In the case of the other half, the urface was rolled by a two-ton roller after grouting, the low spots vere filled with small grit, and then tamped. The surface was inally finished with hand float.

9.6. Cost.

The analysis of cost of this road is given in **Appendix VI**. Figures 14 and 15 show two views of the completed road.

9.7. Joints.

The joints were finished in the same way as in ordinary concrete roads. In the first half all the joints were expansion oints, 3/8 in. wide and 33 ft 4 in. apart. In the other half of he road expansion joints were provided at intervals of 100 ft vith construction joints at every 33⅓ ft and dummy joints, 2 in. leep and 3/8 in. thick, in between the construction joints. The oints were filled in with a mixture of one part of bitumen with hree parts of sand.

9.8. For ready reference a brief summary of the details of hese three sets of experiments in Bombay, Madras and Punjab is given in tabular form in **Appendix VII.**

Figures 14 & 15.
Ambala-Kalka-Simla Road, Mile 38/5.
Experimental grouted concrete pavement.

10. CONCLUSIONS.

10.1. It will be appropriate to conclude with a brief summary of the considerations which led to the writing of this Paper. In many cases, as already mentioned, the comparatively high initial cost of a concrete road is a great handicap. If it is possible to construct a concrete road by a process which is comparatively cheaper, it would certainly be a most welcome development, provided the specifications are well thrashed out by a body of experts like the Indian Roads Congress. Hence this Paper is placed before this Congress primarily to give some food for thought and also for a thorough discussion after which some of the disputed points as given below could be finally settled.

(a) Proportioning of grout. The grout should be the leanest possible for economy so as to give a concrete of just the required strength.

(b) The value of S, the allowable stress in concrete, to be adopted for use in the design formula (see para 3.4).

(c) The question of expansion and construction joints, their spacing, quality, etc.

(d) The water/cement ratio to be adopted for making the grout.

These points can be decided only by experiments carried out all over the country. But these experiments should be carried out in a systematic way in the light of discussions and conclusions arrived at. The value of such systematic research will be much greater than that of individual experiments carried out at random. The purpose of this Paper will have been achieved if the profession gets a clear lead in this matter from the Congress.

11. ACKNOWLEDGMENTS.

11.1. In the end, the Author would like to thank the District Engineers of the Concrete Association of India, at Bombay, Madras and Ambala without whose active assistance the Paper would not have been possible. Thanks are also due to the State Chief Engineers of the Public Works Departments of Madras and Punjab and the Special Engineer of the Bombay Municipal Corporation for readily agreeing to try experimental lengths and also for giving all facilities for maintaining proper statistics at the time of construction.

Appendix I

Table 1. (Para. 1.3)

Approximate quantities and cost per 100 sq. ft of grouted pavement 4 in. thick, 1 : 2 mix

1951

Description	Quantity	Rate	Amount Rs. A. P.
1. Stone metal (1½ in. to 2 in. size)	40 cu. ft	Rs 45/- per 100 cu. ft	18 0 0
2. Sand	8 cu. ft	Rs 75/- per 100 cu. ft	6 0 0
3. Cement	3 cwt.	Rs 5/- per cwt.	15 0 0
4. Preparation of sub-grade, spreading metal, mixing mortar and rolling	100 sq. ft	Rs 5/- per 100 sq. ft	5 0 0
5. Curing	100 sq. ft	Rs 1¾ per 100 sq. ft	1 12 0
6. Expansion joints, etc.			0 8 0
7. Tools & Plant	lump sum,		2 8 0
			48 12 0
8. Contingencies, 5 per cent			2 5 0
		Total	51 1 0

Appendix I (*Contd.*)

Table 2. (Para. 1.3)

Approximate quantities and cost per 100 sq. ft of premixed concrete pavement 4 in. thick, 1 : 2 : 4 mix.

1951

Description	Quantity	Rate	Amount Rs. A. P.
1. Preparation of sub-grade, including watering and cleaning before laying concrete	100 sq. ft	Rs 3/- per 100 sq. ft	3 0 0
2. Cement	6.17 cwt.	Rs 5/- per cwt.	30 14 0
3. Fine aggregate	15 cu. ft	Rs 60/- per 100 cu. ft	9 0 0
4. Coarse aggregate—1½ in. to ¾ in., 20 cu. ft ¾ in. to ⅜ in. 10 cu. ft	30 cu. ft	Rs 45/- per 100 cu. ft	13 8 0
5. Concrete mixing, placing and finishing	33.34 cu. ft	Rs 24/- per 100 cu. ft	8 0 0
6. Curing	100 sq. ft	Rs 1¾/- per 100 sq. ft	1 12 0
7 Expansion joints etc.			0 8 0
8. Tools and plant			3 2 0
			69 12 0
9. Contingencies, 5 per cent			3 8 0
		Total	73 4 0

Appendix II

Quantities of materials per cwt. of cement for making grout.

(Para. 3.9)

Type of Concrete.	Water/cement Ratio.	Sand cu. ft	Water Gallons.	Wetting agent Pints.
Special grade (heavy traffic)	0.55	1[illegible]	6[illegible]	[illegible]
Medium traffic air-fields, runways, ordinary roads, etc.	0.6	$1\frac{1}{2}$	$6\frac{3}{4}$	[illegible]
Secondary roads, footpaths, etc. (light traffic)	0.70	$1\frac{7}{8}$	$7\frac{7}{8}$	[illegible]

Appendix III

Table I. (Para. 7.3)

Sieve analysis, etc., of sands used in the Bombay experiments.

Sieve No.	Percent retained on sieve		
	MUMBRA	BHAYANDAR	JUHU
7	14.5	14.0	—
14	40.5	45.5	0.5
25	69.0	74.0	2.5
52	92.0	92.0	18.0
100	99.0	98.0	77.5
Fineness Modulus	3·15	3.23	.98
Characteristics	Dark colour hard and strong particles.	Dark colour hard and strong particles.	Brown colour bright texture.
Voids, per cent	32	36	50
Silt, per cent	2	2	Negligible
Organic impurities	Negligible	Negligible	Negligible
Remark	Juhu sand contains salt		

Appendix III *(Contd.)*

Table 2. (Para. 7·3)

Tests of coarse aggregate used in the Bombay experiments

Characteristics.	Black trap, hard and strong particles.
Passing 3 in. B. S. sieve	100 per cent
Retained 1½ in. B. S. sieve	100 ,, ,,
Voids	50 ,, ,,
Organic impurities	None

Appendix IV

Table I. (Paras. 4.1 & 7.4)

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 1. **SLAB NO: 1—4½″ thick.**

Grout 1 : 1½; ½″ size stone chips spread on the grouted surface. Surface tamped, floated and brush-finished.

Coarse aggregate	...	Stone metal 1½″ to 2¼″ rolled with a 10 ton roller before grouting.
Fine aggregate	...	Mumbra sand.
Proportion of grout	...	Cement 1 part (by vol.) Sand 1½ ,, ,, Wetting agent ¼ pint per cwt. of cement. Water-cement ratio 0.7 (by wt.)
Curing	...	By ponding for 14 days.
Length	...	33 feet 4 inches.
Breadth	...	11 feet 2 inches.
Volume of slab	...	139.7 cu. ft
Voids in unrolled stone	...	50 per cent.
Voids in rolled stone	...	45 ,, ,,
Total quantity of stone spread		147 cu. ft
Quantity of cement used	...	21.5 cwt.
Quantity of cement used/100 cu. ft		15.4 cwt.
Quantity of ½ in. stone chips used per 100 sq. ft	...	6.72 cu. ft
Proportion worked out to	...	1 : 1.5 : 5.7

Analysis of cost per 100 s. ft.

Item.	Quantity.	Rate Rs.	Amount Rs. a. p.	Total Rs. a. p.	Percentage
CEMENT					
1. Cement at site	5.78 bags.	112-9 per ton	32 9 0	32 9 0	45.15
OTHER MATERIALS					
2. Wetting agent	0.18 gls.	18/- per gal.	3 4 0		
3. Sand at site	16.70 cu.ft	54/- per 100 cu.ft	9 0 0		
4. Coarse aggregate	39.50 ,,	21¾ ,,	8 10 0		
5. Chippings	6.72 ,,	34¾ ,,	2 5 0		
6. Expansion Joints	3.0 r.ft	¼/r.ft.	0 12 0		
7. Water for mixing and curing	400 gls.	1 per 1000 gallons	0 7 0	24 6 0	33.89
LABOUR					
8. Preparation of subgrade	100.0 s.ft	1 per 100 s.ft	1 0 0		
9. Screening, spreading, levelling and rolling metal	39.5cu.ft	6¼ per 100 c.ft	2 8 0		
10. Mixing grout, laying and finishing	100.0 s.ft	14 per 100 c.ft	5 4 0		
11. Curing	1.0	1¾ per 100 s.ft	1 12 0		
12. Joint filling	1.0	1 per 100 s.ft	1 0 0	11 8 0	15.97
TOOLS & PLANT					
13. Tools, etc.	1.0	0/14/-,,	0 14 0		
14. Roller hire	1.0	1/0/- ,,	1 0 0		
15. Mixer hire	1.0	1 2/- ,,	1 2 0	3 0 0	4.16
SUPERVISION	1.0	0/10/- ,,	0 10 0	0 10 0	.83
				72 1 0	100.0

Cost per sq. yd. Rs 6 8 0

Cost per 100 cu. ft Rs 192 0 0

Appendix IV (*Contd.*)

Table 2.

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 2. **SLAB NO. 2—5″ thick.**

Grout 1 : 2 : ½″ size stone chips spread on the grouted surface. Surface tamped, floated and brush finished.

Coarse aggregate	...	Stone metal 1½″ to 2¼″ rolled with a 10 ton roller before grouting.
Fine aggregate	...	Mumbra sand.
Proportion of grout	...	Cement one part by vol., Sand 2 parts, Wetting agent ¼ pint per cwt. of cement. Water-cement ratio 0.8 by wt.
Curing	...	By ponding for 14 days.
Length	...	33 feet and 4 inches.
Breadth	...	11 feet 2 inches.
Thickness	...	5 inches.
Vol. of slab	...	155.4 cu.ft
Voids in unrolled stone	...	50%
Total quantity of stone spread	...	164 cu.ft
Voids in rolled stone	...	45%
Quantity of cement used	...	20.5 cwt.
Quantity of cement used per 100 cu. ft		13.2 cwt.
Quantity of ½″ size stone chips per 100 cu.ft	...	6.72 cu.ft
Proportion worked out to	...	1 : 2 : 6.65

Analysis of cost per 100 s. ft.

Item	Quantity	Rate Rs.	Amount Rs.	a.	p.	Total Rs.	a.	p.	Percentage
CEMENT:									
1. Cement at site	5.51 bags	112-9 a ton	31	0	0	31	0	0	43.35
OTHER MATERIALS									
2. Wetting agent	0.17 gls.	18/- per gall.	3	1	0				
3. Sand at site	15.84 cu. ft	54/- 100 cft	8	9	0				
4. Coarse aggregate	44.0 cu. ft	21¾ ,,	9	9	0				
5. Chippings	6.72 ,,	34¾ ,,	2	5	0				
6. Expansion Joint	3.0 r.ft.	¼ rft	0	12	0				
7. Water for mixing & curing	300.0 gls.	1/- a 1000 gls.	0	5	0	24	9	0	34.41
LABOUR									
8. Preparation of subgrade	100.0 sft	1/- a 100 sft	1	0	0				
9. Screening, spreading, levelling & rolling metal	44.0 cu. ft	6¼ 100 cft	2	12	0				
10. Mixing grout, laying and finishing	100.0 sft	14/- per 100 cu.ft	5	13	0				
11. Curing	100.0 sft.	1¾ per 100 sft	1	12	0				
12. Joint filling	100.0 sft.	1/- ,,	1	0	0	12	5	0	17.21
TOOLS & PLANT									
13. Tools etc.	1.0	-/14/- sft	0	14	0				
14. Roller hire, etc.	1.0	1/-/- ,,	1	0	0				
15. Mixer hire etc.	1.0	1/2/- ,,	1	2	0	3	0	0	4.19
SUPERISVION	1.0	0/10/0 ,,	0	10	0	0	10	0	0.84
						71	8	0	100.0

Cost per sq. yd. Rs 6 7 0

Cost per 100 cu. ft Rs 171 10 0

Appendix IV *(Contd.)*

Table 3.

Experimental grouted concrete pavement opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 2. **SLAB NO. 3 – 4 3/8" thick.**

Grout 1 : 2 ; ½" size stone chips spread on the grouted surface. Surface tamped, floated and brush-finished.

Coarse aggregate	...	Stone metal 1½" to 2½" rolled with a ten-ton roller before grouting.
Fine aggregate	...	Mumbra sand.
Proportion of grout	...	Cement one part (by vol.) Sand 2 parts. Wetting agent ¼ pint per cwt. of cement. Water-cement ratio 0.8 (by wt.)
Curing	...	By ponding for 14 days.
Length	...	33 feet 4 inches.
Breadth	...	11 feet 2 inches.
Thickness	...	4-3/8"
Volume of slab	...	133.5 cu. ft
Voids in unrolled stone	...	50%
Total quantity of stone spread	...	141 cu. ft
Voids in rolled stone	...	45%
Quantity of cement used	...	10 cwt.
Quantity of cement used per 100 s. ft	...	14.2 cwt.
Quantity of ½" size stone chips used for 100 s. ft	...	6.72 cu. ft
Proportion worked out to	...	1 : 2 : 6.16

Analysis of cost per 100 s. ft

Item	Quantity	Rate Rs	Amount Rs. A. P.	Total Rs. A. P.	Per-centage
CEMENT:					
1. Cement at site	5.16 bags	112-9 a ton	29 1 0	29 1 0	43.84
OTHER MATERIALS					
2. Wetting agent	0.16 gls.	18/- per gall.	2 14 0		
3. Sand at site	14.86 cu. ft	54/- 100 cu.ft	8 0 0		
4. Coarse aggte.	38.00 cu.ft.	$21\frac{3}{4}$ "	8 4 0		
5. Chippings	6.72 "	$34\frac{3}{4}$ "	2 5 0		
6. Expansion joint	3.0 r ft	¼ a rft	0 12 0		
7. Water for mixing and curing	300.0 gls.	1/- 1000 gls.	0 5 0	22 8 0	33.96
LABOUR:					
8. Preparation of subgrade	100 s. ft.	1/- per 100 s. ft.	1 0 0		
9. Screening, spreading, levelling and rolling metal	38 cu. ft.	6| per 100 cu. ft.	2 6 0		
10. Mixing grout, laying and finishing	100 s. ft.	14/- per 100 cu. ft.	5 0 0		
11. Curing	100 s. ft.	$1\frac{3}{4}$ per 100 s. ft	1 12 0		
12. Joint Filling	100 s. ft.	1/- p: 100 s. ft.	1 0 0	11 2 0	16.74
TOOLS & PLANT:					
13. Tools, etc.	100 s. ft.	-/14/-per 100 s. ft.	0 14 0		
14. Roller hire, etc.	100 s. ft.	1/- per 100 s. ft.	1 0 0		
15. Mixer hire etc.	100 s. ft.	1/2/- 100 s. ft.	1 2 0	3 0 0	4.54
SUPERVISION:	100 s. ft.	0 10 0	0 10 0	0 10 0	0.82
				66 5 0	100.0

Cost per sq. yd. Rs. 6-0-0

Cost per 100 cu. ft Rs. 181-3-0

Appendix IV (*Contd.*)

Table 4.

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 3 **SLAB NO. 4- 4.95″ thick**

Base course ... Grouted concrete 1 : $2\frac{1}{2}$

Wearing course ... Premixed concrete 1 : 2 : 3

Base course ... 4.2″ thick.

Coarse aggregate ... stone metal $1\frac{1}{2}$″ to $2\frac{1}{2}$″ size rolled with a ten-ton roller before grouting.

Fine aggregate ... Mumbra sand.

Proportion of grout ... Cement one part (by Vol.)

Sand $2\frac{1}{2}$ parts

Wetting agent ¼ pint per cwt. of cement

Water-cement ratio 0.9 (by wt.)

Wearing course ... ¾″ thick.

Coarse aggregate ... Stone metal ½″ to ¾″

Fine aggregate ... Mumbra sand.

Proportion of concrete ... Cement one part, sand 2 parts, ½″ stone metal 3 parts, water-cement ratio 0.5 (by wt.)

The surface is tamped, floated and brush-finished

Curing ... By ponding for 14 days.

Length ... 33 feet 4 inches.

Breadth ... 11 feet 2 inches.

Thickness ... 4.95″

Volume ... 148.3 cu. ft

Base course	...	4.2″ thick
Volume	...	125 cu. ft
Voids in unrolled stone	...	50 per cent
Voids in rolled stone	...	45 ,, ,,
Total quantity of stone spread		131.7 cu. ft
Quantity of cement used	...	14.1 cwt.
Quantity of cement used per 100 cu. ft	...	11.3 cwt.
Proportion worked out to	...	1 : 2.5 : 7.79
Surface course	...	0.75 thick
Quantity of cement used	...	5 cwt.
Quantity of cement used per 100 s. ft	...	1.35 cwt.
Quantity of sand	...	12 cu. ft
Do. per 100 s.ft	...	3.25 cu. ft
Quantity of stone	...	18 cu. ft
Do. per 100 s.ft	...	4.85 cu. ft
Ultimate proportion worked out to	...	1 : 2.37 : 6.53
Cement per 100 cu. ft of finished work	...	12.9 cwt.

Analysis of cost per 100 s. ft.

Item	Quantity.	Rate Rs.	Amount Rs. a. p.	Total Rs. a. p.	Percentage
CEMENT					
1. Cement at site		112-9 a ton	29 0 0	29 0 0	45.75
Base course	3.80 cwt.				
Surface course	1.35 cwt.				
OTHER MATERIALS:					
2. Wetting agent	0.1 gls	18/- a gal.	1 13 0		
3. Sand at site Base course	11.5 cu.ft	54/- per 100 c.ft.	7 9 0		
Surface course	3.25 ,,				
4. Coarse Aggregate					
Base course	35.4 ,,	21¾ } 100 cu. ft	7 11 0		
Surface course	4.9 ,,	34¾ } 100 cu. ft	1 11 0		
5. Expansion Joints	3.0 rft	¼ a rft	0 12 0		
6. Water for mixing and curing	300.0 gls.	1/- } 1000 gls.	0 5 0	19 13 0	31.24
LABOUR:					
7. Preparation of sub-grade	100.0 s.ft	1/- per 100 s.ft	1 0 0		
8. Screening, spreading, levelling & rolling metal	35.4 ,,	6¼ per 100 cu. ft	2 3 0		
9. Mixing grout, laying and finishing	100 ,,	14/- ,,	5 0 0		
10. Curing	100 ,,	1¾ ,,	1 12 0		
11. Joint filling	100 ,,	1/- ,,	1 0 0	10 15 0	17.33
TOOLS & PLANT:					
12. Tools, etc.	100 s.ft	-/14/- 100 cu.ft	0-14-0		
13. Roller hire	100 s.ft	1/- ,,	1 0 0		
14. Mixer hire	100 s.ft	0-10-0 100 s.ft	1 2 0	3 0 0	4.74
SUPERVISION:	100 s.ft.	0-10-0	0 10 0	0 10 0	.94
				63 6 0	100.0

Cost per sq. yd. Rs 7 0 0
Cost per 100 cu.ft Rs 153 10 0

Appendix IV *(Contd.)*

Table 5.

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 3. SLAB NO. 5—5.75" thick.

Base Course	...	Grouted 1 : 2½
Wearing Course	...	Premixed Concrete 1 : 2 : 3
Base Course	...	4⅞ in. thick.
Coarse aggregate	...	Stone metal 1½" to 2¼" rolled with a 10 ton roller before grouting.
Fine aggregate	...	Mumbra sand.
Proportion of grout	...	Cement 1 part (by vol.) Sand 2½ parts Wetting agent ¼ pint per cwt. of cement Water-cement ratio 0.9 (by wt.)
Wearing course	...	0.9" thick.
Coarse aggregate	...	stone metal ½" to ¼"
Fine aggregate	...	Mumbra sand
Proportion of concrete		Cement 1 part (by volume) Sand 2 parts, ½" stone chips, 3 part water-cement ratio 0.5 (by wt.)

The surface is tamped, floated and brush-finished.

Curing	...	By ponding for 14 days.
Length	...	33 feet 4 inches.
Breadth	...	11 feet 2 inches.
Thickness	...	5.75"
Volume	...	172.6 cu.ft
Base course	...	4.66" thick.
Volume	...	144.7 cu.ft

Voids in unrolled stone		50%
Total quantity of stone spread		152.3 c.ft.
Voids in rolled stone	...	45%
Quantity of cement used	...	16.3 cwt.
Do. per 100 cu.ft	...	11.3 cwt.
Proportion worked out to	...	1 : 2.5 : 7.79
Surface Course	...	0.9" thick
Quantity of cement used	...	6 cwt.
Do. per 100 cu.ft	...	1.62 cwt.
Quantity of sand used	...	14.5 cu.ft
Do. per 100 s.ft	...	3.9 cu.ft
Quantity of chips used	...	21.6 cu.ft
Do. per 100 s.ft	...	5.35 cu.ft
Ultimate proportion	...	1 : 2.37 : 6.5
Cement per 100 cu.ft of finished work	...	12.9 cwt.

Analysis of cost per 100 s.ft.

Item	Quantity	Rate Rs.	Amount Rs. a. p.	Total Rs. a. p.	Percentage
CEMENT:					
1. Cement at site Base course	4.4 cwt.	112-9			
Surface course	1.6 cwt.	a ton	33 12 0	33 12 0	46.55
OTHER MATERIALS:					
2. Wetting agent	0.14 gal.	18/- per gallon	2 8 0		
3. Sand at site Base course	13.20 cu.ft	54/- per			
Surface course	3.85 ,,	100 cu.ft	9 3 0		
4. Coarse aggregate. Base course	41.0 ,,	21¾ ,,	8 15 0		
Surface ,,	5.76 ,,	34¾ ,,	2 0 0		
5. Expansion Joints	3.0 rft.	¼ a r.ft	0 12 0		
6. Water for mixing and curing	300.0 gls.	1/- per 1000 gls.	0 5 0	23 11 0	32.74
LABOUR:					
7. Preparation of subgrade	100 s.ft.	1/-per 100 s.ft	1 0 0		
8. Screening, spreading, levelling & rolling metal	41 cu.ft	6¼ per 100 cu.ft	2 9 0		
9. Mixing grout, laying & finishing	100 s.ft.	14/- ,,	5 0 0		
10. Curing	100 s.ft.	1¾ per 100 s.ft	1 12 0		
11. Joint Filling	100 s.ft.	1/- ,,	1 0 0	11 5 0	15.75
TOOLS & PLANT:					
12. Tools etc.	100 s.ft.	-/14/-	0 14 0		
13. Roller hire	100 s.ft.	1/- ,,	1 0 0		
14. Mixer hire	100 s.ft.	1-2-0 ,,	1 2 0	3 0 0	4. 14
SUPERVISION	100 s.ft.	0-10-0 ,,	0 10 0	0 10 0	. 82
				72 6 0	100.0

Cost per sq. yd. Rs 6 8 0
Cost per 100 cu.ft Rs 151 3 0

Appendix IV (*Contd.*)

Table 6.

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 3.	**SLAB NO. 6—4·83″ thick**
Base Course	... Grouted 1 : 2½
Surface Course	... Premixed concrete 1 : 2 : 3
Base Course	... 4·2″ thick.
Coarse aggregate	... Stone metal 1½″ to 2¼″ rolled with a 10-ton roller before grouting.
Fine aggregate	... Mumbra sand
Proportion of grout	... Cement 1 part (by vol.) Sand 2½ parts Wetting agent ¼ pint per cwt. of cement. Water-cement ratio 0·9 (by wt.)
Wearing Course	... 0·63″ thick.
Coarse aggregate	.. Stone metal ¼″ to ½″
Fine aggregate	... Mumbra sand
Proportion of cement	... Cement 1 part. Sand 2 parts. ½″ stone chips 3 parts, water-cement ratio 0·5 (by wt.)

The surface is tamped, floated and brush-finished.

Curing	... By ponding for 14 days.
Length	... 33 feet 4 inches.
Breadth	... 11 feet 2 inches.
Thickness	... 4·83″
Volume	... 142 cu.ft
Base course	... 4·2″ thick.
Volume	... 123·4 cu.ft

Voids in unrolled stone	...	50%
Total quantity of stone spread		130 cu.ft
Voids in rolled stone	...	45%
Quantity of cement used	...	13·9 cwt.
Do. per 100 cu. ft	...	11·26 cwt.
Proportion worked out to	...	1 : 2·5 : 7·79
Surface Course	...	0·63″ thick.
Quantity of cement used	...	4 cwt.
Quantity of cement used per 100 s. ft	...	1·14 cwt.
Quantity of sand used	...	9·6 cwt.
Quantity of sand used per 100 s. ft	...	2·75 cwt.
Quantity of chips used	...	14·5 cwt.
Quantity of chips used per 100 s. ft	...	4·1 cwt.
Ultimate proportion worked out to	...	1 : 2·39 : 6·72
Cement per 100 cu. ft of finished work	...	12·6 cwt.

Analysis of cost per 100 s. ft.

Item	Quantity	Rate Rs.	Amount Rs.	a.	p.	Total Rs.	a.	p.	Percentage
CEMENT									
1. Cement at site		112-9 per ton	28	9	0	28	9	0	44·88
Base course	3.94 cwt.								
Surface ,,	1.14 cwt								
OTHER MATERIALS									
2. Wetting agent	0.12 gln.	18/- per gallon	2	3	0				
3. Sand at site		54/- per 100 cu.ft	7	14	0				
Base course	11.85 cu.ft								
Surface ,,	2.75 cu.ft								
4. Coarse aggregate									
Base course	36.8 cu.ft	21¾ ,,	7	15	0				
Surface ,,	4.1 cu.ft	34¾ ,,	1	6	0				
5. Expansion joints	3.0 rft	¼ a. rft	0	12	0				
6. Water for mixing and curring	300 galls.	1/- per 1000 gls.	0	5	0	20	7	0	32·18
LABOUR									
7. Preparation of subgrade	100.0 sft	1/- per 100 sft	1	0	0				
8. Screening, spreading, levelling and rolling metal	36.8 cu.ft	6¼ per 100 cu.ft	2	5	0				
9. Mixing grout, laying and finishing.	100.0 sft	5/- per 100 sft	5	0	0				
10. Curring	100.0 sft	1¾ per 100 sft	1	12	0				
11. Joint filling	100.0 sft	1/-per 100 sft	1	0	0	11	1	0	17.30
TOOLS & PLANT									
12. Tools, etc.	100.0 sft	-/14/- per 100 sft	0	14	0				
13. Roller hire	100.0 sft	1/- per 100 sft	1	0	0				
14. Mixer hire	100.0 sft	1/2 per 100 sft	1	2	0	3	0	0	4.70
SUPERVISION		5/8 per 100 sft	0	10	0	0	10	0	.94
						63	11	0	100.0
Cost per sq. yd.		Rs	5	12	0				
Cost per 100 cu. ft		Rs	159	4	0				

Appendix IV *(Contd.)*

Table 7

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 4. **SLAB NO. 7—4.88″ thick**

Base Course	... Grouted 1 : 3
Wearing Course	... Premixed concrete 1 : 2 : 3
Base course	... 4.20″ thick.
Coarse aggregate	... Stone metal $1\frac{1}{2}''$ to $2\frac{1}{2}''$ rolled with a 10-ton roller before grouting.
Fine aggregate	... Fine Juhu sand.
Proportion of grout	... Cement 1 part (by vol.) sand 3 parts, wetting agent $\frac{1}{4}$ pint per cwt. of cement, Water-cement ratio 1.3 (by wt.)
Wearing course	... 0.68″ thick.
Coarse aggregate	... Stone metat $\frac{1}{4}''$ to $\frac{1}{2}''$
Fine aggregate	... Mumbra sand.
Proportion of concrete	... Cement 1 part (by vol.), sand 2 parts, $\frac{1}{2}''$ stone chips 3 parts, Water-cement ratio 0.5 (by wt.)

The surface is tamped, floated and brush-finished.

Curing	... By ponding for 14 days.
Length	... 33 feet 4 inches.
Breadth	... 11 feet 2 inches.
Thickness	... 4.87″
Volume	... 133.41 cu.ft
Base course	... 4.25″ thick
Volume	... 114.81 cu.ft
Voids in unrolled stone	... 50%

Total quantity of stone spread	... 121 cu.ft
Voids in rolled stone	... 45%
Quantity of cement used	... 14 cwt.
Do. per 100 c.ft.	... 12.2 cwt.
Proportion worked out to	... 1 : 3 : 7.2
Surface course	... 0.63″ thick.
Quantity of cement used	... 4.0 cwt.
Quantity of cement used per 100 s.ft	... 1.13 cwt.
Quantity of sand used	... 9.6 cu.ft
Do. per 100 s.ft.	... 2.75 cu.ft
Quantity of stone chips used	... 14.4 cu.ft
Quantity of stone chips used for 100 s.ft	... 4.1 cu.ft
Ultimate proportion worked out to	... 1 : 2.78 : 6.27
Cement per 100 cu.ft of finished work	... 13.5 cwt.

Analysis of cost per 100 s. ft.

Item	Quantity	Rate Rs.	Amount Rs.	a.	p.	Total Rs.	a.	p.	Percentage
CEMENT									
1. Cement at site		112-9							
Base course	3.94 cwt.	a ton	28	8	0	28	8	0	47.6
Surface ,,	1.13 ,,								
OTHER MATERIALS									
2. Wetting agent	0.12 gal.	18/-per gallon	2	3	0				
3. Sand at site									
Base course	14.2 cu.ft	25/-100	3	9	0				
Surface ,,	2.75 ,,	54/-cu.ft	1	8	0				
4. Coarse aggregate									
Base course	34.0 ,,	$21\frac{3}{4}$,,	7	3	0				
Surface ,,	4.1 ,,	$34\frac{3}{4}$,,	1	7	0				
5. Expansion joints	3.0 rft.	$\frac{1}{4}$ a rft	0	12	0				
6. Water for mixing and curing	300 gals	1/-per 100 gls.	0	5	0	16	15	0	28.4
LABOUR									
7. Preparation of subgrade	100 s.ft	1/-per 100 sft	1	0	0				
8. Screening, spreading, levelling and rolling metal	34 cu.ft	$6\frac{1}{4}$ per 100 cu.ft	2	2	0				
9. Mixing grout, laying and finishing	100 s.ft	5/-per 100 sft	5	0	0				
10. Curing	100 s.ft	$1\frac{3}{4}$,,	1	12	0				
11. Joint filling	100 s.ft	1/- ,,	1	0	0	10	14	0	18.0
TOOLS & PLANT									
12. Tools etc.	100 s.ft	-/14/- ,,	0	14	0				
13. Roller hire	100 s.ft	1/- ,,	1	0	0				
14. Mixer hire	100 s.ft	1/2 ,,	1	2	0	3	3	0	5.0
SUPERVISION	100 s.ft	5/8 ,,	0	10	0	0	10	0	1.0
						59	15	0	100.0

Cost per sq.yd. Rs 5 6 0

Cost per 100 cu.ft ,, 148 0 0

Appendix IV *(Contd.)*

Table 8.

Experimental grouted concrete pavements opposite the Victoria Gardens for the Bombay Municipal Corporation.

EXPERIMENT NO. 5. **SLAB NO. 8—4.47″ thick.**

Base course	... Grouted 1 : $2\frac{1}{2}$
Wearing course	... Premixed concrete 1 : 2 : 3
Base course	... 3.72″ thick.
Coarse aggregate	... Stone metal $1\frac{1}{2}$″ to $2\frac{1}{4}$″ rolled with a 10-ton roller before grouting.
Fine aggregate	... Fine Juhu sand
Proportion of grout	... Cement 1 part (by vol.) Sand $2\frac{1}{2}$ parts (by Vol.) Wetting agent $\frac{1}{4}$ pint per cwt of cement, water-cement ratio 1.2 (by wt.)
Wearing course	... 0.75″ thick.
Coarse aggregate	... Stone metal $\frac{1}{4}$″ to $\frac{1}{2}$″
Fine aggregate	... Mumbra sand.
Proportion of concrete	... Cement 1 part (by vol.), Sand 2 parts (by vol.), $\frac{1}{2}$″ stone chips 3 parts, water-cement ratio 0.5 (by wt.)

The surface is tamped, floated and brush-finished.

Curing	... By ponding for 14 days.
Length	... 33 ft. 4 inches.
Breadth	... 11 ft. 2 inches.
Thickness	... 4.47″
Volume	... 138.54 cu.ft
Base course	... 3.72″ thick
Volume	... 115.34 cu.ft
Voids in unrolled stone	... 50%

Total quantity of stone spread used	...	121.4 cu. ft
Voids in rolled stone	...	45%
Quantity of cement used	...	14 cwt.
Do per 100 cu ft	...	12.1 cwt.
Proportion worked out	...	1 : 2.5 : 7.23

Surface Course:

Quantity of cement used	...	5 cwt.
Quantity of cement used for 100 sft	...	1.35 cwt.
Quantity of sand used	...	12 cu.ft
Quantity of sand used per 100 sft	...	3.25 cu.ft
Quantity of stone chips used	...	18 cu.ft
Do per 100 sft	...	4.9 cu.ft
Ultimate proportion worked out to	...	1 : 2.37 : 6.11
Cement per 100 cu.ft of finished work	...	13.72 cwt.

Analysis of cost per 100 s. ft.

Item	Quantity	Rate Rs.	Amount Rs.	A.	P.	Total Rs.	A.	P.	Per-cent-age
CEMENT:									
1. Cement at site		112-9 per ton							
Base course	3.75 cwt								
Surface ,,	1.35 ,,		28	11	0	28	11	0	48.16
OTHER MATERIALS:									
2. Wetting agent	0.12 gal.	18/- per gallon	2	3	0				
3. Sand at site									
Base course	11.25 cu. ft	25/-100	2	13	0				
Surface ,,	3.25 ,,	54/-cu.ft	1	10	0				
4. Coarse aggregate									
Base course	32.7 ,,	21¾ ,,	7	1	0				
Surface ,,	4.9 ,,	34¾ ,,	1	12	0				
5. Expansion Joints	3.0 rft	¼ a rft	0	12	0				
6. Water for mixing and curing	300 gls.	1/- per 1000 gls	0	5	0	16	8	0	27.69
LABOUR:									
7. Preparation of subgrade	100.0 sft	1/- per 100 sft	1	0	0				
8. Screening, spreading, levelling and rolling metal	32.7 cu.ft	6¼ per 100 cu. ft	2	1	0				
9. Mixing grout, laying and finishing	100.0 sft	5/- per 100 sft	5	0	0				
10. Curing	100.0 sft	1¾ ,,	1	12	0				
11. Joint filling	100.0 sft		1	0	0	10	13	0	18.12
TOOLS & PLANT:									
12. Tools, etc.	100.0 sft	-/14/ ,,	0	14	0				
13. Roller hire	100.0 sft	1/- ,,	1	0	0				
14. Mixer hire	100.0 sft	1/2/ ,,	1	2	0	3	0	0	5.03
SUPERVISION		5/8 ,,	0	10	0	0	10	0	1.00
						59	10	0	100.0

Cost per sq. yd. Rs 5 5 0
Cost per 100 cu. ft ,, 160 0 0

Appendix V.

Daily progress of grouting at Coimbatore-Mettupalayam Road—Mile 11/0 to 11/3.

(Paras 8.5 and 8.6)

Day	Length (feet)	Cement used. (Cwt.)	Cement Consumed per 100 sq. ft (excluding wastage) Cwt.*	Spacing of dummy joints (feet)	Spacing expansion joints. (feet)	Remarks
1st	158	29	4.35	59 and 66 intervals	158	
2nd	198 99	39 23	4.68 5.52	66	264	Morning Afternoon
3rd	396	70	4.75	66	396	Between 10-15 a. m. and 2-30 p. m. in one stretch
4th	462	79	4.66	66	462	
5th	627	111	4.2	66	330 and 627	Between 9 a. m. and 4 p. m.
Total	1940 ft					

*Based on an average thickness of 4 inches.

Appendix VI

ental grouted stretch on
ad—300 ft × 20 ft × $4\frac{1}{2}$ in.

.6)

nount . a. p.	Total Amount for 6000 sq. ft Rs. a. p.	Break-up figures (a) % sft (b) % cu.ft Rs. a. p.	Percentage of total cost
5 0 0 5 12 0	1730 12 0	(a) 28 13 6 (b) 86 8 6	47.77
) 0 0 2 8 0	682 8 0	(a) 11 6 0 (b) 34 2 0	18.83
l 8 0	261 8 0	(a) 4 5 9 (b) 13 1 3	7.21
l 2 9	211 2 9	(a) 3 8 4 (b) 10 9 0	5.85
l 0 0 0 0	2 0 0	(a) 0 0 9 (b) 0 2 3	...
3 3 0	342 3 0	(a) 5 11 3 (b) 17 1 9	9.44
	14 0 0	(a) 0 3 9 (b) 0 11 3	0.38
	145 5 0	(a) 2 6 9 (b) 7 4 3	4.01
	7 8 0	(a) 0 2 0 (b) 0 6 0	0.20
	130 0 0	(a) 2 2 8 (b) 6 8 0	3.59
	95 10 0	(a) 1 9 6 (b) 4 12 6	2.50
	3623 6 9	(a) 60 6 3 (b)181 2 9	99.78

MARY OF IMPORTANT DETAILS

(Paras. 8.4 & 9.7)

consumed per cu. ft of ·hed work — Coarse aggre-gate. cu. ft	Fine aggre-gate cu. ft	Joints (type & spacing). E = Expansion Jt. C = Construction Jt. D = Dummy Jt.	Cost per 100 cu. ft of finished work Rs.	Percentage saving in cement over 1 : 2 : 4 cement concrete road, 18.5 cwt. cement assumed for 100 cu. ft concrete	Percentage saving in cost over usual 1 : 2 : 4 cement concrete road	Remarks
6	7	8	9	10	11	12
Sl 105	45	E @ 33 ft.	192.0	16.7	4.0	The cost of 1 : 2 : 4 concrete **assumed** Rs 200/100 cu. ft.
106	38	,,	171.6	28.6	14.2	
104	41	,,	181.2	23.2	9.1	
98	36	,,	153.6	30.2	23.2	Note the thickness of base & wearing coat are approximate.
98	36	,,	151.2	30.2	24.8	
102	36	,,	159.3	31.9	20.4	
94	42	,,	148.0	27	26	
101	39.0	,,	160.0	25.8	20	
M 112.5	37.5	C @ 33 ft & E @ 99 ft	198	6.0	5.2	Cost of 1 : 2 : 4 concrete **assmmed** Rs 209/100 cu. ft.
] 120	30	D @ 66 ft & E also	180.4	27.5	13.7	Exp. jt. provided at 158′, 264′, 330′ and 460′.
M 126.0	31	D @ 66 ft & E @ 165 ft	154.1	22.2	16.7 }	Cost of 1 : 2 : 4 concrete **assumed** Rs 185/100 cu. ft.
126.0	35.5	E @ 66 ft	145.7	33.5	21.3 }	
105	26.2	C @ 33 ft & E @ 100 ft	175.0	16.2	17.8	In the southern half, a dummy is provided in middle of each bay. Cost of conconrete **assumed** at Rs 213/100 cu. ft.

INFORMATION SERVICE

(1) A DESIGN FOR REINFORCED CONCRETE PIPES FOR ROAD CULVERTS.

By

SHRI A. NAGESWARA AIYAR.

Of the several types of culverts commonly provided for small drainage crossings under new or existing roads, pipe culverts are often found in practice to be the most economical and easily constructed. The economies of this type are, other things being equal, particularly apparent in areas where there is deep black-cotton soil since wing and curtain walls (necessitating deep foundations) need not be provided for pipe culverts. These culverts can usually be easily and quickly laid to take the discharges of small irrigation channels built subsequent to the construction of the road and, by the addition of one or more pipes, the culverts can often be quickly enlarged to take additional irrigation discharges.

The pipes may be of corrugated steel, cast iron, glazed stoneware, or cement concrete, either plain or reinforced. Of these corrugated sheet pipes and cast iron pipes are often costly, not always easily obtainable and; in some soils, liable to decay or rust. Glazed stoneware pipes and unreinforced cement concrete pipes are generally not strong enough for the heavy traffic of today. Reinforced cement concrete pipes are usually more economical and can be built out of locally available materials to any required strength. They can be laid over a bed of cement concrete or on precast reinforced concrete sleepers below the joints.

PIPES CAN BE MADE LOCALLY.

Several companies have been making reinforced concrete pipes. The main feature of these pipes is the dense cement mortar obtained by the special spinning process employed. Extensive use is being made of such pipes in road culverts and, in one big State, large quantities of such pipes of various sizes were found stacked in many inspection bungalows, evidently for use in road culverts. The pipes had to be conveyed from the factory by rail and carted to site. Of the stock in the sheds, many, possibly 10 to 15 per cent, had badly cracked or were otherwise damaged in transit. There is a danger that, in order to avoid audit objections which may arise from the rejection of broken pipes, these would be used in road culverts thereby permanently weakening them. Buying pipes from a manufacturing company is an easy but not a very efficient or desirable way of spending the year's grant.

With a little organization it is not difficult to manufacture the required pipes at or near the site of work. By using good aggregate and vibrators, it is possible to get pipes as suitable for culverts as those made by the spunconcrete process. Stone metal, broken to pass through a half inch round mesh screen and retained on a ¼ inch mesh screen, or alternatively pebbly gravel of the same grading, may be used as aggregate. A 1 : 1½ : 3 mix would be suitable.

COSTS AND STRENGTHS.

Such pipes manufactured by the Highways Department are in extensive use in the State of Madras, not only in road culverts but also as staining for village wells in out-of-the-way places where supervision is difficult. Present day comparative costs are not available but the cost per lineal foot in 1936 was less than 60 per cent of that charged by one of the manufacturing companies for spun pipes of the same diameter.

In this connexion it is important to remember that pipes for culverts do not require to have the same properties as pipes designed to carry liquids under pressure. For culverts beam strength is very important and, in order to ascertain the strength of locally made pipes, a four-foot diameter pipe, three feet long, selected at random from stock, was tested to destruction. The method of testing and the test results were described in a Paper published by the Engineers' Association Madras and are reproduced here in **Appendices I & II**. The results showed that the load bearing capacity was more than that claimed for spunconcrete pipes of the same diameter. The concrete for the pipe under test was of 1 : 2 : 4 proportion and crushed granite aggregate was used. Vibration was then unusual in India and the concrete was hand tamped. Results with vibrated concrete of 1 : 1½ : 3 mix could be expected to be better still.

CONSTRUCTION DETAILS.

To provide adequate strength for modern road traffic the shell thickness for pipes of 2 ft, 3 ft and 4 ft diameter may be 2 inches, 2½ inches, and 3 inches respectively and they may be reinforced with steel hoops aggregating 0.9 per cent and longitudinal steel aggregating 0.6 per cent of the volume of concrete.

It would be desirable to stagger the hoop reinforcement so that half of it might be near the inner surface of the pipe and half near the outer. It is difficult to have two separate grills and keep them in the correct position while pouring concrete. The following method which was successfully used at Madras is commended for adoption.

In the 2 ft diameter pipes, where the shell thickness was only 2 inches, the longitudinal bars were ⅜ inch round. Hoops of ¼ inch round steel were tied alternately to the inside and outside of the longitudinals. This reinforcement grill had a cover of about half an inch.

For a 3-foot diameter pipe whose shell thickness is 2½ inches, ¼ inch round rods might be bent double with a space of ½ inch between the two legs. The hoop reinforcement, of ¼ inch rods, would be tied alternately to the outer and inner legs of the longitudinal.

In a 4 foot diameter pipe ⅜ in. rods bent double with a space of ¾ inch between the legs would be used as longitudinal reinforcement, and ¼ inch hoop rods tied alternately to the outside of each leg. These grills can be kept in position and concreted. Hoop reinforcement could be welded to the longitudinals if welding facilities are available.

Rods of ¼ inch diameter are sometimes available in long lengths in rolls. If so, they could be helically wound and tied to the longitudinals thus avoiding a number of welds.

MOULDS.

To manufacture reinforced concrete pipes it is necessary to have moulds and handling equipment. The moulds may consist of two concentric hollow cylinders enclosing between them an annular space into which the cement concrete can be poured to form the pipe. The pipes to be cast should be of standard lengths of 5 or 6 feet.

The outer form may consist of two half cylinders which can be bolted together to form a full cylinder. As it would be difficult to consolidate concrete if the height to be poured at a time exceeded 2 ft 6 in. to 3 feet, the form, should be of that length, two forms being joined together to make one pipe length.

Each half cylinder could be built by welding a steel plate, ⅛ inch thick to the webs of three or four channel ribs (4 in. × 2 in.) bent to form a semicircle, with the ends projecting a little to be bolted to the corresponding part on the other half cylinder. By bolting the two half cylinders together a smooth steel face can be obtained. It is essential that the top and bottom channels should be horizontal so that when placing two 3-ft forms one over the other and bolting them together, a true surface concentric with the outer surface of the inner cylinder, might be obtained.

The arrangement for the inner cylinder has to be more elaborate as it has to be contracted to a smaller diameter to enable it to be withdrawn without damaging the partially set concrete. The inner cylinder should be of the full length of the pipe to be cast. It is made in two segments with two gaps of 6 to 9 inches each (See Plate). Each segment has angle or channel ribs (the Plate shows channel ribs) spaced about two feet centres to the outer faces of which a $\frac{1}{8}$ inch steel plate is welded. The gaps would be closed by wedge-shaped wooden beams, 6 to 9 inches wide and 4 inches deep, extending over the full length of the cylinder. These beams are fitted near the top and bottom with bolts with right and left handed threads. The bolts are connected with bottle nuts by the turning of which the beams are drawn towards or forced away from each other.

A shaft fitted with two worm wheels is fitted to one of the segments. The worms gear with two spur wheels fixed on to the bottle nuts. By turning the shaft handle the two bottle nuts turn simultaneously and the two beams are drawn together or forced away. As soon as they get clear of the channel ribs of the segment, the segments can be pushed in and the whole inner cylinder assembly lifted out. To prevent the wedge-shaped beams moving beyond the cylinder face into the annular space, two rings made of flat steel, 3 in. × $\frac{1}{2}$ in. are loosely fitted to the top and bottom ends of the cylinder. These rings also serve to form a recess for connecting consecutive pipe lengths.

The arrangement of the mould is shown in the accompanying Plate. At Madras only one pair of bolts was used, being fitted to the centre of the beams, and a boy used to get in and turn the bottle nuts. The pipes there were five feet long for diameters of two and three feet, and three feet long for the 4-feet diameter pipes. These lengths were standardised to facilitate conveying the pipes by bullock-cart, two pipes of 2-feet diameter or one of bigger diameter forming a full cart load. The suggestion made here to have two sets of bolts, synchronously operated, would make the movement of the beams smooth and easy.

SIMPLE EQUIPMENT.

In addition to the moulds a pair of light tripod stands, a differential pulley block capable of lifting two tons, and two or three segment shaped stools about 3 feet high would be required.

The estimated weights and costs of pipe moulds constructed on the above lines are given in the Table below.

Only one pipe can be manufactured with one mould in a day. For economical working, so that there may be no wastage of labour, three moulds of each size are desirable as one group of labourers can easily manufacture three pipes per day. In most cities the cost of pipes including adequate allowance for mould rental and overhead charges at 15 per cent, is not expected to exceed the figures given in the Table.

TABLE

Details of locally manufactured pipes.

Standard length 6 feet : Mix 1 : $1\frac{1}{2}$: 3.

Diameter Feet.	Wt. of mould. Lb.	Estimated cost of mould Rupees.	Shell thick-ness.	Steel per rft. Lb.	Estimated cost per foot of pipe Rupees.
2	1200	950	2 in.	8.7	7.2
3	2000	1350	$2\frac{1}{2}$,,	15.6	13.0
4	2500	1600	3 ,,	26.0	21.0

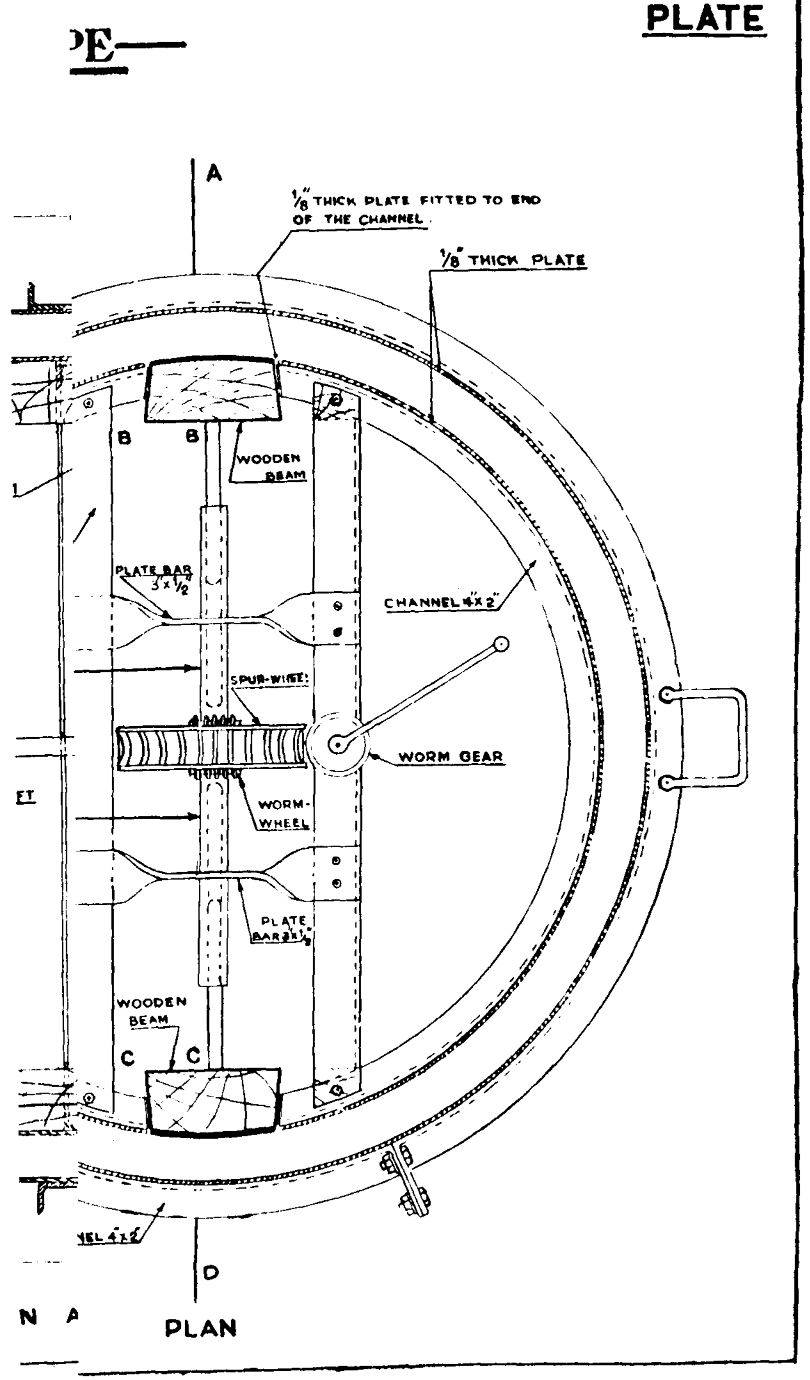
These pipes would have a shell thickness $\frac{1}{2}$ inch more than that of the corresponding size of patent pipes manufactured by some firms in India and would have 50 per cent more steel reinforcement. While being cheaper in cost, these departmentally manufactured pipes would have greater beam strength. They do not require collars.

a 4-ft diameter pipe, 3 ft long.

Appendix. I.

	Deflection.	Remarks.
bserv- at the m (A).	No deflection.	Load maintained for one hour.
	No deflection.	
more	Deflection of $\frac{1}{8}$ in. at the centre.	Load maintained for five min nutes; no further development
	Deflection increased to $\frac{1}{4}$ in.	Load maintained for ten min nutes ; no development,
ppear- F.&.G).	Deflection increased to $\frac{5}{8}$ in.	Load maintained for ten min nutes; no further development
sed a	Deflection increased to one inch. After 5 minutes it increased to 1.1/16 inch; after another 5 minutes to $1.\frac{3}{8}''$; after still another 5 minutes to $1\frac{1}{2}$ in.	No further increase in deflec tion.
	Deflection increased to 2 in. and continued without further loading. After 15 minnutes it was $2\frac{1}{2}$ in.	No further increase in defle tion.
	Deflection increased to $3\frac{1}{8}$ in. Concrete was crushed at the cracks and peeled off. Reinforcement bent at cracks.	

PLATE



A
1/8" THICK PLATE FITTED TO END OF THE CHANNEL.
1/8" THICK PLATE
B
B
WOODEN BEAM
PLATE BAR 3"x1/2"
CHANNEL 4"x2"
SPUR-WHEEL
WORM GEAR
WORM-WHEEL
PLATE BAR 3"x1/2"
WOODEN BEAM
C
C
NEL 4"x2"
D
N A
PLAN

(ii) INDIAN STANDARD

RULES FOR ROUNDING OFF NUMERICAL VALUES

One of the earliest standards issued by the Indian Standards Institution laid down rules for rounding off numerical values. Apart from the popular practice of rounding off such values, a simple rule has been suggested for treating ambiguous cases like 1.3500, 1.4500. As the Standard deserves to be widely known extracts* are given below here with the permission of the Institution.

1. PROBLEM OF ROUNDING.

1.1. In calculations involving numbers expressed to several decimal places it is usually necessary to follow a definite rule in "rounding off".

1.2. The rule usually followed in rounding off decimals is to keep unchanged the last figure retained when the first figure discarded is less than 5, and to increase by 1 the last figure retained when the first figure discarded is more than 5. There is diversity of practice when the first figure discarded is 5. In such cases some computers "round up", that is, increase by 1, the last figure retained; others "round down", that is, discard everything beyond the last figure retained. Obviously, if the retained value is always "rounded up", the sum and the average of a series of values so rounded will be too large; while if always "rounded down", the sum and the average of a series of rounded values will be too small.

2. RECOMMENDED RULES.

2.1. In setting up rules for rounding off decimals there are three general cases that should be considered. They may be stated as follows :—

2.1.1. When the figure next beyond the last figure or place to be retained is less than 5, the figure in the last place retained should be kept unchanged.

Example

1.2342	1.234	1.23	1.2

2.1.2. When the figure next beyond the last figure or place to be retained is more than 5, the figure in the last place retained should be increased by 1.

* Copies of the complete Standard can be had from the Indian Standards Institution, 19 University Road, Delhi-8, at eight annas per copy.

Example

1.6789	1.679	1.68	1.7

2.1.3. When the figure next beyond the last figure or place to be retained is 5, and

(a) there are no figures, or only zeros, beyond this 5, if the figure in the last place to be retained is odd, it should be increased by 1; if even, it should be kept unchanged.

Example

1.35	1.4
1.3500	1.4
1.45	1.4
1.4500	1.4

(b) If the 5 next beyond the figure in the last place to be retained is followed by any figures other than zero, the figure in the last place retained should be increased by 1, whether odd or even.

Example

1.3501	1.4
1.3599	1.4
1.4501	1.5
1.4599	1.5

2.2. The above rules for rounding off decimals may be retained as follows :

2.2.1. The figure in the last place to be retained should be kept unchanged :

(a) when the figure in the next place is less than 5 ;

(b) when the figure in the next place is 5 followed by no other figures or only by zeros, and the figure in the last place retained is even.

2.2.2. The figure n the last place to be retained should be increased by 1

(a) when the figure in the next place is more than 5 ;

(b) when the figure in the next place is 5 followed by no other figures or only by zeros, and the figure in the last place retained is odd ;

(c) when the figure in the next place is 5, followed by any figure or figures other than zero.

2.3. The final rounded value should be obtained from the most precise value available, and not from a series of successive roundings. For example, 0.5499 should be rounded off successively to 0.550 and 0.5 (not 0.6), since the most precise value available is less than 0.55. Similarly, 0.5501 should be rounded off as 0.550, 0.55 and 0.6, since the most precise value available is more than 0.55.

3. EXPLANATION OF RULES

3.1. Justification of the recommended method of rounding off decimals can be obtained from consideration of any large group of decimal values in which random distribution of figures occurs. It will be found that, on the average, the number of values "rounded up" and the number "rounded down" will be nearly equal. Therefore, the sum and the average of the rounded values will be more nearly correct than would be the case if all were rounded in the same direction ; that is, either all up or all down.

RESEARCH PUBLICATIONS

TREATMENT OF WET AGGREGATES WITH TURKEY RED OIL AND SLAKED LIME FOR BITUMINOUS ROAD CONSTRUCTION

By

I. S. UPPAL, INDUSTRIAL RESEARCH LABORATORIES,
DEPARTMENT OF INDUSTRIES, PUNJAB.

Bituminous mixtures which are complex mixtures of hydrocarbons having no definite chemical composition play an important role in the development of roads designed to meet the exacting demands of modern traffic. Bituminous road surfacings must not only resist the stresses induced by traffic and the forces of expansion and contraction but must also retain their properties under conditions of severe exposure to weather. For this purpose the perfect adhesion of bitumen to road aggregate is a very important factor. As a rule a bituminous mixture adheres quite satisfactory to dry aggregate giving it a uniform coating when properly mixed. But a bituminous mixture does not stick to wet aggregate, and great difficulty is felt in carrying out the work when the aggregate stored on the road side gets wet, specially during the rainy season.

In order to overcome this difficulty, incorporation of some surface active substances such as heavy metallic soaps in the bituminous mixture or the treatment of the aggregate with such compounds has been recommended. [Road Research Technical Paper No. 12 – " Properties of Road Tars and Asphaltic Bitumens in Relation to Road Construction " issued by the Department of Scientific and Industrial Research, Road Research Laboratory, London.] It has also been reported that due to its phenolic constituents tar has better adhesion properties than bitumen in the presence of water and consequently use of creozote oil with at least 10 per cent tar acid content has been recommended as a primer for pre-treating the stone chips prior to the addition of the bituminous mixture. Snyder and Palvish (Ind. Eng. Chem. 41, XI, 2649) have studied the use of various metallic soaps and amine hydrochlorides for the bitumen coating of wet aggregate and have finally found that the treatment of any type of aggregate with cupric chloride and amine hydrochloride produced an excellent affinity for the bitumen. Similarly after carrying out extensive experiments the Harmondsworth Road Research Laboratory discovered that the use of a solution of creozote and cetyk pyridinium bromide was completely successful in this respect (Chemical Age LXIII, 1628, 427).

In view of its cheapness, ease of preparation, and availability the suitability of Turkey red oil for the pretreatment of wet stone chips before coating with bitumen mixture was investigated by the Author. Turkey red oil is a partially neutralised product of ricinolic sulphuric acid having a chemical formula $C_{17}\ H_{32}$ (S04)H CooH. Its main raw constituents, viz., castor oil and sulphuric acid are abundantly available in this country at cheap rates. Castor oil is probably one of the cheapest vegetable oils available at present. The simplicity of the process and the equipment required for the sulphonation of castor oil allow Turkey red oil to be manufactured at the very site where it is to be consumed. Concentrated Turkey red oil has got the property of being miscible with water on the one hand and with bitumen on the other and thus serves a good medium for the bitumen to adhere to the stone surfaces.

Preliminary experiments conducted in the Laboratory showed that although by treatment with Turkey red oil the stones developed a great affinity for bitumen, the coating was not stable when put to the water-immersion test but when the requisite quantity of slaked lime was added to the primer the coating of bitumen became stable and did not strip off the stones during the water immersion test at 40 degrees centigrade. After standardising the optimum proportions of Turkey red oil and lime an experiment was conducted in a rotating mixing drum. The aggregate treated thus was put to the water immersion test at 40 degrees centigrade with very satisfactory results.

PREPARATION OF TURKEY RED OIL.

Ten pounds of commercial castor oil were taken in a wooden vessel fitted with a mechanical agitator. Two pounds of concentrated sulphuric acid were added to the oil (stirring all the time) at such a rate that the temperature of the mixture remained in the neighbourhood of 55 to 58 degrees centigrade*. When all the acid had been added the mixture was agitated for a few minutes, and the vessel was covered and allowed to stand till the mixture, which was tested from time to time, gave a clear solution when a drop was added to a test tube half full of distilled water. The reaction took about three hours to reach this stage when an equal quantity of water was added and thoroughly mixed to a homogeneous emulsion. On allowing the mixture to stand fer a few hours the water layer separated and was removed by means of a tap fitted at the bottom of the vessel. The oil was then washed two or three times with about 25 per cent Glauber salt solution till it was free from mineral acid.

* For details please see Ind. Text Jr. LVII, 683, 1016-1019.

After removing the aqueous layer completely the oil was neutralised with a 40 per cent caustic soda solution till the whole mass became quite transparent and gave a clear solution in water. In the initial stages of neutralisation the oil gives a turbid or even milky solution in water. This turbidity or milkiness disappears on further addition of the alkali.

On analysis the oil showed the following results :—

Total fatty matter	64.317 per cent
Combined SO_3	3.66 per cent
Alkalinity	2.57 per cent

In fact when slaked lime is to be used the oil need not be neutralised with caustic soda. In such cases the oil can be used after merely a couple of washings with water and glauber salt solution to remove the excess of sulphuric acid.

Treatment of the Aggregate :—Laboratory experiments were conducted by first treating separately one kilogramme of wet stone chips in each of seven enamelled basins with (1) 5 gm. T.R.O. (2) 10 gm. slaked lime (3) 20 gm. slaked lime (4) 5 gm. T.R.O. plus 15 gm. slaked lime (6) 6 gm. T.R.O. plus 15 gm. slaked lime (7) 5 gm. T.R.O. plus 20 gm. slaked lime, and then mixing in each case 40 gm. (4 per cent on weight of the aggregate) of hot bitumen cutback (75/25) prepared from S4 type bitumen till the aggregate appeared to be uniformly coated. About half an hour after this treatment each sample was tested for the stability of the bitumen coating by immersing in a jar of water maintained at 40 degrees centigrade. The results of the observation made are given below :—

Pretreatment.	**Observations.**
1. 0.5 per cent Turkey Red Oil.	Mixing was good resulting in a thin bitumen coating which chipped off when immersed in water leaving the stone uncoated.
2. 1 per cent lime alone. 3. 2 per cent lime alone.	Mixing not uniform, slight chipping off of bitumen in water at 40 degrees centigrade.
4. 1 per cent lime plus 0.5 per cent Turkey Red Oil.	Mixing good but the bitumen coat not stable.
5. 1.5 per cent lime plus 0.5 per cent Turkey Red Oil.	Mixing good, slight chipping off in water.
6. 1.5 per cent lime plus 0.6 per cent Turkey Red Oil.	Mixing easy; unaffected in water.
7. 2.0 per cent lime plus 0.5 per cent Turkey Red Oil.	Mixing was somewhat difficult but the bitumen coat was as stable as in No. 6.

It will be observed from the above results that the optimum quantities of the Turkey Red Oil and lime for getting the best results in the bitumen coating are 1.5 per cent lime and 0.6 per cent Turkey Red Oil by weight of the aggregate. Where Turkey Red Oil alone was used the coating was not stable. This was probably due to the oil-in-water type emulsion formed by the Turkey Red Oil on the stones. But when lime is mixed along with oil an insoluble compound, i.e., calcium salt of ricinoleic acid sulphonate is formed which acts as a binding agent between the wet stones and the bitumen.

A few experiments carried out with dry stones having smooth surfaces (shingle) showed that the bitumen coating strips off by immersion in water when no primer has been used, but the coating is stable when the stones are pretreated with a mixture of T.R.O. and lime. From this it would appear that this pre-treatment of the aggregate is not only required when the chips are wet but also helps considerably in developing stable adhesion of bitumen to chips when dry.

Incorporation of Turkey Red Oil in the bitumen mixture was not found to be a satisfactory procedure as, in that case, more of it was required to obtain the desired results.

Assuming that 3.3 cubic ft of $\frac{1}{2}$ in—1 in. stone chips (weighing 90 lbs. per cubic foot) are used for 100 sq. ft the quantity of T.R.O. and lime per 100 sq. ft of treated surface work out to :

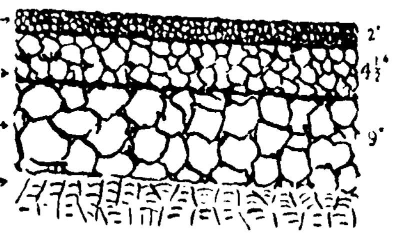
T.R.O. – 1.75 lbs.

Slaked or Fat lime – 5.0 lbs.

T.R.O. is not expected to cost more than nine annas a pound when prepared at site, which means an additional cost of about a rupee for every 100 sq. ft of treated surface. This is not much considering the stability of adhesion which it imparts to the aggregate resulting in a more weather-proof road.

Specification FOR A GOOD ROAD

1. (Shalimar) Road Tar macadam.
2. Waterbound macadam.
3. Adequate soling.
4. Stable formation.



Shalimar

Managing Agents:
TURNER MORRISON & CO. LTD.
6, Lyons Range, Calcutta, 1.

TAR PRODUCTS (1935) LIMITED

TMH7

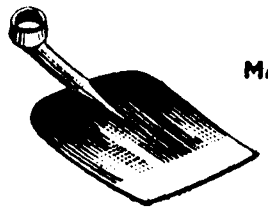
TATA AGRICO IMPLEMENTS

help him to

GROW MORE FOOD

Strong, durable, easy-to-handle Agrico implements are the *first choice* **of farmers all over the country—** *first essentials* **to successful farming.**

THERE'S AN AGRICO IMPLEMENT FOR EVERY FARMING JOB



MAMMOOTIES:

In three patterns including the popular Swan-necked design Sharp cutting edges ensure efficient working. Balanced construction enables easy handling.

POWRAHS:

In five patterns to suit varying work conditions. Made from high-carbon, heat-treated steel like all other Agrico Implements.

PICKS & BEATERS:

In four basic patterns designed to do various types of work. Cutting points are specially strengthened to retain sharpness. Extremely sturdy and long lasting.

TATA AGRICO *Implements*

THE TATA IRON & STEEL COMPANY LIMITED
Sales Office: 23-B, Netaji Subhas Road, Calcutta
Branches at: Bombay, Madras, Nagpur, Ahmedabad, Kanpur, Secunderabad, Vizianagram Cantt. and Jullunder Cantt.

Jandola Road Bridge, North West Frontier Province, 38 R.S. Joist Spans, 36-feet, on Screw Pile Piers.

BRAITHWAITE & CO.,

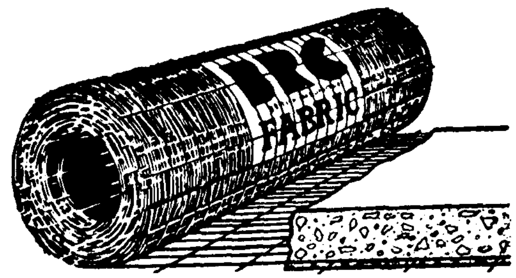
(INDIA) LIMITED

CALCUTTA

BRC

Welded Fabric

EVERY WELL-PLANNED ROAD LAID IN REINFORCED CONCRETE IS A STEP NEARER TO NATIONAL HIGHWAY PERFECTION



Is Reinforcement At Its Best For Roads.

SOLE AGENTS:

HEATLY & GRESHAM LIMITED

ESTABLISHED 1892 — INCORPORATED IN ENGLAND

P. O. Box 190 **CALCUTTA**	P. O. Box 225 **BOMBAY**	P. O. Box 228 **MADRAS**
L-18, Connaught Circus **NEW DELHI**	No. 4, West Wharf Road, **KARACHI 2**	P. O. Box 45 **LAHORE**

BRC is manufactured in India under license from The British Reinforced Concrete Engineering Co., Ltd., Stafford, England.

ASPHALT IS BEST
Because, as you know, asphalt is the easiest, fastest and most economical way to build new roads or repair broken surfaces
STANVAC IS BEST IN ASPHALTS
Because for village roads, city streets, National and Provincial highways, and airport runways there are special types of Stanvac Asphalt Construction to give you the most miles of smooth-riding, easily maintained surfaces for the funds at your disposal.
STANVAC ASPHALTS

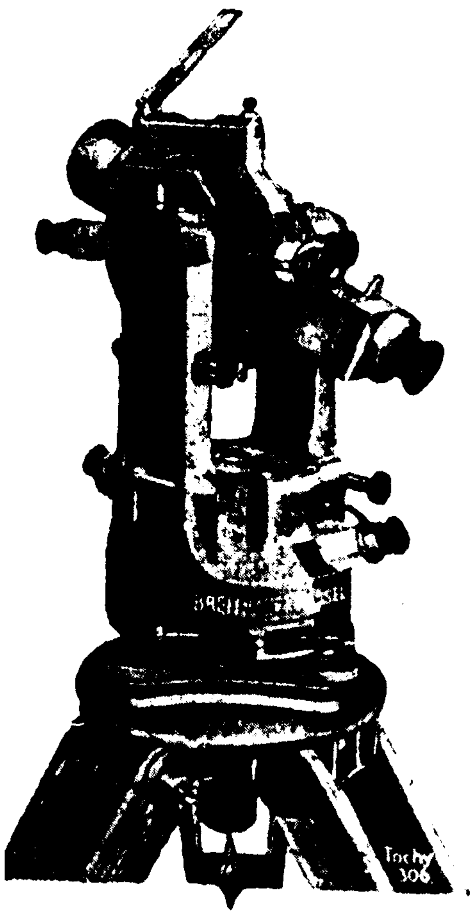
1762-1951 !

For Nearly Two Centuries

BREITHAUPT

(Germany)

have been delivering



THEODOLITES

AUTOREDUCTION-

TACHEOMETERS

TRANSITS

ALIDADES

PLANETABLE OUTFITS

GEOLOGICAL-AND

MINING-COMPASSES

USUAL ACCESSORIES

for all Surveying Work

CONTACT DEALERS:

OR

THE SCIENTIFIC INSTRUMENT CO., LTD.

11, Esplanade East, CALCUTTA - 1.

29, Regal Buildings, NEW DELHI - 1.

240, Hornby Road, BOMBAY - 1.

6, Tej Bahadur Sapru Road, ALLAHABAD - 1.

30, Mount Road, MADRAS - 2.

DIAMOND HARBOUR ROAD

8th MILE

2″ Shelcrete in 1935 sealed with Colas in 1937. Resealed with bitumen in 1946.

TRAFFIC—HEAVY BULLOCK CART

BURMAH-SHELL OIL STORAGE & DISTRIBUTING CO. OF INDIA LTD. (Incorporated in England)

CALCUTTA · BOMBAY · MADRAS · NEW DELHI

BS. 96