Vasant Matsagar *Editor*

Advances in Structural Engineering

Materials, Volume Three

Springer

Vasant Matsagar
Editor

Advances in Structural Engineering

Materials, Volume Three

Springer

Editor
Vasant Matsagar
Department of Civil Engineering
Indian Institute of Technology (IIT) Delhi
New Delhi, Delhi
India

ISBN 978-81-322-2186-9 ISBN 978-81-322-2187-6 (eBook)
DOI 10.1007/978-81-322-2187-6

Library of Congress Control Number: 2014955611

Springer New Delhi Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer (India) Pvt. Ltd. is part of Springer Science+Business Media (www.springer.com)

Foreword

Structural Engineering Convention (SEC-2014) is organised by IIT Delhi at Delhi during 22–24 December 2014. Its proceedings are published in three volumes. The first and second volumes contain papers dealing with the themes of Mechanics of Structures and Structural Dynamics, respectively. The present third volume contains research papers dealing with Structural Materials and Structural Behaviour.

On Structural Materials

In contrast to plant-manufactured materials like steel and cement, and naturally occurring materials like wood, concrete is designed and produced by civil engineers in the concrete plants or even at the construction site itself. Designing concrete mixes for achieving the specified strength, durability and economy requires considerable knowledge about the physical, chemical and mechanical properties of concrete. Perhaps, this is why most of the papers on structural materials presented here deal with concrete and its constituent materials.

Extended cost–benefit analysis of infrastructural projects demands that their negative environmental impacts should be included in the estimation of their costs. On this score, energy-intensive process of cement manufacture is known to make substantial contribution to global warming. Use of waste pozzolanic mineral matter as part replacement of cement for producing concrete is credited to be an attempt towards reducing such negative impacts. In this context, geopolymers promise to be a substitute for cement in concrete. Geopolymers are composed of alkali-activated silicon molecular chains similar to carbon-based polymers. As in the case of cement hydration, polymerisation of geopolymers results in the development of cohesive and adhesive properties. These papers deal with the mix design and properties of geopolymer materials and its applications in concrete structures and masonry blocks. For achieving the same purpose, search is on for cement clinker

replacements. Of course, research on the pozzolanic cement concrete continues. Because of their environmental friendliness, 10 papers are devoted to the production and properties of these materials.

It is worth remembering that the consumption of aggregate in concrete is about three to four times that of the cement. This is why their continued availability in the coming decades is a matter of concern. Many potential substitutes for the currently popular crushed aggregate have been explored. These substitutes include river and marine sand, quarry dust, marble powder, recycled aggregate, demolished concrete, rubber particles, polyethylene terephthalate (PET) granules, etc. Some papers in these proceedings deal with these alternatives to aggregates in concrete.

Fibre-reinforced concretes (FRC) exhibit higher impact resistance and better cracking control. Here, some papers explore the effectiveness of biofibres, polypropylene and nanocarbon fibres in addition to the more popular steel and glass fibres. Bamboo concrete has also been explored as an alternative structural material.

About seven papers report investigations dealing with the durability of concrete and corrosion of rebars. Chemically deteriorating effect of sea water, rain, etc., on the properties of concretes containing high-volume fly ash and rice husk ash, high strength concrete and fibrous mortars is investigated. Also, the vulnerability of reinforcement steel bars to corrosion on exposure to marine as well as to chloride and sulphate-bearing ambient environment is delineated. A model for the prediction of service life of concrete structures is also presented.

Mix design procedures for pozzolanic, high performance, fibrous and self-compacting concrete are continuously being upgraded. Of course, new concrete constituents like geopolymers, aggregate substitutes and fibres demand the acquisition of the required empirical database as well as the development of appropriate concrete mix design procedures. Most of these papers present the results of experimental investigations. The absence of any papers on the constitutive models simulating the damage, elastoplastic, viscoelastic and viscoplastic response of concrete is noted.

On Structural Behaviour

Perhaps, because of considerable seismic risk to public life and property, the discipline of structural dynamics is dominated by seismic analysis and design. This observation is confirmed by the almost total absence of the papers, in this conference, on the other sources of dynamic loading on structures. It is well known that the classical theory of linear elastic vibrations is not valid for nonlinear elastoplastic concrete structures. Because of the complexity of seismic behaviour of concrete structures, the present methods of their seismic analysis and design are predominantly empirical–computational in nature. Many papers, about one-third of those on structures, in this volume are devoted to their static, quasi-static and dynamic response.

Structural performance of concrete non-ductile frames as well as frames with infills and shear walls is investigated. Static response of concrete structures with welded rebars, shear-deficient concrete beams, fibre-reinforced concrete beams, partially prestressed concrete, slabs, precast structures, etc., is reported. Pushover analysis as an essential input to seismic analysis is presented. Effect of exposure to elevated temperatures or fire is determined. Behaviour of precast member connections and concrete members under fatigue and load reversal is also investigated. The effectiveness of metallic dampers in enhancing the lateral capacity is evaluated. The progressive collapse of buildings and the cyclic response of concrete shear walls are presented. One paper each is devoted to the determination of the natural period of infilled concrete frames and to the dynamic stability of concrete beam columns. Effect of buoyancy on rafts of a building with five basements is determined. At least 15 papers report their findings on these issues.

Failure of concrete frames is catastrophic when it is triggered by the column failure than by beam failure. Perhaps, this is why there are about four papers on the performance of concrete columns. Most of these papers deal with the behaviour of concrete-filled steel tube (CFST) columns. Tension stiffening in torsion as well as cyclic behaviour of reinforced concrete (RC) columns is also studied.

Concrete structures partially damaged by moderate earthquakes need to be strengthened or retrofitted. Also, structures may have to be strengthened to satisfy the more stringent design requirements of the revised design code or to enhance their load carrying capacity. Such retrofitting is carried out by jacketing the structural members with glass or carbon fibre-reinforced plastic (GFRP or CFRP) sheets. The bond–slip relations for such FRP sheets have been studied. The performance of the FRP columns and beams in flexure and shear is evaluated. One-way spiral ties and ultra-high performance concrete overlay have been explored for retrofitting. Also, the effectiveness of glass reinforced plastic fibre (GRPF) rebars as potential replacement for steel rebars is evaluated. Nine papers are devoted to search for effective retrofitting measures.

Behaviour of steel and masonry structures beyond the linear elastic range is not so well understood. The effectiveness of braced steel frames in enhancing their seismic resistance is evaluated. Other problems dealt with here include stress concentration in tubular member connections, fatigue life of welded and bolted connections, complex behaviour of fillet welds, etc. Strength values exhibited by LDSS columns with different section details are compared. Low-cycle fatigue resistance and fatigue-induced damage of bridges upon overloading as well as performance of FRP-strengthened bridges are evaluated. Performance of concrete block masonry, compressed earth blocks, rammed earth columns and soft brick and strong mortar masonry is reported. In-plane and out-of-plane behaviour of masonry walls is explored. Seven and five papers are devoted to steel and masonry structures, respectively. A paper is presented which identifies the challenges posed by the tall buildings to the profession.

Uncertainties in the structural properties as well as the loading details demand probability-based approaches to structural analysis and design. Risk and confidence levels associated with even well-designed structures are to be evaluated. Reliability

analysis may demand stochastic simulation. An attempt to establish the relation between the damage index and fragility curve of concrete structures is reported. The reliability of petroleum and geotechnical structures is reported. About five papers address these research issues.

Considerable research attention is currently being focused on the development of economical non-destructive testing (NDT) methods for evaluating the performance of structures. Vibration-based as well as wave-based methods are being developed for the purpose of damage detection and structural health monitoring. Sensitivity of piezo material lead zirconate titanate (PZT) patches is determined. New areas, like piezoelectric energy harvesting, beyond structural engineering are being explored. Degradation of concrete strength upon exposure to fire can be quantified by using NDT methods.

Dr. Gurmail S. Benipal
Associate Professor
Department of Civil Engineering
Indian Institute of Technology (IIT)
Hauz Khas, New Delhi, India

Preface

I am delighted that the Department of Civil Engineering, Indian Institute of Technology (IIT) Delhi has hosted the eagerly awaited and much coveted 9th Structural Engineering Convention (SEC2014). The biennial convention has attracted a diverse range of civil and structural engineering practitioners, academicians, scholars and industry delegates, with the reception of abstracts including more than 1,500 authors from different parts of the world. This event is an exceptional platform that brings together a wide spectrum of structural engineering topics such as advanced structural materials, blast resistant design of structures, computational solid mechanics, concrete materials and structures, earthquake engineering, fire engineering, random vibrations, smart materials and structures, soil-structure interaction, steel structures, structural dynamics, structural health monitoring, structural stability, wind engineering, to name a few. More than 350 full-length papers have been received, among which a majority of the contributions are focused on theoretical and computer simulation-based research, whereas a few contributions are based on laboratory-scale experiments. Amongst these manuscripts, 205 papers have been included in the Springer proceedings after a thorough three-stage review and editing process. All the manuscripts submitted to the SEC2014 were peer-reviewed by at least three independent reviewers, who were provided with a detailed review proforma. The comments from the reviewers were communicated to the authors, who incorporated the suggestions in their revised manuscripts. The recommendations from three reviewers were taken into consideration while selecting a manuscript for inclusion in the proceedings. The exhaustiveness of the review process is evident, given the large number of articles received addressing a wide range of research areas. The stringent review process ensured that each published manuscript met the rigorous academic and scientific standards. It is an exalting experience to finally see these elite contributions materialise into three book volumes as SEC2014 proceedings by Springer entitled "Advances in Structural Engineering". The articles are organised into three volumes in some broad categories covering subject matters on mechanics, dynamics and

materials, although given the diverse areas of research reported it might not have been always possible.

SEC2014 has ten plenary speakers, who are eminent researchers in structural engineering, from different parts of the world. In addition to the plenary sessions on each day of the convention, six concurrent technical sessions are held every day to assure the oral presentation of around 350 accepted papers. Keynote speakers and session chairmen for each of the concurrent sessions have been leading researchers from the thematic area of the session. The delegates are provided with a book of extended abstracts to quickly browse through the contents, participate in the presentations and provide access to a broad audience of educators.

A technical exhibition is held during all the 3 days of the convention, which has put on display the latest construction technologies, equipment for experimental investigations, etc. Interest has been shown by several companies to participate in the exhibition and contribute towards displaying state-of-the-art technologies in structural engineering. Moreover, a pre-convention international workshop organised on "Emerging Trends in Earthquake Engineering and Structural Dynamics" for 2 days has received an overwhelming response from a large number of delegates.

An international conference of such magnitude and release of the SEC2014 proceedings by Springer has been the remarkable outcome of the untiring efforts of the entire organising team. The success of an event undoubtedly involves the painstaking efforts of several contributors at different stages, dictated by their devotion and sincerity. Fortunately, since the beginning of its journey, SEC2014 has received support and contributions from every corner. I thank them all who have wished the best for SEC2014 and contributed by any means towards its success. The edited proceedings volumes by Springer would not have been possible without the perseverance of all the committee members.

All the contributing authors owe thanks from the organisers of SEC2014 for their interest and exceptional articles. I also thank the authors of the papers for adhering to the time schedule and for incorporating the review comments. I wish to extend my heartfelt acknowledgment to the authors, peer-reviewers, committee members and production staff whose diligent work put shape to the SEC2014 proceedings. I especially thank our dedicated team of peer-reviewers who volunteered for the arduous and tedious step of quality checking and critique on the submitted manuscripts. I am grateful to Prof. Tarun Kant, Prof. T.K. Datta and Dr. G.S. Benipal for penning the forewords for the three volumes of the conference proceedings. I wish to thank my faculty colleagues at the Department of Civil Engineering, Indian Institute of Technology (IIT) Delhi, and my Ph.D. Research Scholars for extending their enormous assistance during the reviewing and editing process of the conference proceedings. The time spent by all of them and the midnight oil burnt is greatly appreciated, for which I will ever remain indebted. The administrative and support staff of the department has always been extending their services whenever needed, for which I remain thankful to them. Computational

laboratory staff of the department had handled the online paper submission and review processes, which hardly had any glitch therein; thanks to their meticulous efforts.

Lastly, I would like to thank Springer for accepting our proposal for publishing the SEC2014 conference proceedings. Help received from Mr. Aninda Bose, the acquisition editor, in the process has been very useful.

Vasant Matsagar
Organising Secretary, SEC2014

About the Editor

Dr. Vasant Matsagar is currently serving as an Associate Professor in the Department of Civil Engineering at Indian Institute of Technology (IIT) Delhi. He obtained his doctorate degree from Indian Institute of Technology (IIT) Bombay in 2005 in the area of seismic base isolation of structures. He performed post-doctoral research at the Lawrence Technological University (LTU), USA in the area of carbon fibre reinforced polymers (CFRP) in bridge structures for more than 3 years. His current research interests include structural dynamics and vibration control; multi-hazard protection of structures from earthquake, blast, fire, and wind; finite element methods; fibre reinforced polymers (FRP) in prestressed concrete structures; and bridge engineering. He has guided students at both undergraduate and post-graduate levels in their bachelor's and master's projects and doctoral research. Besides student guidance, he is actively engaged in sponsored research and consultancy projects at national and international levels. He has published around 40 international journal papers, 60 international conference manuscripts, a book, and has filed for patents. He is also involved in teaching courses in structural engineering, e.g. structural analysis, finite element methods, numerical methods, structural stability, structural dynamics, design of steel and concrete structures, to name a few. He has organised several short- and long-term courses as quality improvement programme (QIP) and continuing education programme (CEP), and delivered invited lectures in different educational and research organisations.

Dr. Matsagar is the recipient of numerous national and international awards including "Erasmus Mundus Award" in 2013; "DST Young Scientist Award" by the Department of Science and Technology (DST) in 2012; "DAAD Awards" by the Deutscher Akademischer Austausch Dienst (DAAD) in 2009 and 2012; "DAE Young Scientist Award" by the Department of Atomic Energy (DAE) in 2011; "IBC Award for Excellence in Built Environment" by the Indian Buildings Congress (IBC) in 2010; "IEI Young Engineer Award" by the Institution of Engineers (India) in 2009; and "Outstanding Young Faculty Fellowship" by the Indian Institute of Technology (IIT) Delhi in 2009. He has also been appointed as "DAAD Research Ambassador" by the German Academic Exchange Programme since the academic session 2010.

About Structural Engineering Convention (SEC) 2014

The ninth structural engineering convention (SEC) 2014 is organised at Indian Institute of Technology (IIT) Delhi, for the first time in the capital city of India, Delhi. It is organised by the Department of Civil Engineering during Monday, 22nd December 2014 to Wednesday, 24th December 2014. The main aim towards organising SEC2014 has been to facilitate congregation of structural engineers of diverse expertise and interests at one place to discuss the latest advances made in structural engineering and allied disciplines. Further, a technical exhibition is held during all the 3 days of the convention, which facilitates the construction industry to exhibit state-of-the-art technologies and interact with researchers on contemporary innovations made in the field.

The convention was first organised in 1997 with the pioneering efforts of the CSIR-Structural Engineering Research Centre (CSIR-SERC), Council of Scientific and Industrial Research, Chennai and Indian Institute of Technology (IIT) Madras. It is a biennial event that attracts structural engineers from India and abroad, from both academia and industry. The convention, as much as it did in its history, is contributing to scientific developments in the field of structural engineering in a global sense. Over the years, SEC has evolved to be truly international with successive efforts from other premier institutes and organisations towards the development of this convention.

Apart from the 3 days of the convention, an international workshop is also organised on "Emerging Trends in Earthquake Engineering and Structural Dynamics" during Saturday, 20th December 2014 to Sunday, 21st December 2014. Eleven experts in the areas of earthquake engineering and structural dynamics delivered keynote lectures during the pre-convention workshop. The convention includes scholarly talks delivered by the delegates from academia and industry, cultural programmes presented by world-renowned artists, and visits to important sites around the historical National Capital Region (NCR) of Delhi.

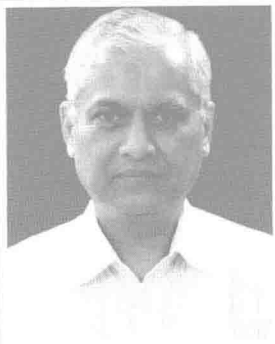
Composition of Committees for SEC2014

Organizing Committee

Patron	 R.K. Shevgaonkar Director, IIT Delhi	Areas of Interest: Fiber Optic Communication, Photonics, Nonlinear Fiber Optics, Antennas, Image Processing, Radio Astronomy. E-mail: rks@ee.iitd.ac.in director@admin.iitd.ac.in Phone: +91-11-2659-1701

(continued)

(continued)

Organizing Committee		
Organizing Chairman	 A.K. Jain Professor Civil Engineering Department, IIT Delhi	Areas of Interest: Earthquake Resistant, Analysis of Structures, Wind load, Dynamic Behaviour of Offshore Structure. E-mail: akjain@civil.iitd.ac.in Phone: +91-11-2659-1202
Mentor	 Tarun Kant Institute Chair Professor Civil Engineering Department, IIT Bombay, Mumbai	Areas of Interest: Solid Mechanics, Finite Element and Other Numerical Methods, Polymer Composites, Composite and Computational Mechanics. E-mail: tkant@civil.iitb.ac.in Phone: +91-22-2576-7310

(continued)

(continued)

Organizing Committee		
Members	 A.K. Nagpal Dogra Chair Professor Civil Engineering Department, IIT Delhi	Areas of Interest: Structural Engineering, Tall Buildings, Bridges, Earthquake Engineering. E-mail: aknagpal@civil.iitd.ac.in Phone: +91-11-2659-1234
	 Abhijit Ganguli Assistant Professor Civil Engineering Department, IIT Delhi	Areas of Interest: Non-destructive Evaluation of Structures, Subsurface Imaging, Ultrasonics, Wave Scattering Problems, Structural Dynamics, Active Control of Structural Vibration Mechatronics. E-mail: abhijit.ganguli@civil.iitd.ac.in Phone: +91-11-2659-6426

(continued)

(continued)

Organizing Committee

Alok Madan
Professor
Civil Engineering
Department,
IIT Delhi

Areas of Interest: Structural Engineering, Nonlinear Structural Dynamics, Concrete Structures, Computing in Structural Engineering, Structural Masonry.

E-mail: madan@civil.iitd.ac.in
Phone: +91-11-2659-1237

Ashok Gupta
Professor
Civil Engineering
Department,
IIT Delhi

Areas of Interest: Structural Engineering, Artificial Intelligence, Technology Enhanced Learning, Web Based Courses.

E-mail: ashokg@civil.iitd.ac.in
Phone: +91-11-2659-1194

(continued)

(continued)

Organizing Committee

B. Bhattacharjee
Professor
Civil Engineering
Department,
IIT Delhi

Areas of Interest: Durability of Concrete, Rebar Corrosion, Cement-Based Composites, Construction Technology, Building Science.

E-mail: bishwa@civil.iitd.ac.in
Phone: +91-11-2659-1193

D.R. Sahoo
Assistant Professor
Civil Engineering
Department,
IIT Delhi

Areas of Interest: Earthquake Engineering, Large-Scale Testing, Supplemental Damping and Energy Dissipation Devices, Performance-Based Seismic Design, Steel-Fiber Reinforced Concrete.

E-mail: drsahoo@civil.iitd.ac.in
Phone: +91-11-2659-1203

(continued)