Lecture Notes in Civil Engineering

K. S. Sreekeshava
Sreevalsa Kolathayar
N. Vinod Chandra Menon *Editors*

Recent Advances in Structural Engineering

Select Proceedings of IACESD-2023

Springer

Lecture Notes in Civil Engineering

Volume 455

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering—quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

– Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
– Swati Meherishi at swati.meherishi@springer.com (Asia—except China, Australia, and New Zealand);
– Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

K. S. Sreekeshava · Sreevalsa Kolathayar ·
N. Vinod Chandra Menon
Editors

Recent Advances in Structural Engineering

Select Proceedings of IACESD-2023

Springer

Editors
K. S. Sreekeshava
Department of Civil Engineering
Jyothy Institute of Technology
Bengaluru, Karnataka, India

N. Vinod Chandra Menon
Amrita Vishwa Vidyapeetham
Kollam, Kerala, India

Sreevalsa Kolathayar
Department of Civil Engineering
National Institute of Technology
Karnataka, Surathkal
Mangalore, Karnataka, India

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-99-9501-1 ISBN 978-981-99-9502-8 (eBook)
https://doi.org/10.1007/978-981-99-9502-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Structural engineers face an ever-expanding array of challenges, from the demand for innovative materials that reduce environmental impact to the imperative of creating structures that can withstand natural disasters and climate change. The Structural Engineering discipline that underpins the very framework of our built environment has undergone constant transformation, driven by advancements in materials, technology, and innovative design philosophies.

This volume presents the select proceedings of the G20 C20 International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development (IACESD-2023) which showcase the remarkable diversity of thought and expertise that defines the field of civil engineering today. The chapters within this book span a wide spectrum of topics, showcasing the diversity and depth of contemporary structural engineering and provide a glimpse into the innovative solutions that are driving the sustainable construction movement. The influence of digitalization on structural engineering in terms of Building Information Modeling (BIM), parametric design, and the integration of artificial intelligence is undeniable as they have revolutionized the way structures are planned, designed, and constructed.

We extend our heartfelt gratitude to all the authors, presenters, participants, and reviewers who contributed to the success of the G20 C20 International Conference on Interdisciplinary Approaches in Civil Engineering.

We thank all the staff of Springer for their full support and cooperation at all the stages of the publication. We hope that this book shall be beneficial to students, academicians, professionals, and researchers.

Bengaluru, India	Dr. K. S. Sreekeshava
Mangalore, India	Dr. Sreevalsa Kolathayar
Kollam, India	Prof. N. Vinod Chandra Menon

Contents

About the Editors

Dr. K. S. Sreekeshava is currently working as Associate Professor and Head of the Department of Civil Engineering, Jyothy Institute of Technology, Bengaluru. He obtained Ph.D. from BMS College of Engineering, Visvesvaraya Technological University, Belagavi in the year 2020. His research interests are in the field of Masonry Structures, Bio-composites, and Structural Design. He has published more than 30 research articles in reputed journals, Elsevier and Springer publishing houses. He has successfully coordinated funded AICTE-ISTE faculty refresher programme and is also working as Student Project Proposal (SPP) Coordinator. He has the honours of life member of ISTE, ICI, INSC, NICEE, and IAENG. He has successfully completed the research funding grant under competitive research funding scheme initiated under scheme of TEQIP by Visvesvaraya Technological University, Belagavi. Dr. Sreekeshava is the organizing chair of G20 C20 International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development (IACESD-2023).

Dr. Sreevalsa Kolathayar pursued M.Tech. from IIT Kanpur, Ph.D. from IISc, and served as International Research Staff at UPC Barcelona Tech Spain. He is an Associate Professor in the Department of Civil Engineering, National Institute of Technology Karnataka (NITK) Surathkal, India. He has authored five books, edited twelve books, published over 100 research articles, and holds two patents. He is on the Editorial Board of several International Journals. In 2017, The New Indian Express honored him with South India's Most Inspiring Young Teachers Award. He received the ISET DK Paul Research Award from the Indian Society of Earthquake Technology for the best Ph.D. thesis on Earthquake Risk Reduction in India. He received the "IEI Young Engineers Award" from The Institution of Engineers (India) in 2019. He is on the roster of two technical committees of ASCE Geo-Institute and is a Member of the Working Groups of BIS CED 39 for three IS codes. Dr. Sreevalsa has eight funded R&D projects and completed over 50 civil engineering consultancy projects.

Prof. N. Vinod Chandra Menon has worked as Professor in the Centre for Disaster Management at the Yeshwantrao Chavan Academy of Development Administration (YASHADA), Pune. He has worked in charge of Emergency Preparedness and Response in UNICEF India Country Office in New Delhi. Prof. Menon was nominated by the Prime Minister of India in 2005 as one of the Founder Members of the National Disaster Management Authority (NDMA), Government of India with the status of a Union Minister of State in the Government of India. He is currently Adjunct Professor at Amrita Vishwa Vidyapeetham, India; President of RedR India, and Regional Director Asia of The International Emergency Management Society (TIEMS) Oslo. He has over 37 years of working experience, of which more than a quarter century has been in the fields of disaster risk reduction, climate change adaptation and public policy analysis. He is currently Member of the Peer Committee on "Technological Preparedness to Deal with National Disruptions" established by the Indian National Academy of Engineering (INAE). He is the recipient of the SKOCH Challenger Award 2010 for his contributions in the field of disaster management.

Recent Advances in Structural Engineering—An Introduction

K. S. Sreekeshava, Sreevalsa Kolathayar, N. Vinod Chandra Menon, and C. Bhargavi

1 Introduction

In an era where environmental concerns and resource limitations shape the way we approach construction, the integration of sustainability principles into structural engineering has become not just an option, but a necessity. This introductory overview delves into the multifaceted realm of structural engineering, highlighting key elements that contribute to sustainable and resilient designs. Incorporating sustainability into structural engineering involves a profound analysis of design aspects. Understanding the intricacies of strength criteria is vital to ensuring structures can endure the test of time while optimizing the use of resources. Beyond basic strength, the performance of a sustainable structure must align with contemporary expectations for energy efficiency, occupant comfort and minimal environmental impact. The modern structural engineer wields an array of tools and techniques to create environmentally responsible designs.

2 Analysis and Design Aspects

The study titled "Analysis and design of the multi-storied building with floating columns, at various seismic zones in India: A review" by Ashish et al., focusses on the analysis and designing of buildings with floating columns under seismic loads

K. S. Sreekeshava (✉) · C. Bhargavi
Jyothy Institute of Technology, Bengaluru, Karnataka, India
e-mail: sreekeshava.ks@jyothyit.ac.in

S. Kolathayar
National Institute of Technology Karnataka, Surathkal, Karnataka, India

N. Vinod Chandra Menon
Amrita Vishwa Vidyapeetham, Amritapuri, Kollam, India

K. S. Sreekeshava et al. (eds.), *Recent Advances in Structural Engineering*, Lecture Notes in Civil Engineering 455, https://doi.org/10.1007/978-981-99-9502-8_1

and various design parameters such as column layout, structural configurations and other seismic provisions. Challenges faced by Skew pier bridges due to asymmetric geometry and varying load distributions have been studied on the basis of finite element analysis in the contribution titled “Finite element-based dynamic analysis of a T-beam bridge with skew supports” by Saad et al., Fundamental frequencies of footings and deck of skew bridges can be determined using empirical and semi-empirical formulae as discussed in the study. Gravity and lateral load analysis is performed in both manual approach and using SAP2000 software on a typical Intze water tank and later designed as per IS 1893-2016 and IS 875-1987 (Part III) in the study titled “SAP2000 Software Analysis and Design of the Intze Water Tank” by Naveen et al. Abhishek et al., in their work titled Comparative Study of Design of Elevated Storage Reservoir with IS:3370-2009 and IS:3370-2021 have demonstrated the after effects of the revisions in codes on the designing process. A comparison is presented to serve as a reference to understand the effects. Critical factors related to skywalk design and their framing systems have been discussed previously [1, 2]. A similar study emphasizing the framing system that supports the skywalk bridge based on the topography, slope and stability is presented titled “Analysis and Design of Steel Skywalk Bridge” by Mahalakshmi et al. Adarsh et al., in their paper titled “Modified Steel Tubes of Wind Turbine Tower Subjected to Compression-Bending Load” discuss about the failure that occurs at the bottom of wind turbine tower tube in terms of local buckling. The paper emphasizes on few structural modifications that can be made in order to resist failure. The impact of location size of damage caused by critical buckling load and their impact on buckling behaviour of thin-walled slender columns are studied by Rajanna et al., in their contribution titled “Effect of Localized Damages on the Buckling Behaviour of Slender RC Columns”.

In the study titled “Characteristics of Fiber Reinforced Polymer Piles through Finite Element Modeling” by Aamir et al., mechanical strength inclusive of strengths, failure analysis, stress and strain profiles of piles with fibre-reinforced polymer and without fibre-reinforced polymers have been evaluated by using finite element modelling in ABAQUS software. Concrete Damage Plasticity Model is used to perform the four-point bending test. Research about high-performance concrete has gained immense interests and progress mainly due to its advantageous characteristics such as enhanced durability, strength, workability, very little or no maintenance or need for repairs, enhanced impermeability and good resistance to external agents like chemicals [3]. Taking such research work forward is the contribution titled “Experimental Behaviour of Square High-Performance Concrete Slender Columns Under Different Loading” by Mane et al., who have investigated the performance of 81 square high-performance slender columns subjected to uniaxial and biaxial loading considering the grade of HPC, reinforcement ratios and eccentricity of loading as the parameters. FEM being one of the powerful tools to predict concrete strength, accuracy, flexibility, cost-effectiveness, etc. is a very important tool to analyse the structures [4]. The study titled “Comparison of Finite Element Method Models for Predicting Concrete Compression and Flexural Strength” by Megha et al., investigates the viability of utilizing waste quarry dust as partial replacement for fine aggregates using a simulation-based approach and compares the compressive and flexural strength of specimen tested experimentally. Linear and non-linear analysis on beam column joints along with their mechanical properties has been studied and presented in notable research works [5, 6]. A non-linear FEA is carried out to simulate the load deflection behaviour of steel fibre-reinforced concrete beams under monotonic loading in flexure using ANSYS in the paper titled "Studies on the behaviour of Steel Fibre-Reinforced Concrete (SFRC) under monotonic loading in Flexure: A systematic and simplified Finite Element model for assessing the structural performance" by Bhavish et al. Perforated hybrid composite laminates consisting of carbon and glass fibres arranged in various sequences subjected to vibration analysis are studied in the paper titled "Effect of Different Hybrid Configurations on the Static and Vibration Analysis of Perforated Composite Laminates" by Rajanna et al.

The seismic response and load-carrying capacity of a five-storey RC frame before and after reinforced concrete jacketing was analysed using incremental non-linear static analysis in the paper titled "Effectiveness of Concrete Jacketed Reinforced Concrete Frame Subjected to Non-linear Static Analysis" by Praveen et al. The research work titled "Performance Analysis of fixed and seismic base isolation system for multi-story building" by Anurag et al., focusses on adopting an effective base isolation system for RC structures during seismic events modelled using SAP2000 software. The paper also discusses the formation of flooring spectrum obtained through time history analysis.

The study titled "Assessment of Periphery Free-Standing Masonry Wall for Structural Safety and Integrity" by Swaroop et al., discusses about various forms of cracks in masonry walls which are caused due to vegetation growth, differential settling, weathering action which causes the walls to compress and expand thus leading to fractures.

"A Comprehensive Evaluation of Progressive Collapse Analysis: Insights on Research and Regulations through a Systematic Review" by Harshit et al., discusses about the progressive failure of a building's structural components once there is an impact to critical component along with various design strategies that can contribute towards preventing progressive collapse, alternate load paths, etc.

3 Performance Evaluation of Structural Systems

The failure mode and behaviour under load in terms of deflection of cold-formed steel tubular column encompassed with the retrofit of ring stiffener and steel wraps was discussed in the study titled "Effect of External Ring Stiffener and GFRP Strip Wrapping on the Buckling Behaviour of Cold-Formed Steel Tubular (CFST) Column" by Sangeetha et al. An extensive review of materials and structural features of SSRC is presented in the contribution titled "Stainless Steel-Reinforced Concrete (SSRC): A Review" by Sai et al. The study was carried forward with similar analysis for rectangular opening in a deep beam by Manasa et al., in their work titled "Experimental and Numerical Study on Flexural Behaviour of Deep Beam with Rectangular Openings Under Static Loading".

The seismic performance of primary auxiliary buildings which are built using a series of multi-layer shell elements in the Korean Standards is studied in the notable contribution to the volume by Nguyen et al., entitled "Correlation Analysis Between Seismic Response of Primary Auxiliary Building and Ground Motion Intensity Measures". Considering crucial failure modes that include yield stress failure and lateral torsional buckling is an important aspect of designing steel structures [7]. The study titled "The Influence of the Non-dimensional Slenderness Ratio on the Flexural Strength of Beams" by Hari et al., discusses about the no dimensional slenderness ratio's effect on the flexural behaviour of I section. There have been significant contributions towards the research of deep beams with various combinations. The studies have evaluated the impact of the compressive strength and reinforcing yield stress of concrete and steel, respectively, on behaviour of self-compacted concrete deep beams [8]. The study titled "Experimental and Numerical Study on Flexural Behaviour of Deep Beam with Circular Openings Under Static Loading" by Shashikumar et al., investigates experimental and analytical response such as ultimate load-bearing capacity and crack patterns of fibre-reinforced concrete deep beams with and without circular openings. Finite element software has been extensively used in the past decade for examining multiple behaviours of sections such as I-beams that are made of Lead Duplex Stainless Steel (LDSS), Hybrid Stainless Steel (HSS) and Duplex Stainless Steel (DSS) [9]. The contribution by Athira et al., titled "Structural performance of a perforated hybrid stainless steel I-beam" discusses about the numerical investigation to study the flexural behaviour of HSS I-beams using ABAQUS. The responses towards free vibrations from bare frame model, model including shear wall, model with X- and V-type bracing systems are studied experimentally using horizontal shake table, analytically using ETABs and theoretically to compare and observe the best possible lateral load-resisting system in the study titled "Experimental and Analytical Study of Building Models (Frames) Subjected to Free vibration Response using Horizontal Shake Table" by Sachin et al. In the research titled "Performance studies on structural floor systems—An Analytical Approach" by Ajay et al., an attempt is made to evaluate the performance of multiple floor slab systems under gravity loads, including conventional slab-beam systems, RC flat slabs, RC band beams and bonded post-tensioning slab systems.

Behaviour of concrete under high temperature is an important aspect, when concrete parameters are taken into consideration. The study titled "Performance of Concrete at Elevated Temperatures: A Review" by Guruprasad et al., discusses about the impact of elevated temperature on concrete that includes spalling, strength reduction and thermal cracking along with strategies to resist fire. The eco-friendly approach that involves microorganisms to create self-healing concrete is called biologically healed concrete [10]. The study titled "A Critical Review of Bacterial-Based Taxonomy for Self-healing Concrete" by Nageswari et al., discusses about many methods of self-healing concrete with various healing agents and efficiencies. Suitable monitoring methods are discussed to track the progress of the self-healing over the duration of specific component. The influence of specific surface, activator concentration and type of activator have played a crucial role in evaluating the mechanical strength of alkali-activated mortars [11]. One of the notable contributions to the volume is by Nagashree et al., titled “Performance of Paste Phase of Alkali-Activated Composite Produced by Utilizing fly Ash and GGBS”, which discusses about the impact of paste phase of AAC in defining the mechanical and durability properties of mortar along with micro-structural analysis. Recent researches on alternative materials to be incorporated in concrete are taken forward by the contribution titled “Impact of Jute fibre, Sugarcane Bagasse ash and Nano-alumina on mechanical properties of concrete” by Insha et al. The study focusses on investigating the mechanical properties of concrete.

Delay in any constructional projects is a matter of major concern as it withholds the resources and money and indicates poor management of associated risks in the pathway. The complexity of this problem increases when bridges are taken into consideration. Such risk factors have been identified using the Analytical Hierarchical Process Approach and prioritized to produce a robust framework in the study titled “AHP Framework for Prioritizing Risk Factors in Bridge Construction” by Shreyas et al.

4 Strength Criteria of Structural Components

Ultimate capacity, energy absorption capacity, axial stiffness, durability, etc. are prominent parameters that are considered when we discuss about the strength criteria of a structural member. The study titled “Combined Metakaolin and Ground Granulated Blast-furnace Slag induced Concrete for Marine Environment” by Thomas et al., presented an experimental investigation on combined usage of metakaolin and GGBS by replacing cement partially in various percentages. Various tests including durability properties like water absorption, permeable void, sorptivity and compressive and flexural strength tests of concrete exposed to saline water were conducted. The comparison of resistance towards sulphuric acid attack of an eco-friendly alternative to OPC, alkali-activated concrete (AAC) with OPC is discussed in the study titled “Comparative study between alkali-activated mortar and conventional mortar towards sulphuric acid” by Amina et al. The study with respect to OPC blends has been extensively studied previously [12, 13]. LC3 which is a ternary blended cement has been researched to be utilized as a partial alternative to the cement in the contribution titled “Use of Coconut Coir Fibre in Limestone Calcined Clay Cement (LC3) Concrete” by Sachin et al. Mechanical and thermal properties of alkali-activated concrete with fine aggregates that are partially replaced with quartz sand is discussed by Sai et al., in their research titled “Study on Properties of Alkali-Activated Concrete by Replacement of Fine Aggregate with Quartz Sand”. Polyethylene glycol has been recently used to study its contribution towards enhancement of concrete’s properties [14, 15]. The study by Rinu et al., titled “Analyzing the Strength and Self-Curing Properties of Recycled Concrete with PEG400 Addition”, discusses about the utilization of polyethylene glycol-400 in recycled concrete due to its ability to maintain optimum hydration thus reducing the consumption of excessive water required for curing. A comparison of binary cementitious systems of mechanical properties to determine the optimum percentage of red mud, silica fume with manufactures sand is discussed by Saravanan et al., in their contribution titled “Relationships between compressive, tensile and flexural strengths of concrete using binary blends of red mud and silica fume with M-Sand”. Sustainable alternatives as potential replacement for coarse aggregates in concrete is discussed by Bhakti et al., in their contribution titled “Mechanical and Durability Properties of Concrete using Hemp Shives as a Partial Replacement of Coarse Aggregates”. Varying partially replaced specimens are tested for their mechanical properties including compressive strength, split tensile strength and flexural strength. Lilesh et al., in their study titled “Assessment of Optimum Percentages of Chemical Admixture in composite Self-compacting concrete” have discussed the determination of ideal admixture percentages for a composite self-compacting concrete in which they have varied the GGBS and fly ash contents and tested for flexural strength and split tensile strength along with observing their behaviour at various ages.

Bamboo as an alternative construction material when pre-treated with certain resins has been researched excessively in the past decade. Due to its enhanced mechanical qualities, specially, tensile property, it has been extensively used in concrete construction [16]. It further has contributed towards a sustainable society [17]. Alisha et al., in their study titled “Epoxy resin-treated bamboo-reinforced concrete beams for rural construction buildings” discussed about performing tests on flexural and durability properties of bamboo-reinforced concrete beams and compared them with steel concrete beams in low-cost construction buildings. Valuable contributions to the field of strengthening of beams using GFRP strips have indicated various advantages that include the customizable ability and orientation ease [18]. The contribution titled “An experimental study on the structural performance of full-scale RC beams strengthened for shear using NSM GFRP strips” by Rohin et al., discussed their experimental work where a full-scale RC beam models were strengthened with near-surface mounted GFRP strips and observed for load–deflection relationship, ultimate load-carrying capacity, cracking pattern and mode of failure. Carbon being non-corrosive and lightweight is a good replacement to steel [19]. The work titled “Study on development of FRC and its application in sluice gate” by Deepthi et al., discusses about the application of FRC using carbon fibres in construction of sluice gates in small dams. CFRP sheathing with rectangular, rounded rectangular and elliptical openings is studied for the ultimate strength of the beam on the basis of the load–deflection curve observations in the paper titled “Experimental study on effect of CFRP sheathing on the behaviour of RCC beams with opening” by Neethu et al. Strength of stabilized geopolymer mud block with varying compositions of mortar utilizing masonry prisms was experimentally determined in the study titled “Experimental Investigation on the Strength of Stabilized Geopolymer Mud Blocks with various types of Mortar” by Ramya et al. Various tests including the dimensionality, water absorption test, initial rate of absorption and density of the blocks were performed.

The role of mortar in masonry unit is to bond the units and distribute the stress [20]. The contribution titled “Study on compression strength of masonry prism using cementitious grouting material as mortar” by Kavyashree et al., aims to study the effect of increase in strength of mortar and bond by utilizing the grouting material as mortar at 3, 7 and 28 days. Further, cementitious grouting materials were also studied for their shear and flexural bond strength in the research work titled "Studies on Flexural and Shear bond strength of masonry using cementitious grouting materials as mortar" by Maniranganath et al. The study indicated faster rate of construction when the thickness of mortar joints is reduced and an increased bond strength on utilization of cementitious grouting materials as mortar.

Experimental studies that investigate the free vibration analysis of fixed base and column supported cooling tower shell which includes the study on different modes of vibration including torsion mode, circumferential mode and meridional mode have been presented by Sachin et al., in their paper titled "Study on Circumferential and Meridional Modes of Free Vibration Response for Fixed base and Column-Supported Cooling Tower Shell". Janhavi et al., in their study titled "Effect of Wind Load on RCC and Steel Buildings in Different Terrain Category" have analysed a G + 40 building for wind loads by varying wind zones, utilizing both RCC and steel in four terrain categories using ETABs v20 to evaluate bending moment, storey drift and displacement.

5 Summary

With knowledge about topics, such as seismic design, durability properties and masonry, we gain insights into how these components harmoniously converge to shape the built environment of the future. By setting comprehensive performance criteria, we seek to strike a balance between structural functionality and the well-being of inhabitants, all while minimizing the building's ecological footprint. This exploration will empower engineers, architects and stakeholders to forge a path towards a more sustainable future, one structurally sound and environmentally resilient building at a time.

References

1. Banerjee A, Maurya AK (2020) Planning for better skywalk systems using perception of pedestrians: case study of Mumbai, India. J Urban Plan Dev 146(2):05020003
2. Bhatia SY, Patil GR, Chopadekar AD, Sharma S (2022) Skywalk facility utilization and factors influencing its use: a case study of Mumbai Metropolitan Region, India. Case Stud Transp Policy 10(1):396–405
3. Chekravarty DSVSMRK, Mallika A, Sravana P, Rao S (2022) Effect of using nano silica on mechanical properties of normal strength concrete. Mater Today: Proc 51:2573–2578. https://doi.org/10.1016/j.matpr.2021.12.409
4. Oñate E, Cornejo A, Zárate F, Kashiyama K, Franci A (2022) Combination of the finite element method and particle-based methods for predicting the failure of reinforced concrete structures under extreme water forces. Eng Struct 251:113510

5. Balaji S, Thirugnanam GS (2017) Study on exterior RC beam-column joints upgrade with SIFCON in joint core under reversed cyclic loading. KSCE J Civ Eng 21(1):346–352. https://doi.org/10.1007/s12205-016-0643-x
6. Vasudevan G, Kothandaraman S, Azhagarsamy S (2013) Study on non-linear flexural behavior of reinforced concrete beams using Ansys by discrete reinforcement modeling
7. De'nan F, Hashim NS, Che Aziz MS (2021) Parametrical study of lateral torsional buckling behaviour for triangular web profile steel section. J Struct Monitor Built Environ 1(1). https://doi.org/10.30880/jsmbe.2021.01.01.004
8. Abdul-Razzaq KS, Jebur SF, Mohammed AH (2018) Concrete and steel strengths effect on deep beams with reinforced struts. Int J Appl Eng Res 13(1). ISSN: 0973-4562
9. Lalthazuala R, Singh KD (2019) Investigations on the structural performance of hybrid stainless steel I-beams based on slenderness. Thin-Walled Struct 137:197–212
10. Magaji A et al (2019) A review paper on self-healing concrete. Proc Int J Eng Sci 8:47–54
11. Fernández-Jiménez A, Palomo JG, Puertas F (1999) Alkali-activated slag mortars: Mechanical strength behaviour. Cem Concr Res 29(8):1313–1321. ISSN: 0008-8846. https://doi.org/10.1016/S0008-8846(99)00154-4
12. Gifford P, Gillott J (1996) Alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR) in activated blast furnace slag cement (ABFSC) concrete. Cem Concr Res 26:21–26. https://doi.org/10.1016/0008-8846(95)00182-4
13. Fayomi GU, Mini SE, Fayomi OSI, Ayoola AA (2019) Perspectives on environmental CO_2 emission and energy factor in cement industry. In: International conference on energy and sustainable environment, p 331. https://doi.org/10.1088/1755-1315/331/1/012035
14. Sudharson G, Kalpana M, Anburaja D, Prathap MG (2021) PEG 400 effect on properties of self curing concrete. IOP Conf Ser: Mater Sci Eng 1026(1): 012014. https://doi.org/10.1088/1757-899X/1026/1/012014
15. Dhanya BS, Koshy BI, Jisha KV, Jayamohanan A, Mathew N (2020) Evaluation of the mechanical performance of M25 grade recycled aggregate concrete. In: IOP conference series: earth and environmental science, vol 491, 012034. IOP Publishing
16. Ghavami K (2005) Bamboo as reinforcement in structural concrete elements. Cement Concr Compos 27(6):637–649
17. Amran M, Huang SS, Onaizi AM, Makul N, Abdelgader HS, Ozbak-kaloglu T (2022) Recent trends in ultra-high-performance concrete (UHPC): current status, challenges, and future prospects. Constr Build Mater 352:129029
18. Rizzo A, De Lorenzis L (2009) Behavior and capacity of RC beams strengthened in shear with NSM FRP reinforcement. Constr Build Mater 23(4)
19. Muthukumarana TV et al (2023) A review on the variation of mechanical properties of carbon fibre-reinforced concrete. Constr Build Mater 366:130173
20. Zengin B, Toydemir B, Ulukaya S, Oktay D, Yuzer N, Kocak A (2018) The effect of mortar type and joint thickness on mechanical properties of conventional masonry walls. Struct Eng Mech 67(6):579–585

Analysis and Design Aspects

Analysis and Design of the Multi-storied Building with Floating Columns, at Various Seismic Zones in India: A Review

Ashish Rathi, M. P. Bhorkar, and K. R. Dabhekar

1 Introduction

One of the most shattering natural disasters, earthquakes, results in substantial loss of lives and assets. The need for structures that can withstand the effects of earthquakes has become increasingly important in recent years. Multi-storied buildings with floating columns have emerged as a promising solution to mitigate the impact of earthquakes on buildings in high-risk seismic zones. Floating column structures (Fig. 1) have become increasingly popular in high-risk seismic zones due to their ability to lessen the effects of earthquakes on buildings. The design of a floating column structure involves placing columns on a beam that is supported by the foundation. The beam acts as a bridge between the columns and the foundation, allowing the columns to move independently during an earthquake. The purpose of this design is to reduce the impact of lateral forces on the structure, which can cause damage or collapse. The flexibility and resilience of floating column structures make them ideal for multi-storied buildings in high-risk seismic zones. During an earthquake, the ground moves back and forth, causing lateral forces that can cause the building to sway or collapse. This design can also help distribute the weight of the building evenly across the foundation, reducing the stress on any one area of the foundation. The use of floating column structures can significantly improve the seismic performance and safety of multi-storied buildings in high-risk seismic zones. The design allows for flexibility and resilience, enabling the building to move with the ground during an earthquake, reducing the impact of lateral forces, and protecting the structure from damage or collapse.

Eldar et al. [2] conducted a study in which they assessed the seismic load response of multi-story buildings incorporating floating columns. The authors found that the floating column structure was effective in reducing the impact of lateral forces during

A. Rathi (✉) · M. P. Bhorkar · K. R. Dabhekar
Civil Engineering Department, GH Raisoni College of Engineering, Nagpur, India
e-mail: rathiashish4@gmail.com

K. S. Sreekeshava et al. (eds.), *Recent Advances in Structural Engineering*, Lecture Notes in Civil Engineering 455, https://doi.org/10.1007/978-981-99-9502-8_2

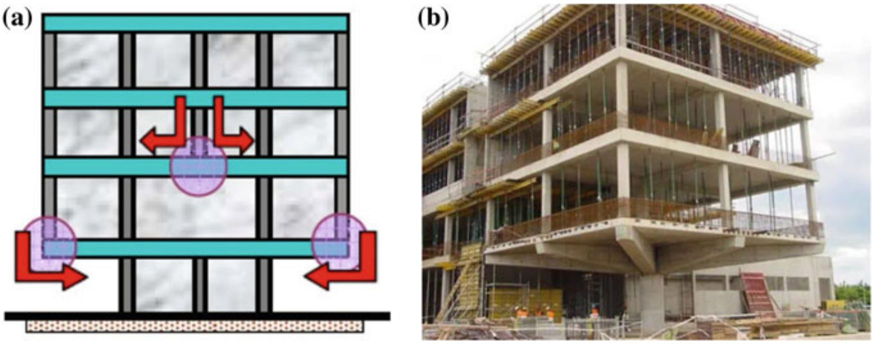

Fig. 1 **a** CAD model of floating column, **b** building with floating column [1]

an earthquake, resulting in reduced damage to the building. Another study by Kakpure and Mundhada [3] conducted a separate investigation that focused on the seismic behavior of multi-story buildings with floating columns. The researchers utilized nonlinear time-history analysis as their methodology. The authors concluded that the floating column structure significantly reduced the displacement and acceleration of the building during an earthquake. The use of floating columns in multi-storied buildings is particularly important in seismic zones, such as those in India, where the risk of earthquakes is high. The seismic hazard levels in different zones in India are defined by the Bureau of Indian Standards (BIS). Kumar and Soni [4] conducted a study in which they assessed the seismic performance of multi-story buildings incorporating floating columns across different seismic zones in India. They found that the effectiveness of the floating column structure was dependent on the seismic hazard level of the zone in which the structure was located.

The design process for multi-story buildings incorporating floating columns necessitates careful consideration of various factors, including column layout, structural configuration, and adherence to seismic provisions. Patil and Shah [5] conducted a study to examine the influence of column layout on the seismic behavior of such buildings. They discovered that the spacing between columns and the number of floating columns had a significant impact on the building's performance during seismic events.

The seismic provisions for multi-story buildings with floating columns are outlined in several codes, such as the Indian Standard Code of Practice for Structural Safety of Buildings (IS 1893) and the International Building Code (IBC). Kakatkar [6] conducted a study to evaluate the seismic performance of multi-story buildings with floating columns designed according to the IS 1893 code. The study revealed that the floating column structure effectively minimized the impact of seismic forces on the building.

However, the implementation of floating columns in multi-story buildings presents challenges. Jain and Ashirwar [1] conducted a study to investigate the behavior of multi-story buildings with floating columns under combined wind and earthquake loads. They found that while the floating column structure effectively reduced the impact of seismic forces, it was less successful in mitigating the effects of wind loads.

In recent times, scholars have also explored the utilization of alternative materials like fiber-reinforced polymer (FRP) in the design of multi-story buildings incorporating floating columns. In a study conducted by Singh [7], the author evaluated the seismic performance of multi-storied buildings with floating columns using FRP composite materials. They found that the use of FRP in the floating column structure resulted in improved seismic performance of the building. Despite the growing interest in the usage of floating column structures in multi-storied buildings, there is still a need for further research to optimize the design strategies for such structures in different seismic zones. In a study conducted by Chatterjee [8], the authors evaluated the seismic performance of multi-storied buildings using floating columns in different seismic zones in India using a probabilistic seismic hazard analysis. They found that the design strategies for floating column structures need to be tailored to the specific seismic hazard levels of each zone. In another study by Mahajan [9], the author evaluated the effectiveness of retrofitting existing multi-storied buildings with floating columns to improve their seismic performance. The authors concluded that the retrofitting of existing buildings with floating columns is a cost-effective solution for improving their seismic performance.

The current state of floating columns in construction reflects their continued popularity for achieving open floor layouts and architectural flexibility. However, it is important to recognize the need for further advancements in construction practices to address the specific challenges associated with floating columns and mitigate the risk of failure. While floating columns offer design advantages, their unique load distribution and behavior require careful consideration during the design and construction stages. Inadequate shear reinforcement and improper detailing can lead to shear failure, compromising the structural integrity of the columns. Similarly, the concentrated loads from floating columns can result in punching shear failure at the column–slab interface. To ensure the long-term performance and safety of structures incorporating floating columns, there is a growing need for improved construction practices. This includes enhanced design guidelines, detailing requirements, and construction techniques that specifically address the challenges posed by floating columns. Additionally, industry professionals should stay updated with the latest research findings and advancements in structural engineering to implement best practices effectively. Further research and development efforts are necessary to deepen our understanding of the behavior and failure modes of floating columns. This knowledge can inform the development of more robust design strategies and construction practices. By investing in research, collaboration between researchers, engineers, and construction professionals, we can improve the reliability and safety of structures incorporating floating columns, meeting the demands of modern architectural designs while ensuring structural integrity.

The purpose of this research paper is to present a comprehensive review focusing on the analysis and design aspects of multi-story buildings with floating columns across different seismic zones in India. The article aims to explore various structural systems commonly employed in such buildings, including reinforced concrete, steel, and masonry. It intends to assess the merits and drawbacks of each system in terms of seismic performance. Furthermore, the paper aims to provide a detailed explanation of floating columns, elucidating their role in providing additional support to multi-story buildings and their effectiveness in mitigating the impacts of earthquakes. The ultimate objective of this review article is to offer valuable insights and recommendations for future research endeavors in this field while emphasizing the potential advantages of multi-story structures with floating columns in seismic zones within India.

2 Seismic Zones

India is known for being highly susceptible to seismic activity, housing numerous seismic zones with elevated risks. The classification of these seismic zones is determined by the intensity and frequency of earthquakes observed in specific regions. Geographically, the Indian subcontinent is situated at the convergence of two tectonic plates, namely, the Indian Plate and the Eurasian Plate. Consequently, the country frequently encounters seismic events, which pose a substantial hazard to both human lives and infrastructure. In this comprehensive review, we will delve into an exploration of India's seismic zones and investigate the extensive research conducted to gain a deeper understanding of earthquakes and develop effective strategies to mitigate their impact.

2.1 Seismic Zones in India

India's seismic activity is classified into four distinct zones (refer to Fig. 2) based on the frequency and intensity of earthquakes in each region. Zone V represents the highest level of seismic activity, whereas Zone I indicates the lowest. Seismic Zone V, encompassing the Himalayan belt, the Northeast region, and portions of Gujarat, is the most seismically active area in India. The collision between the Indian Plate and the Eurasian Plate makes this region particularly prone to intense earthquakes. Research conducted by Zilio et al. [10] revealed that the topography and geological structure of the Himalayan region influence its seismic activity.

Seismic Zone IV comprises Himachal Pradesh, Jammu and Kashmir, Uttarakhand, and parts of Northeastern India, making it susceptible to high-intensity earthquakes due to the presence of active faults. Seismic Zone III encompasses the Indo-Gangetic plain, along with sections of Rajasthan, Madhya Pradesh, Maharashtra, and West Bengal. This region experiences moderate-to-low-intensity earthquakes. Seismic Zone II, which includes Kerala, Tamil Nadu, Karnataka, and parts of Andhra Pradesh, represents the least seismically active area in India, characterized by low-intensity earthquakes.

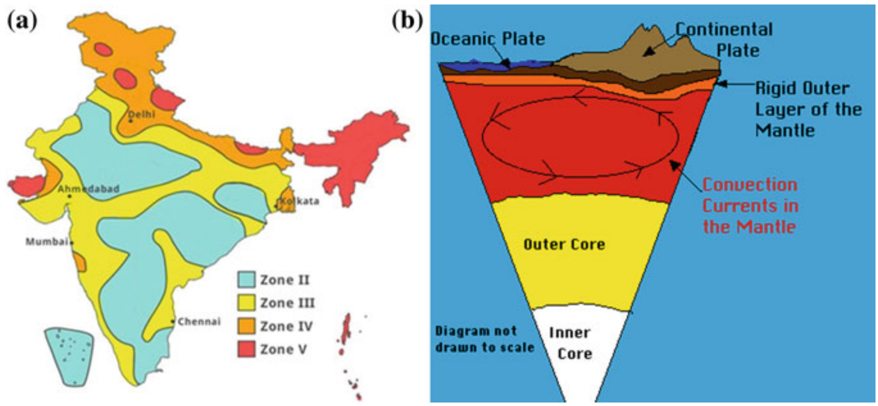

Fig. 2 **a** Seismic zones, **b** tectonic plate [10]

2.2 Research on Seismic Zones in India

Numerous studies have been conducted to investigate the seismic zones in India, aiming to enhance our understanding of earthquake frequency, intensity, and their effects. For instance, Yadav et al. [11] conducted a study on the seismic hazard of the Kachchh region, located within Seismic Zone V. The findings indicated that the region was prone to moderate-to-high-intensity earthquakes. Similarly, Sen [12] explored the seismic hazard of the Andaman and Nicobar Islands, also falling under Seismic Zone V. The study concluded that the region was susceptible to high-intensity earthquakes due to the presence of active faults.

Moreover, research efforts have been dedicated to comprehending the impact of earthquakes on various types of structures. For instance, Alam et al. [13] investigated the seismic performance of reinforced concrete buildings in Seismic Zone III. The study emphasized the significance of energy dissipation capacity and ductility in ensuring the buildings' seismic resilience.

In summary, India exhibits significant seismic activity, with multiple high-risk seismic zones. Extensive research has been conducted to gain insights into and mitigate the impact of earthquakes across different seismic zones in India. The findings of these studies contribute to the improvement of design and construction practices, ultimately enhancing the seismic performance and safety of structures in these zones.

Floating column structure has gained increasing popularity in earthquake-prone regions due to their ability to reduce the impact of lateral forces on the structure. However, their effectiveness depends on various design parameters such as column layout, structural configuration, and seismic provisions. This section provides a detailed analysis of the behavior of floating column structures under seismic loads and discusses the different design parameters that are critical for ensuring their safety during seismic events.

The arrangement of columns, known as column layout, is a crucial design factor that significantly impacts the performance of a floating column structure when subjected to seismic loads. Askar et al. [12] conducted a study to examine the influence of column layout on the behavior of such structures. The findings revealed that an optimal column layout for a floating column structure consists of a regular grid pattern with evenly spaced columns. Additionally, the structural configuration of a floating column structure plays a vital role in its seismic response. Kassesm and Nazri [13] conducted a study that focused on analyzing the seismic behavior of a multi-story floating column structure with various structural configurations. The study concluded that the structural configuration of a floating column structure should be designed to provide adequate stiffness and strength to withstand seismic loads effectively.

Seismic provisions are of utmost importance in ensuring the safety of a floating column structure during seismic events. Radkia et al. [14] conducted a study that focused on the behavior of asymmetric sliding buildings equipped with steel moment frame systems under earthquake loading, considering soil–structure interaction. The analysis involved 24 three-dimensional structural models, and the findings revealed that seismic isolation had a significant impact on the dynamic responses of the buildings, particularly in single-story structures as shown in Fig. 3. The study also observed that structural irregularities did not influence the dynamic response of the structure, while the substructure soil type had a notable effect on the design parameters of isolators.

Furthermore, the choice of foundation type has a substantial influence on the seismic behavior of a floating column structure. Singla et al. [15] conducted a study to assess the impact of different foundation types on the seismic response of such structures. The research concluded that a raft foundation is the most effective type of foundation for a floating column structure, considering its seismic performance.

The seismic behavior of a floating column structure is also influenced by the soil type. Zhang et al. [16] conducted a study to assess the impact of soil–structure interaction on the behavior of such structures. The research concluded that the seismic response of a floating column structure is significantly influenced by the soil type, emphasizing the need to incorporate appropriate considerations for soil–structure interaction during the design phase. Moreover, the material properties of the structural elements employed in a floating column structure play a crucial role in its seismic performance. Mohidini et al. [17] conducted a study to investigate the effect of material properties on the seismic response of such structures. The study concluded that careful attention should be given to the material properties of the structural elements during the design process to ensure the structural integrity and safety of the floating column structure during seismic events.

The seismic behavior of a floating column structure is also influenced by its dynamic characteristics, including natural frequency and damping ratio. Gupta et al. [18] conducted a study to analyze the impact of dynamic features on the behavior of such structures. The research concluded that optimizing the dynamic characteristics of a floating column structure is essential to ensure its safety during seismic events.

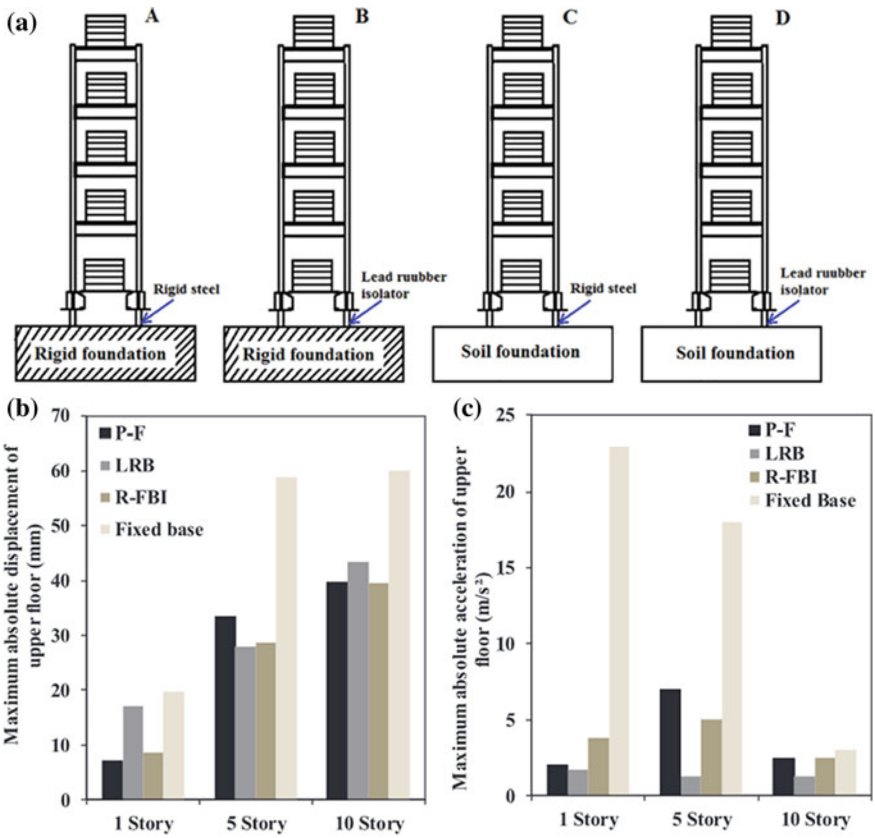

Fig. 3 **a** Shaking table tests designed for the four different conditions, **b** maximum absolute displacement of the upper floor for different isolators, **c** maximum absolute acceleration of the upper floor for different isolators [14]

Furthermore, Ismail et al. [19] conducted a study to investigate the influence of various design parameters on the seismic performance of floating column structures. The study examined the effects of parameters such as beam-to-column ratio, column spacing, and column height on the structural behavior of the floating column structure. The findings indicated that increasing the beam-to-column ratio and reducing the column spacing can enhance the seismic performance of the structure.

The failure of buildings with floating columns can be influenced by several factors, such as design deficiencies, construction errors, material quality, and external loads. It is important to consider the overall structural system and its interaction with the floating columns. Key failure mechanisms include progressive collapse, shear and punching shear failure, foundation failure, and material degradation. Progressive collapse can occur if load paths are inadequately designed or if weak connections exist between columns, beams, and slabs. Shear failure and punching shear failure may result from insufficient shear reinforcement, improper detailing, or high concentrated loads. Foundation failure can occur due to settlement, differential movement, or inadequate bearing capacity. Material degradation, including corrosion, spalling, and deterioration, can weaken the structural integrity. Implementing sound engineering practices, such as proper design, quality control, inspections, and adherence to building codes and standards, is essential for mitigating these failure mechanisms. Advanced analysis techniques, like structural modeling and load testing, can aid in identifying potential risks in buildings with floating columns [20].

In summary, these studies highlight the effectiveness of floating column structures in reducing the impact of earthquakes on multi-storied buildings. The design parameters such as column layout, structural configuration, and seismic provisions play a significant role in ensuring the safety of such structures during seismic events. Further research is required to develop optimal design strategies for floating column structures in different seismic zones of India.

3 Structural Systems

Structural systems used in multi-storied buildings with floating columns should be carefully selected to ensure safety and durability, especially in seismic zones. Reinforced concrete, steel, and masonry are the most commonly used structural systems in such buildings, and each system has its advantages and disadvantages. Reinforced concrete structures are durable and resistant to fire, and they have excellent compressive strength. However, they can be expensive and time-consuming to construct, and they may not perform well in seismic zones unless designed and reinforced properly [19]. Steel structures are lightweight and flexible, which allows for easier installation and greater design flexibility. They also have excellent tensile strength, which makes them suitable for high seismic zones. However, steel structures are vulnerable to fire and corrosion, and their installation may require skilled labor [21]. Masonry structures are cost-effective and have good thermal properties, making them suitable for hot climates. However, they may not perform well in seismic zones without proper detailing and reinforcement, and their construction may require more time and effort than other systems [22]. The suitability of each system for different seismic zones depends on various factors, such as the building height, occupancy, and location. For example, reinforced concrete structures may be suitable for low-to-moderate seismic zones, while steel structures may be more appropriate for high seismic zones. Masonry structures may be suitable for low-rise buildings in seismic zones with low-to-moderate hazard levels [23]. Designing multi-storied buildings with floating columns in seismic zones requires careful consideration of the structural system and its behavior under lateral loads. Computer simulations and performance-based seismic design can improve the seismic performance of reinforced concrete and steel structures with floating columns [24].

In summary, the selection of the appropriate structural system for multi-storied buildings with floating columns in seismic zones should consider factors such as