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Vijay P. Singh
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Energy and Environment

Select Proceedings of ICWEES-2016

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Water Science and Technology Library

Volume 80

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Preface

Fundamental to sustainable economic development, functioning of healthy ecosystems, reliable agricultural productivity, dependable power generation, maintenance of desirable environmental quality, continuing industrial growth, enjoyment of quality lifestyle, and renewal of land and air resources is water. With growing population, demands for water for agriculture and industry are skyrocketing. On the other hand, freshwater resources per capita are decreasing. There is therefore a need for effective water resources management strategies. These strategies must also consider the nexus between water, energy, environment, food, and society. With these considerations in mind, the International Conference on Water, Environment, Energy and Society (WEES-2016) was organized at AISECT University in Bhopal, MP, India, during March 15–18, 2016. The conference was fifth in the series and had several objectives.

The first objective was to provide a forum to not only engineers, scientists, and researchers, but also practitioners, planners, managers, administrators, and policy-makers from around the world for discussion of problems pertaining to water, environment, and energy that are vital for the sustenance and development of society.

Second, the Government of India has embarked upon two large projects: one on cleaning of River Ganga and the other on cleaning River Yamuna. Further, it is allocating large funds for irrigation projects with the aim to bring sufficient good-quality water to all farmers. These are huge ambitious projects and require consideration of all aspects of water, environment, and energy as well as society, including economics, culture, religion, politics, administration, law, and so on.

Third, when water resources projects are developed, it is important to ensure that these projects achieve their intended objectives without causing deleterious environmental consequences, such as water logging, salinization, loss of wetlands, sedimentation of reservoirs, loss of biodiversity, etc.

Fourth, the combination of rising demand for water and increasing concern for environmental quality compels that water resources projects are planned, designed, executed and managed, keeping changing conditions in mind, especially climate change and social and economic changes.

Fifth, water resources projects are investment intensive and it is therefore important to take a stock of how the built projects have fared and the lessons that can be learnt so that future projects are even better. This requires an open and frank discussion among all sectors and stakeholders.

Sixth, we wanted to reinforce that water, environment, energy, and society constitute a continuum and water is central to this continuum. Water resources projects are therefore inherently interdisciplinary and must be so dealt with.

Seventh, a conference like this offers an opportunity to renew old friendships and make new ones, exchange ideas and experiences, develop collaborations, and enrich ourselves both socially and intellectually. We have much to learn from each other.

Now the question may be: Why India and why Bhopal? India has had a long tradition of excellence spanning several millennia in the construction of water resources projects. Because of her vast size, high climatic variability encompassing six seasons, extreme landscape variability from flat plains to the highest mountains in the world, and large river systems, India offers a rich natural laboratory for water resources investigations.

India is a vast country, full of contrasts. She is diverse yet harmonious, mysterious yet charming, old yet beautiful, ancient yet modern. Nowhere we can find mountains as high as the snow-capped Himalayas in the north, the confluence of three seas and large temples in the south, long and fine sand beaches in the east as well as architectural gems in the west. The entire country is dotted with unsurpassable monuments, temples, mosques, palaces, and forts and fortresses that offer a glimpse of India's past and present.

Bhopal is located in almost the center of India and is situated between Narmada River and Betwa River. It is a capital of Madhya Pradesh and has a rich, several century-long history. It is a fascinating amalgam of scenic beauty, old historic city, and modern urban planning. All things considered, the venue of the conference could not have been better.

We received an overwhelming response to our call for papers. The number of abstracts received exceeded 450. Each abstract was reviewed and about two thirds of them, deemed appropriate to the theme of the conference, were selected. This led to the submission of about 300 full-length papers. The subject matter of the papers was divided into more than 40 topics, encompassing virtually all major aspects of water and environment as well energy. Each topic comprised a number of contributed papers and in some cases state-of-the-art papers. These papers provided a natural blend to reflect a coherent body of knowledge on that topic.

The papers contained in this volume, "Energy and Environment," represent one part of the conference proceedings. The other parts are embodied in six companion volumes entitled, "Hydrologic Modelling," "Groundwater," "Environmental Pollution," "Water Quality Management," "Climate Change Impacts," and "Water Resources Management." Arrangement of contributions in these seven books was a natural consequence of the diversity of papers presented at the conference and the topics covered. These books can be treated almost independently, although significant interconnectedness exists among them.

This volume contains seven parts organized under two sections. The first section deals with environment containing four parts, whereas the second section, containing three parts, is on energy. Part I deals with some aspects of hydrologic impacts of global warming and anthropogenic changes. Part II is on bio-environment and discusses plants, biomass, and bacterial species. Part III focuses on chemical environment. Section one is concluded with Part IV on social environment. Section two starts out with Part V on solar energy. Hydropower is discussed in Part VI. The concluding Part VII deals with biogas.

The book will be of interest to researchers and practitioners in the field of water resources, hydrology, environmental resources, agricultural engineering, watershed management, earth sciences, as well as those engaged in natural resources planning and management. Graduate students and those wishing to conduct further research in water and environment and their development and management may find the book to be of value.

WEES-16 attracted a large number of nationally and internationally well-known people who have long been at the forefront of environmental and water resources education, research, teaching, planning, development, management, and practice. It is hoped that long and productive personal associations and friendships will be developed as a result of this conference.

College Station, USA — Vijay P. Singh, Conference Chair
Bhopal, India — Shalini Yadav, Conference Organizing Secretary
Hazaribagh, India — Ram Narayan Yadava, Conference Co-Chair

Acknowledgements

We express our sincere gratitude to Shri Santosh Choubey, Chancellor, and Dr. V.K. Verma, Vice Chancellor, Board of Governing Body, and Board of Management of the AISECT University, Bhopal, India, for providing their continuous guidance and full organizational support in successfully organizing this international conference on Water, Environment, Energy and Society on the AISECT University campus in Bhopal, India.

We are also grateful to the Department of Biological and Agricultural Engineering, and Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas, USA, and International Centre of Excellence in Water Management (ICE WaRM), Australia, for their institutional cooperation and support in organizing the ICWEES-2016.

We wish to take this opportunity to express our sincere appreciation to all the members of the Local Organization Committee for helping with transportation, lodging, food, and a whole host of other logistics. We must express our appreciation to the Members of Advisory Committee, Members of the National and International Technical Committees for sharing their pearls of wisdom with us during the course of the Conference.

Numerous other people contributed to the conference in one way or another, and lack of space does not allow us to list all of them here. We are also immensely grateful to all the invited Keynote Speakers, and Directors/Heads of Institutions for supporting and permitting research scholars, scientists and faculty members from their organizations for delivering keynote lectures and participating in the conference, submitting and presenting technical papers. The success of the conference is the direct result of their collective efforts. The session chairmen and co-chairmen administered the sessions in a positive, constructive, and professional manner. We owe our deep gratitude to all of these individuals and their organizations.

We are thankful to Shri Amitabh Saxena, Pro-Vice Chancellor, Dr. Vijay Singh, Registrar, and Dr. Basant Singh, School of Engineering and Technology, AISECT University, who provided expertise that greatly helped with the conference organization. We are also thankful to all the Heads of other Schools, Faculty Members and Staff of the AISECT University for the highly appreciable assistance in different organizing committees of the conference. We also express our sincere thanks to all the reviewers at national and international levels who reviewed and moderated the papers submitted to the conference. Their constructive evaluation and suggestions improved the manuscripts significantly.

Sponsors and Co-sponsors

The International Conference on Water, Environment, Energy and Society was Jointly organized by the AISECT University, Bhopal (M.P.), India and Texas A&M University, Texas, USA in association with ICE WaRM, Adelaide, Australia. It was partially supported by the International Atomic Energy Agency (IAEA), Vienna, Austria; AISECT University, Bhopal; M.P. Council of Science and Technology (MPCOST); Environmental Planning and Coordination Organization (EPCO), Government of Madhya Pradesh; National Bank for Agriculture and Rural Development (NABARD), Mumbai; Maulana Azad National Institute of Technology (MANIT), Bhopal; and National Thermal Power Corporation (NTPC), Noida, India. We are grateful to all these sponsors for their cooperation and providing partial financial support that led to the grand success to the ICWEES-2016.

Contents

Part VII Energy: Biogas

About the Editors

Prof. Vijay P. Singh is University Distinguished Professor, Regents Professor, and the inaugural holder of the Caroline and William N. Lehrer Distinguished Chair in Water Engineering in the Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering at Texas A&M University. He received his B.S., M.S., Ph.D., and D.Sc. degrees in engineering. He is a registered professional engineer, a registered professional hydrologist, and an Honorary Diplomate of American Academy of Water Resources Engineers.

Professor Singh has extensively published the results of an extraordinary range of his scientific pursuits. He has published more than 900 journal articles; 25 textbooks; 60 edited reference books, including the massive Encyclopedia of Snow, Ice and Glaciers and Handbook of Applied Hydrology; 104 book chapters; 314 conference papers; and 72 technical reports in the areas of hydrology, ground water, hydraulics, irrigation engineering, environmental engineering, and water resources.

For his scientific contributions to the development and management of water resources and promoting the cause of their conservation and sustainable use, he has received more than 90 national and international awards and numerous honors, including the Arid Lands Hydraulic Engineering Award, Ven Te Chow Award, Richard R. Torrens Award, Norman Medal, and EWRI Lifetime Achievement Award, all given by American Society of Civil Engineers; Ray K. Linsley Award and Founder's Award, given by American Institute of Hydrology; Crystal Drop Award, given by International Water Resources Association; and Outstanding Distinguished Scientist Award given by Sigma Xi, among others. He has received three honorary doctorates. He is a Distinguished Member of ASCE, and a fellow of EWRI, AWRA, IWRS, ISAE, IASWC, and IE and holds membership in 16 additional professional associations. He is a fellow/member of 10 international science/engineering academies. He has served as President and Senior Vice President of the American Institute of Hydrology (AIH). Currently he is editor-in-chief of two book series and three journals and serves on editorial boards of 20 other journals.

Professor Singh has visited and delivered invited lectures in all most all parts of the world but just a sample: Switzerland, the Czech Republic, Hungary, Austria, India, Italy, France, England, China, Singapore, Brazil, and Australia.

Prof. Shalini Yadav is Professor and Head of the Department of Civil Engineering, AISECT University, Bhopal, India. Her research interests include solid and hazardous waste management, construction management, environmental quality and water resources. She has executed a variety of research projects/consultancy in Environmental and Water Science and Technology and has got rich experience in Planning, formulating, organizing, executing and management of R&D programs, seminars, and conferences at national and international levels. She has got to her credit guiding an appreciable number of M.Tech. and Ph.D. students. She has published more than 10 journal articles and 30 technical reports. Dr. Shalini has also visited and delivered invited lectures at different institutes/universities in India and abroad, such as Australia, South Korea, and Kenya.

Professor Shalini Yadav graduated with a B.Sc. in Science from the Bhopal University. She earned her M.Sc. in Applied Chemistry with a specialization in Environmental Science from Bhopal University and M.Tech. in Civil Engineering with a specialization in Environmental Engineering from Malaviya National Institute of Technology, Jaipur, India in 2000. Then she pursued the degree of Ph.D. in Civil Engineering from Rajiv Gandhi Technical University, Bhopal, India in 2011. Also, she is a recipient of national fellowships and awards. She is a reviewer for many international journals. She has been recognized for one and half decades of leadership in research, teaching, and service to the Environmental Engineering Profession.

Dr. Ram Narayan Yadava holds the position of Vice Chancellor of the AISECT University, Hazaribagh, Jharkhand. His research interests include solid mechanics, environmental quality and water resources, hydrologic modeling, environmental sciences and R&D planning and management. Yadava has executed a variety of research/consultancy projects in the area of water resources planning and management, environment, remote sensing, mathematical modeling, technology forecasting, etc.

He has got adequate experience in establishing institutes/organizations, planning, formulating, organizing, executing and management of R&D programs, seminars, symposia, conferences at national and international level. He has got to his credit guiding a number of M.Tech. and Ph.D. students in the area of mathematical sciences and Earth sciences. Dr. Yadava has visited and delivered invited lectures at different institutes/universities in India and abroad, such as USA, Canada, United Kingdom, Thailand, Germany, South Korea, Malaysia, Singapore, South Africa, Costa Rica, and Australia.

He earned an M.Sc. in Mathematics with a specialization in Special Functions and Relativity from Banaras Hindu University, India in 1970 and a Ph.D. in Mathematics with specialization in Fracture Mechanics from Indian Institute of Technology, Bombay, India, in 1975. Also, he is a recipient of Raman Research

Fellowship and other awards. Dr. Yadava has been recognized for three and half decades of leadership in research and service to the hydrologic and water resources profession. Dr. Yadava's contribution to the state of the art has been significant in many different specialty areas, including water resources management, environmental sciences, irrigation science, soil and water conservation engineering, and mathematical modeling. He has published more than 90 journal articles; 4 textbooks; 7 edited reference books.

Part I
Environment: Hydrologic Impacts

Structural Evaluation of Cell-Filled Pavement

Subrat Roy and K.K. Pathak

Abstract This paper describes the findings of a study carried out for evaluating the performance of cell-filled pavement for low-volume roads. Details of laboratory investigations and the methodology adopted for construction of cell-filled pavement are presented. The aim of this study is to evaluate the structural behavior of cement concrete filled cell pavement laid over three different types of subbases (Water-bound macadam, soil–cement and moorum). A formwork of cells of thin plastic sheet was used to construct the cell-filled pavements to form flexible, interlocked block pavements. Surface deflections were measured using falling weight deflectometer and benkelman beam methods. Resilient moduli of pavement layers were estimated from the measured deflections. A comparison of deflections obtained from both the methodologies is also presented.

Keywords Cell-filled pavement · Low-volume roads · Falling weight deflectometer · Moorum

Introduction

Many states in India face the problem of scarcity of road quality aggregates and sand. Cost of aggregates escalated due to different restrictions enforced on the quarrying industry. In many places, carriage cost of aggregates and sand is very high resulting in high cost of construction of roads. Conventional flexible pavements for village roads consist of granular subbase and base with a wearing course of thin bituminous layer. The thick layers of granular base and subbase use significant quantities of aggregates. Traditional flexible pavements require regular maintenance which has been found to be difficult in the absence of adequate funds

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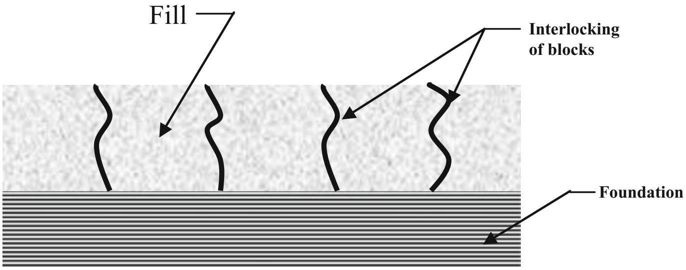

Fig. 1 Schematic representation of deformed plastic cells

and proper guidelines in the case of village roads. Therefore, it is necessary to explore alternative types of pavements that can be constructed using locally available materials and which require less frequent maintenance.

The concept of cell-filled pavement was developed in South Africa (Visser 1994; Visser and Hall 1999, 2003). Cell-filled pavement consists of a formwork of cells of plastic sheet laid over a compacted subbase. The form work of cells is stretched on the carriageway and held in position with the help of steel pegs driven into the base at suitable locations. Figure 1 shows the schematic arrangement of a formwork of cells stretched over a base. Cement-bound materials are filled into the cells and compacted. During compaction, cell walls get deformed and provide interlocking vertical joints between the blocks as illustrated in Fig. 1.

Due to the relatively larger flexibility of the cast in situ block pavements in comparison to rigid (concrete) pavements, these are termed as flexible-concrete pavements (Visser and Hall 1999). The present study aims at investigating the cell-filled pavement layers laid over different types of subbases.

Three test sections, each of 2.5 m × 2.5 m size, were constructed inside the IIT Kharagpur campus as per the following details.

- 100 mm thick roller compacted concrete filled cell pavement laid over 150 mm thick moorum subbase.
- 100 mm thick roller compacted concrete filled cell pavement laid over 150 mm thick water-bound macadam (WBM) subbase.
- 100 mm thick roller compacted concrete filled cell pavement laid over 150 mm thick soil–cement subbase.

Roller compacted concrete (RCC) is a stiff low water mix concrete compacted using a roller. Because of its low water cement ratio, RCC typically has high strength similar to or even greater than conventional concrete. Surface deflections of the test sections were measured using Falling Weight Deflectometer and Benkelman beam methods. Effective moduli of cell-filled pavement layers were back calculated. A comparison of deflections obtained from both the methodology is also presented.

Material Used for Construction of Pavements

Plastic Cell

Polyethylene sheet of 200 µm thickness, readily available in the market, was used for preparing the formwork of cells of 150 mm × 150 mm size. Depth of formwork was maintained as 100 mm in accordance with the proposed thickness of cell-filled layer. Strips of polyethylene sheets were heat-welded at appropriate locations to fabricate the formwork of cells.

Cement

Portland slag cement meeting the requirement of IS 455 (1989) was used for preparing the cement concrete and for stabilizing soil.

Soil and Moorum

Properties of the soil and moorum used are presented in Table 1.

Crushed Aggregate for Surface Layer

Crushed aggregates collected from Rampurhat in the state of West Bengal were used for preparing cement concrete. The coarse and fine aggregates were blended and the combined gradation adopted for roller compacted concrete (RCC) is shown in Table 2 (MORD 2004).

Table 1 Properties of soil and moorum

S. No.	Property	Value		Procedure followed
		Soil	Moorum	
1	Optimum moisture content	13.8%	10.3%	IS 2720—Part 7 (1980)
2	Maximum dry density	1940 kg/m^3	2136 kg/m^3	IS 2720—Part 7 (1980)
3	CBR			IS 2720—Part 16 (1987)
	Soaked (4 day)	7.8%	21.87%	
	Unsoaked	10.5%	28.6%	

Table 2 Aggregate gradation adopted for RCC

Sieve size (mm)	Percent passing by weight (%)
26.5	100
19.0	80–100
9.5	55–75
4.75	35–60
0.600	10–35
0.075	0–8

Crushed Aggregate for WBM Subbase

Crushed aggregates collected from Rampurhat in the state of West Bengal were used for water-bound macadam (WBM) subbase course. Gradations of coarse aggregates and screenings are given in Tables 3 and 4 respectively.

Soil–Cement Mix for Subbase Layer

Unconfined compressive strength and durability were the two criteria considered for the design of soil–cement mix. Unconfined compressive strength test was conducted under static axial loading condition on cylindrical specimens at a constant strain rate of 1.25 mm/min as per IS 4332-Part 5 (1970). Results of unconfined compression strength tests are given in Table 5.

To evaluate the durability of soil–cement mix, wetting and drying test was conducted on cylindrical specimens of 50 mm diameter and 100 mm height prepared using 5, 10, 15% cement contents and cured for 28 days. The test was performed according to ASTM D599 (2003). The specimens with 5% cement content crumbled in the first cycle. However, the specimens with 10 and 15%

Table 3 Aggregate gradation adopted for WBM base

Sieve size (mm)	Percent passing by weight (%)
63	100
53	95–100
45	85–90
22.4	0–10
11.2	0–5

Table 4 Gradation for screenings

Sieve size (mm)	Percent passing by weight (%)
11.2	100
5.6	90−100
0.180	15–35

Table 5 Unconfined compressive strength test results

Cement content (%)	Curing period (days)	Average unconfined compressive strength (mPa)
5	7	2.1
5	28	3.0
10	7	3.8
10	28	6.0
15	7	4.5
15	28	8.1

cement contents showed good results. The average material loss of the specimens with 10 and 15% cement content was 0.8 and 0.4% respectively after 12 cycles.

The British requirement for soil–cement stipulates minimum unconfined compression strength of 2.8 mPa to cater to heavy traffic requirement (Noor Megat 1994). Canadian Portland Cement Association recommended a maximum allowable loss of 7% for clay soil and 10% for silt soil (Noor Megat 1994). For the present investigation, soil–cement mix with 10% cement content was considered as it satisfied both the strength and durability criteria.

Mix Composition and Strength of Cement Concrete

Roller Compacted Concrete

A minimum compressive strength of 30 mPa is desirable for concrete block for village roads (MORD 2004). Cement, sand and coarse aggregates were taken in the proportion of 1:1.25:2.5 by volume since volume batching is convenient in remote villages. The optimum moisture content for concrete mix was obtained as five percent by weight of total weight of coarse aggregates, fine aggregates and cement (MORD 2004). Concrete cubes of dimension 150 mm × 150 mm × 150 mm were cast and their 28-day compressive strength was determined in the laboratory. Average 28 day compressive strength was obtained as 38.6 mPa.

Construction of Test Sections

Three test sections with different base materials were constructed in front of Vikram Sarabhai Complex inside Indian Institute of Technology, Kharagpur campus. Length and width of each section are 2.5 and 2.5 m, respectively.

Preparation of Subgrade

One of the earthen shoulders of the service road in front of Vikram Sarabhai Complex was excavated to prepare the test sections. 7.5 m long, 2.5 m wide trench was excavated for this purpose. Average depth of excavation was 300 mm. The trench was backfilled with selected soil and was compacted at optimum moisture content by 80 kN static roller in two layers of 150 mm thickness each. The field density of subgrade soil was determined by core cutter method as per IS 2720—Part 24 (1975). Cores were taken from three locations. Average field dry density and moisture content of subgrade were found to be 1830 kg/m^3 and 11.4% respectively. The degree of compaction achieved was close to 95% of standard proctor compaction (1940 kg/m^3).

Construction of Subbase

Local soil was used for preparation of soil–cement subbase. 10% Cement was added to soil and mixed at optimum moisture content. After mixing, it was spread on the prepared subgrade to the required depth and rolled with 80 kN static roller. The compacted surface was kept under moist condition for 14 days using wet jute gunny mats. WBM subbase was laid on the prepared subgrade to required thickness and rolled with 80 kN static roller. MORTH procedure and specifications were adopted for the construction of WBM base. Moorum was laid on the subgrade to the required thickness and rolled with 80 kN static roller. Optimum moisture content was used for preparing moorum subbase.

Construction of Surface Layer

Formwork of plastic cells of size 2.5 m × 2.5 m was stretched over the carriage way. Steel pegs and clips were used to hold the cell walls vertical. Test sections were constructed using roller compacted concrete. Cement concrete, prepared in a concrete mixture was placed manually inside the plastic cells. Compaction of the layer was done using 80 kN static roller. Curing was done for 14 days using wet jute gunny mats.

Structural Evaluation of Cell-Filled Pavement

Using Falling Weight Deflectometer

The three pavement sections were structurally evaluated using a Falling Weight Deflectometer developed by IIT Kharagpur. FWD was positioned in such a way that the loading plate is in the interior of the 2.5 m × 2.5 m test section. Deflections were measured at five radial distances (0, 300, 600, 900 and 1200 mm) from the center of the pavement section. Deflections were normalized to a load of 41 kN. Deflection data obtained for the three pavement sections are given in Table 6.

Elastic moduli of pavement layers were estimated from the deflection data given in Table 6 using BACKGA, a genetic algorithm based back calculation software developed at IIT Kharagpur (Reddy et al. 2002). The program uses linear elastic layered theory for computation of surface deflections. Layer thicknesses, surface deflections measured at radial distances of 0, 300, 600, 900 and 1200 mm, Poisson ratio values of the pavement layers and loading details were the main inputs for BACKGA. The following GA parameters were used for the analysis.

Population size = 60, Maximum number of generations = 60, Probability of crossover = 0.74, Probability of mutation = 0.1.

The back calculated moduli are given in Table 7.

Using Benkelman Beam

The pavement sections were also evaluated using Benkelman beam method. This was done for the purpose of comparing the deflection data obtained from FWD with those obtained using Benkelman beam which is a relatively simple procedure commonly adopted in India for structural evaluation of pavements. The probe of the beam was positioned in the middle of the 2.5 m × 2.5 m pavement section. A truck

Table 6 Measured deflection data from FWD

S. No.	Layer combinations	Deflection measurement (mm) at a radial distance (mm) of				
		0	300	600	900	1200
1	100 mm RCC 150 mm M	0.5940	0.3009	0.1568	0.0721	0.0433
2	100 mm RCC 150 mm WBM	0.5636	0.3561	0.2063	0.1021	0.0665
3	100 mm RCC 150 mm SC	0.3944	0.2454	0.1920	0.1140	0.0685

RCC Roller compacted concrete, *SC* soil–cement, *M* moorums
WBM Water-bound macadam

Table 7 Backcalculated layer moduli

S. No.	Layer combinations	Elastic modulus (mPa)		
		Cell-filled layer	Base	Subgrade
1	100 mm RCC 150 mm M	3025	152	95
2	100 mm RCC 150 mm WBM	2501	159	101
3	100 mm RCC 150 mm SC	4077	660	91

loaded with bricks with a rear axle load of 82 kN was used for deflection survey. The truck was made to move away from its initial position at creep speed and the rebound deflection was measured at 300 mm intervals. Different load positions of dual wheel considered in the investigation are shown in Fig. 2. All the dial gauge readings were taken with the probe of the beam placed at point A. When the wheel was at position A, initial reading was taken. When the wheel moved to subsequent points, corresponding readings were noted. Near-complete rebound of deflection was obtained when the load moved to a distance of 1.2 m (position E). Shape of the deflection bowl was deduced from these readings. Deflections obtained for different test sections as per this procedure are given in Table 8.

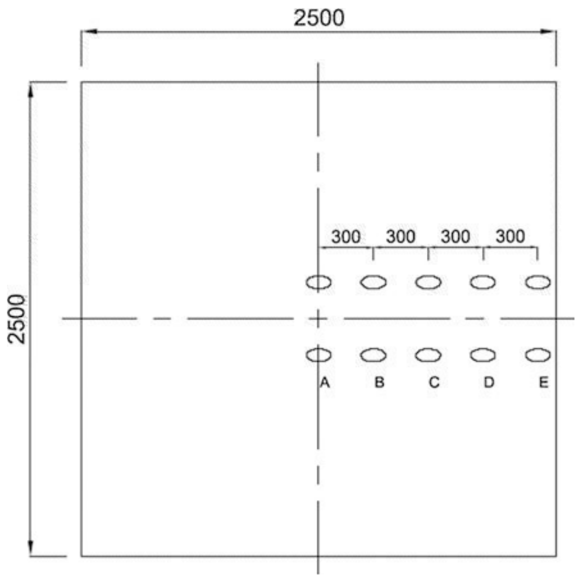

Fig. 2 Different load positions considered for deflection measurement

Table 8 Measured deflection data from Benkelman beam

S. No.	Layer combinations	Deflection measurement (mm) at a radial distance (mm) of				
		0	300	600	900	1200
1	100 mm RCC 150 mm M	0.8382	0.6604	0.3725	0.1863	0.0623
2	100 mm RCC 150 mm WBM	0.6953	0.3937	0.2286	0.1143	0.0781
3	100 mm RCC 150 mm SC	0.5956	0.2616	0.2008	0.1208	0.0772

Comparison of Deflections Measured Using Benkelman Beam Method and FWD

Comparison of deflections measured using Benkelman beam method and FWD on pavement sections is presented in Fig. 3. It can be observed from the figures that for most of the pavement sections, deflections obtained using Benkelman beam method is larger than those obtained using FWD. It is mainly due to the lower moduli of pavement layers under static/creep loading condition adopted in Benkelman beam method.

Fig. 3 Comparison of deflections radial distance (mm)