



Conference eProceeding

ICSRI-2026

13-15th March 2026

eProceeding of International Conference on Seismic Resilient Infrastructure-2026

Published by

Department of Civil Engineering

Indian Institute of Technology

(BHU) Varanasi

Organized in Association with

**Indian Society of
Earthquake Technology,
Varanasi Chapter**

ISBN 978-816853490-2





International Conference on Seismic Resilient Infrastructure-2026

Conference eProceeding

Edited by

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&

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Published by

Department of Civil Engineering

Indian Institute of Technology (BHU)

Varanasi



Kulgeet – English Translation

So sweet serene, infinitely beautiful
This is the presiding center of all learning
Radiant Kashi, wonder of the three worlds
Treasure-Chest of Jnana , Dharma and Satya
Nesting on Ganga`s bank, center of all disciplines.
(So sweet, serene, infinitely beautiful)
No Recent work of brick and stone
Primordial design of divinity alone
Mansions of Vidya, center of all creation.
(So sweet, serene, infinitely beautiful)
Clear here is the doctrine pure
Truth first, then only one' self
Home of Harishchandra, Truth's testing ground.
(So sweet, serene, infinitely beautiful)
The voice of God in Vedic record
Constant Inspiration for soul-accord
Work-shop of Veda Vyasa, center freedom for Bhrahma Vidya
(So sweet, serene, infinitely beautiful)
Find here the steps of freedom
Tread here the path of Dharma
Flaming trail Budha`s and Shankara`s center for philosopher-kings.
(So sweet, serene, infinitely beautiful)
Life-Giving waters of Varuna and Assi
Sustenance of Kabir and Tulsi
Fountainhead of eloquent speech and poetry.
(So sweet, serene, infinitely beautiful)
Music, Economics, other arts so many
Maths, Mining, Medicine and Chemistry
Fraternal forum of East and West , university in trust sense.
(So sweet, serene, infinitely beautiful)
Patriotism of Malviyaji
His intrepidity and energy
All in youthful manifestation, centre for men of action
(So sweet, serene, infinitely beautiful)

कुलगीत

मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ।
यह तीन लोकों से न्यारी काशी ।
सुज्ञान धर्म और सत्यराशी ॥
बसी है गंगा के रम्य तट पर, यह सर्वविद्या की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
नये नहीं हैं ये ईंट पत्थर ।
है विश्वकर्मा का कार्य सुन्दर ॥
रचे हैं विद्या के भव्य मन्दिर, यह सर्वसृष्टि की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
यहाँ की है यह पवित्र शिक्षा ।
कि सत्य पहले फिर आत्म-रक्षा ॥
बिके हरिश्चन्द्र थे यहीं पर, यह सत्यशिक्षा की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
वह वेद ईश्वर की सत्यवाणी ।
बनें जिन्हें पढ़ के ब्रह्मज्ञानी ॥
थे व्यास जी ने रचे यहीं पर, यह ब्रह्म-विद्या की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
वह मुक्तिपद को दिलाने वाले।
सुधर्म पथ पर चलाने वाले॥
यहीं फले-फूले बुद्ध, शंकर, यह राज-ऋषियों की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी॥
सुरम्य धाराएँ वरुणा अस्सी ।
नहाये जिनमें कबीर तुलसी ॥
भला हो कविता का क्यों न आकर, यह वाग्विद्या की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
विविध कला अर्थशास्त्र गायन ।
गणित खनिज औषधि रसायन ॥
प्रतीचि-प्राची का मेल सुन्दर, यह विश्वविद्या की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥
यह मालवीय जी की देशभक्ति ।
यह उनका साहस यह उनकी शक्ति ॥
प्रगट हुई है नवीन होकर, यह कर्मवीरों की राजधानी ।
मधुर मनोहर अतीव सुन्दर, यह सर्वविद्या की राजधानी ॥



Vision of an Extraordinary Man

Malaviyaji envisioned BHU as a premier, comprehensive institution grounded in the ideals of enlightenment, intellectual freedom, and holistic learning. Conceived as a “National Temple of Learning,” the university has shaped successive generations of distinguished scholars, scientists, technologists, economists, artists, medical practitioners, jurists, and public leaders, all of whom have made substantial contributions to national development. Drawing inspiration from leading educational reformers of his time—such as Maharshi Karve in Pune, Sir Ashutosh Mukherji in Calcutta, and Dr. Annie Besant in Varanasi—Malaviyaji articulated an educational philosophy founded on broad-mindedness, tolerance, and a universal spiritual ethos.





International Conference on Seismic Resilient Infrastructure-2026

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International Conference on Seismic Resilient Infrastructure-2026

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• Rachit Panda	Research Scholar
• Jhunarani Ojha	Research Scholar
• Trinarayan Bordoloi	PG Student
• Sudheer Kumar	PG Student



Foreword

Proceedings of the International Conference on Seismic Resilient Infrastructure – 2026

It gives me great pleasure to present the proceedings of the **International Conference on Seismic Resilient Infrastructure (ICSRI 2026)**, a forum dedicated to advancing knowledge, innovation, and collaboration in the field of earthquake engineering and resilient infrastructure development. The conference brings together researchers, practitioners, policymakers, industry experts, and students from across the world to deliberate on emerging challenges and transformative solutions that can strengthen the safety and sustainability of our built environment.

With rapid urbanization, climate variability, and increasing exposure of critical infrastructure to seismic hazards, the pursuit of resilience has become a global imperative. ICSRI 2026 provides a timely platform for sharing cutting-edge research on seismic hazard assessment, advanced materials, structural systems, performance-based design, retrofitting strategies, smart monitoring technologies, and policy frameworks. The diversity of contributions in this volume reflects the expanding interdisciplinary nature of resilience studies, integrating engineering science with geoscience, urban planning, data analytics, and societal risk management.

The papers included in this compilation have undergone rigorous review to ensure academic quality and relevance. They represent valuable insights from established researchers as well as emerging scholars who together enrich the scientific discourse and chart future directions for research and practice. We believe that the ideas, methodologies, and case studies presented here will contribute meaningfully to global efforts aimed at mitigating seismic risk and enhancing the robustness of infrastructure systems.

I extend my sincere appreciation to all authors for their scholarly contributions, to reviewers for their meticulous evaluations, and to the organizing committee for their dedicated efforts in bringing this conference to fruition. I also acknowledge our partner institutions, sponsors, and technical collaborators whose support has been instrumental in realizing IC-SRI 2026.

It is our hope that these proceedings will serve not only as a record of the conference but also as a lasting resource for academicians, engineers, planners, and decision-makers committed to building safer and more resilient communities.

Prof. Pabitra Ranjan Maiti

Chairman

International Conference on Seismic Resilient Infrastructure – 2026



International Conference on Seismic Resilient Infrastructure- 2026

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आचार्य अमित पात्रा
निदेशक
Prof. Amit Patra
Director

Message



It is my great pleasure to welcome distinguished delegates, researchers, academicians, industry leaders, and students from across the globe to the International Conference on Seismic Resilient Infrastructure (ICSRI)-2026 at the Indian Institute of Technology (Banaras Hindu University), Varanasi being held on 13-15th March 2026.

Seismic resilience has emerged as one of the most critical priorities in infrastructure planning and development, particularly in regions experiencing rapid urbanization, high population density, and increasing demands on public infrastructure. The need to design, assess, retrofit, and manage infrastructure systems capable of withstanding seismic events is essential for safeguarding lives, protecting investments, and ensuring sustainable growth.

IIT (BHU) has a long-standing tradition of excellence in engineering education, research, and innovation. Through interdisciplinary collaboration and strong engagement with industry and government agencies, the Institute remains committed to addressing pressing societal challenges, including disaster risk reduction and resilient infrastructure development.

This conference brings together leading experts and young researchers to exchange ideas, present cutting-edge research, and deliberate on practical solutions for enhancing the seismic performance of buildings, transportation systems, lifeline infrastructure, and heritage structures. I am confident that the discussions and outcomes of this conference will contribute significantly to advancing knowledge and shaping future policies and practices.

I extend my sincere appreciation to the organizing committee for their dedicated efforts and thank all participants for their valuable contributions. I wish the conference every success.


(Amit Patra)

Date: 06th March 2026

संस्कार ही शिक्षा  Education is Character



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अधिष्ठाता कार्यालय
(अनुसंधान एवं विकास)

Office of the Dean
(Research & Development)

Message from the Dean R&D



It is a privilege to extend my warm greetings to all participants of the International Conference on Seismic Resilient Infrastructure – 2026. This conference embodies the spirit of innovation and collaboration that is essential for addressing one of the most pressing challenges of our time—building infrastructure that can withstand seismic hazards while fostering sustainable urban growth.

At IIT (BHU), research and development are driven by the vision of integrating advanced science, engineering, and technology with societal needs. Seismic resilience is not only a matter of structural safety but also of community well-being, economic stability, and long-term sustainability. The deliberations at this conference will serve as a catalyst for interdisciplinary research, policy dialogue, and global partnerships that advance these goals.

I am confident that the exchange of ideas and experiences here will inspire transformative solutions and strengthen our collective resolve to create safer, smarter, and more resilient societies. On behalf of the Office of Research & Development, I commend the organizers and contributors for their dedication, and I wish the conference great success in shaping pathways toward a resilient future.

With best regards

(Prof. Rajesh Kumar)
Dean (Research & Development)
IIT (BHU) Varanasi

अधिष्ठाता (अनुसंधान एवं विकास)
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TECHNOLOGY
BANARAS HINDU UNIVERSITY

Prof. Krishna Kant Pathak
Professor and Head of the Department

Message from the Head of Department



It gives me immense pleasure to welcome distinguished scholars, practitioners, and innovators to the International Conference on Seismic Resilient Infrastructure – 2026 conducted at IIT(BHU) Varanasi during 13-15th March 2026. This gathering marks a significant step in our collective journey toward safer, more sustainable, and resilient built environments.

At IIT (BHU) Varanasi, we have long recognized that seismic resilience is not merely a technical challenge but a societal imperative. The increasing frequency and intensity of disasters demand that we, as engineers and researchers, advance knowledge, foster collaboration, and translate innovation into practice.

This conference provides a unique platform to exchange ideas, showcase pioneering research, and build networks that transcend borders. I am confident that the deliberations here will inspire actionable strategies for integrating resilience into infrastructure planning, design, and policy frameworks.

On behalf of the Department of Civil Engineering, I extend my heartfelt gratitude to all participants, organizers, and partners who have made this event possible. May the discussions and collaborations forged here contribute meaningfully to a safer and more resilient future for communities worldwide.

With best wishes,

(Prof. Krishna Kant Pathak)
Professor and Head of the Department
Department of Civil Engineering
IIT (BHU) Varanasi



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Prof. Pabitra Ranjan Maiti
Conference Chairman
ICSRI-2026

Message from the Chairman



It is with immense pleasure and a deep sense of responsibility that I welcome you to the International Conference on Seismic Resilient Infrastructure at the Indian Institute of Technology (Banaras Hindu University), Varanasi.

The increasing vulnerability of infrastructure systems to seismic hazards, coupled with rapid urbanization and growing population density, demands innovative, research-driven, and implementable solutions. The objective of this conference is to provide a dynamic platform for researchers, academicians, practicing engineers, policymakers, and industry professionals to deliberate on recent advances in seismic analysis, design methodologies, performance-based engineering, retrofiting strategies, smart materials, and resilient urban systems.

Varanasi, a city of immense cultural and historical significance, experiences large-scale human congregation and infrastructure demand throughout the year. Ensuring the safety and resilience of critical infrastructure in such contexts is both a technical challenge and a societal imperative. Through focused technical sessions, keynote lectures, panel discussions, and collaborative interactions, we aim to foster meaningful dialogue and translate research outcomes into practical applications.

The enthusiastic response from the national and international community reflects the growing importance of seismic resilience in infrastructure development. I am confident that the exchange of ideas during this conference will lead to impactful collaborations, new research directions, and actionable strategies for building safer and more sustainable infrastructure systems.

I extend my sincere gratitude to all keynote speakers, contributors, sponsors, organizing committee members, and participants for their valuable support and engagement. I wish you a productive and intellectually enriching conference experience.

With best wishes,

(Prof. Pabitra Ranjan Maiti)
Conference Chairman, ICSRI 2026
IIT (BHU) Varanasi



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Dr. Supriya Mohanty
Conference Convenor
ICSRI-2026

Message from the Convenor



It is with great honour and enthusiasm that I welcome you to the International Conference on Seismic Resilient Infrastructure – 2026. This conference is envisioned as a vibrant forum where leading researchers, engineers, policymakers, and industry professionals converge to address the urgent need for resilient infrastructure in seismic-prone regions.

The challenges posed by earthquakes demand not only technical excellence but also interdisciplinary collaboration and global solidarity. Through keynote lectures, technical sessions, and panel discussions, this conference seeks to foster dialogue that bridges research and practice, while inspiring innovative solutions that safeguard communities and advance sustainable development.

As Convener, I am deeply grateful to our distinguished speakers, participants, and organizing partners for their commitment to this cause. I am confident that the knowledge shared and networks built here will leave a lasting impact, guiding us toward safer, smarter, and more resilient societies.

I warmly invite all delegates to engage wholeheartedly in the deliberations and collaborations that will define the success of this conference. Together, let us chart pathways that transform resilience from aspiration into reality.

With best regards

(Dr. Supriya Mohanty)
Conference Convenor, ICSRI 2026
IIT (BHU) Varanasi



INDIAN SOCIETY OF EARTHQUAKE TECHNOLOGY

(Established 1962)

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Prof. B.K. Maheshwari

President, ISET

Ph.D. (Japan), Post-doc (USA)

Member: ASCE, EERI, ISSMGE

Fellow: ISET, IGS, IWRS, IE (I),

Professor (HAG) & Head

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Message for ICSRI 2026 Participants

It is my pleasure to extend warm greetings to all the participants of the International Conference on Seismic Resilient Infrastructure i.e., ICSRI2026. This conference represents a vital platform for advancing our collective understanding of seismic safety and resilience, bringing together experts from academia, industry, and policymaking.

The ICSRI 2026 is organized by Varanasi Chapter of Indian Society for Earthquake Technology (ISET) and Dept. of Civil Engineering, IIT BHU. The presence of ISET a National Society on Earthquake Engineering in this endeavor adds immense value. As a premier professional body dedicated to earthquake engineering, ISET's involvement strengthens the bridge between research, practice, and policy, ensuring that the outcomes of this conference resonate widely and meaningfully.

At IIT Roorkee, there is a strong emphasize on the importance of integrating scientific rigor with practical solutions to safeguard communities against seismic hazards. I am sure that the deliberations in ICSRI2026 will inspire innovative approaches, foster interdisciplinary cooperation, and contribute to the global mission of disaster risk reduction and resilient infrastructure development.

I congratulate the organizers and ISET Varanasi Chapter for their vision and commitment. I wish all the delegates fruitful discussions and impactful collaborations. This conference will serve as a milestone in our shared journey toward safer and more resilient societies.

Best Wishes and Regards,

(B.K. Maheshwari)



प्रो. आर. प्रदीप कुमार

निदेशक

Prof. R. Pradeep Kumar

Director



सीएसआईआर - केंद्रीय भवन अनुसंधान संस्थान
रूड़की - 247 667 (भारत)

CSIR-Central Building Research Institute

(A constituent Establishment of CSIR)

ROORKEE-247 667- INDIA

Dear Prof Supriya,

Warm greetings from CSIR-CBRI!

It is a privilege to join the International Conference on Seismic Resilient Infrastructure – 2026 as Chief Guest and to witness this distinguished gathering of scholars, engineers, and policymakers committed to advancing resilience in our built environment.

Seismic safety is not merely a technical challenge—it is a societal imperative. The increasing complexity of urban systems and the growing exposure of communities to seismic hazards demand innovative approaches, interdisciplinary collaboration, and a shared vision for sustainable development.

CSIR-Central Building Research Institute (CBRI) has long championed research and innovation in structural safety, disaster risk reduction, and resilient infrastructure. This conference exemplifies the spirit of collaboration that is essential to translate scientific knowledge into practical solutions that safeguard lives and livelihoods.

I am confident that the deliberations here will inspire new pathways for resilient design, strengthen international cooperation, and contribute meaningfully to global efforts in disaster preparedness. Let us reaffirm our collective responsibility to build infrastructure that not only withstands seismic forces but also embodies sustainability, inclusivity, and human-centric progress.

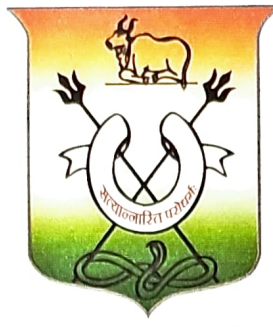
I extend my heartfelt congratulations to the organizers and best wishes to all participants for a successful and impactful conference.

With warm regards,

Prof. R Pradeep Kumar

Director, CSIR-CBRI, Roorkee

अशोक कुमार तिवारी महापौर



अ.शा.प.सं.-.....

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ई-मेल : ashokktiwari@bjp@gmail.com

पत्रांक : 30/महापौर कार / 2025-26

दिनांक 10/3/2026.

Dear Speakers, Participants and Organizers

It gives me immense pleasure to extend my heartfelt greetings and best wishes to the organizers, distinguished delegates, researchers, academicians, and industry experts participating in the International Conference on Seismic Resilient Infrastructure (ICSRI)-2026 at the Indian Institute of Technology (Banaras Hindu University), Varanasi held on 13th to 15th March 2026.

Varanasi, one of the world's oldest living cities and a global spiritual capital, witnesses a continuously increasing influx of religious pilgrims and visitors throughout the year. With large congregations, festivals, and mass movements of people, the city's infrastructure is subjected to significant dynamic loading and operational stress. In such a context, ensuring seismic resilience and structural safety is not merely a technical necessity but a civic responsibility.

As urban centers face growing challenges from seismic hazards, rapid urbanization, and increasing population density, the development of resilient infrastructure systems capable of withstanding natural disasters and supporting large-scale human movement becomes critically important. Conferences like this provide an essential platform for advancing research, sharing global best practices, and fostering collaborative solutions to safeguard lives and heritage.

IIT (BHU), Varanasi with its rich legacy of academic excellence and engineering innovation, has consistently contributed to nation-building through research and technological leadership. Hosting an international forum on seismic resilience reflects the institute's commitment to sustainable urban development and public safety.

I am confident that the deliberations, technical sessions, and discussions during this conference will generate valuable insights, foster international collaboration, and help formulate strategies to build safer, smarter, and more resilient infrastructure for rapidly growing cities like Varanasi and beyond.

I extend my sincere appreciation to the organizing committee for their commendable efforts and wish the conference every success.

With best regards,

(Ashok Kumar Tiwari)



International Conference on Seismic Resilient Infrastructure- 2026

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Earthquake Safety Assessment of Buildings For Increasing Infrastructure Resilience

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ABSTRACT

A significant portion of India's built environment remains highly vulnerable to earthquake-induced damage. This vulnerability stems from self-styled construction practices, lack of adherence to earthquake-resistant design standards, and the widespread presence of moderate to severe seismic zones across the country. With over 300 million buildings constructed without proper engineering oversight, the urgency to assess and retrofit these structures is critical to enhancing infrastructure resilience.

This paper will explore methodologies for evaluating the earthquake safety of existing buildings, emphasising scalable assessment techniques suitable for large-scale implementation. Additionally, emerging technologies, such as drone-based identification of structural features, will be discussed as innovative tools for rapid and efficient structural assessment.



Recent Advances in Seismic Soil-Structure Interaction

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ABSTRACT

Soil-Structure Interaction (SSI) is one of the design issues, which cannot be ignored for the structures founded on the weak soils particularly when these are subjected to strong excitation. During strong shaking, the behavior of soil is highly nonlinear; further if it is saturated loose sand, the liquefaction may occur. To deal effectively with such complex scenario, numerical modeling provides the best solution. For Soil-Structure Interaction considering earthquake loads, there are a number of important issues which need to be dealt rationally for a reasonably accurate analysis. First issue is modeling of unbounded soil media to satisfy the radiation conditions. Second, for dynamic loading, behavior of soil is frequency dependent and it needs to be taken care. Third is modeling material nonlinearity of soil. Fourth is modeling of liquefaction. To deal with boundary, both simplified and rigorous methods are available. To capture the frequency dependent behavior of soil, complex dynamic stiffness and unit impulse response function are discussed. To model the material nonlinearity of soil, equivalent linear, cyclic nonlinear and advanced plasticity models have been deliberated. To deal with liquefaction in numerical modeling, appropriate constitutive models are discussed.

Some of the new upcoming nuclear power plants (NPP) in India are proposed to be founded on the soft soil i.e. alluvium in active seismic zone, necessitating to consider SSI for analysis. Some of these will be founded on Combined Piled-Raft Foundation (CPRF). So far, no study has been reported considering nonlinearity of soil for the NPP structures founded on CPRF considering earthquake loads. The speaker and his research group examined the dynamic responses of raft, pile group and CPRF of a NPP simulating the nonlinear finite element model. The effect of nonlinearity is examined. The study indicated the importance of CPRF over the raft foundation and pile group foundation for the design of nuclear power plants. The same will be discussed in this lecture.

Keywords: *Soil-Structure Interaction, Raft, Pile Groups, Combined Piled Raft Foundation, Finite Element Method, Nonlinear Seismic Analysis, Nuclear Power Plant*



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GeoSutras – Principles for Modern Geopractice

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ABSTRACT

Geotechnical Engineering as a subdiscipline of Civil Engineering is hundred years old from the time enunciated his effective stress principle. The practice of geotechnical engineering has been following many of the tenets, e.g., linear stress – strain behavior, etc., rigid plastic (incompressible) material, homogeneous ground, etc. Recent developments have occurred over a variety of topics that reveal the true behavior of soils and the ground. GeoSutras highlight some of these new insights which have significant bearing on GeoPractice. The new approaches cover the influence of non-linear behavior on consolidation, effect of compressibility of the soil, consequence of ignoring over consolidation, non-uniqueness of deformation modulus, etc. The new paradigm Ground versus Soil will be presented.



Seismic Hazard and Geotechnical Vulnerability of Kashmir Valley

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ABSTRACT

The Kashmir Nappe Zone forms an asymmetrical synclinorium bounded by the Panjal Thrust and Zaskar Thrust. Its oldest basement comprises the Precambrian Salkhala Series and Dogra Slates (Wadia, 1931), overlain by Panjal Volcanics and Triassic limestones. The Kashmir Valley basin is primarily filled with Plio-Pleistocene Karewa deposits and Holocene alluvium. These formations create a unique geomorphological setting where elevated Karewa terraces coexist with low-lying alluvial floodplains. The surrounding mountains, wetlands, reclaimed swamps, and river systems further contribute to high spatial variability in soil conditions.

According to the seismic design provisions of Bureau of Indian Standards in IS 1893 (2016), the Kashmir Valley lies in seismic Zones IV and V, indicating very high earthquake hazard. The region has experienced several damaging earthquakes, including the Mw 7.6 2005 Kashmir earthquake, which caused landslides, ground fissures, flooding, structural damage, and significant loss of life. Liquefaction has also been reported in several parts of Jammu and Kashmir during past seismic events.

This study aims to evaluate the geotechnical and seismic behaviour of soil deposits in the Kashmir region and to develop simplified guidelines for selecting suitable foundation depths and ground improvement strategies for future development. A comprehensive geotechnical database from approximately 700 investigation sites across the valley was compiled to characterize soil properties and their spatial variability, particularly within Karewa highlands and alluvial floodplains. These data were integrated with geological information to develop basin-scale cross sections.

Seismic hazard assessment was conducted using deterministic and probabilistic approaches. An earthquake catalogue was prepared and seismicity parameters were estimated to generate peak ground acceleration (PGA) and spectral acceleration maps at bedrock. Based on PGA distribution, the region was divided into five seismic hazard zones with mean PGA values



ranging from 0.175 g to 0.514 g for a 2475-year return period.

Geophysical investigations at approximately 192 locations included Multichannel Analysis of Surface Waves (MASW) and microtremor measurements to estimate shear wave velocity and site frequency characteristics. VS30 values vary from 150–200 m/s in alluvial plains to 350–500 m/s in Karewa deposits and up to 900 m/s in hilly terrains. Joint inversion analyses indicate deep sedimentary deposits reaching depths of 900–1300 m.

Nonlinear ground response analyses reveal that these deep deposits amplify long-period seismic waves while attenuating short-period motions, which may significantly affect tall structures. Detailed liquefaction and bearing capacity assessments conducted for the Greater Srinagar region indicate that young alluvial deposits in the Jhelum floodplains are highly susceptible to liquefaction and possess low bearing capacity, necessitating deep foundations and ground improvement. In contrast, Karewa highlands show lower liquefaction potential but may experience seismic bearing capacity reduction. Integrated hazard assessment resulted in four vulnerability zones, providing guidance for foundation design and urban planning in the Kashmir Valley.



Enhancing Building Ductility, Stiffness and Strength for Earthquake Resistance

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ABSTRACT

Enhancing ductility, stiffness, and strength is essential for improving a building's earthquake resistance. Each property contributes differently to how a structure responds to seismic forces. The present work focuses on different methodologies available for improvement in ductility, stiffness and strength in structural systems. Ductility allows a structure to deform significantly without sudden failure, enabling it to dissipate earthquake energy. Strength ensures the building can withstand the seismic forces without structural failure. Stiffness reduces excessive lateral displacement and inter-story drift during earthquakes. The focus will be on discussing these aspects together with advanced protection techniques like base isolation.



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Future prospect of Artificial Intelligence (AI) in Seismic Resilient Infrastructure

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ABSTRACT

The development of seismic resilient infrastructure is key task in civil engineering. Traditional models have made various assumptions for designing seismic resilient infrastructure. However, Artificial Intelligence (AI) does not make any assumption. It uses only dataset for the development of model. In this article, various AI techniques {Deep Learning (DL), Random Forest (RF), Recurrent Neural Network (RNN), K Nearest Neighbour (KNN), Decision Tree (DT), Classification and Regression Trees (CART), Logistic Regression (LR), Histogram-based Gradient Boosting (HGB) and Naive Bayes (NB)} have been employed in the various fields of earthquake engineering such as liquefaction, ground motion, etc. Various examples will be given to show the working procedures of AI models in different problems of earthquake engineering. The use of MATLAB for development of different AI techniques will be also described in this article. The practical application of various AI will be discussed in the field of earthquake engineering. This article also gives the advantages & disadvantages of various AI techniques.



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Significance of Nonstructural Systems and Components as Key Drivers of Operational Continuity in Seismic and Multi-Hazard Environments

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ABSTRACT

Over the past few decades, research on the seismic performance of nonstructural systems and components (NSCs) has significantly advanced in life-safety objectives, and operational continuity. It is now desired that future seismic design not only takes care of collapse prevention but also ensures rapid recovery of critical systems and facilities such hospitals, data centers, water supply network, power generation & distribution systems, and various industrial facilities. This aspect specifically requires performance metrics that explicitly quantify downtime, recovery trajectories, and system-level functionality rather than isolated component fragility, which has been the focus of much of the research carried out till date. However, any attempt in this direction must integrate multi-hazard exposure (seismic combined with wind, flood, or environmental degradation) for deterioration-informed fragility and resilience models. This presentation will focus on these aspects toward a unified, probabilistic and multi-hazard framework for seismic resilience of nonstructural systems and components.



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Geotechnical Seismic Hazard Evaluation and Mitigation in Engineering Practice

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ABSTRACT

Several dams in the Pacific Northwest were constructed prior to the 1990s. Seismic performance of these dams was not considered in the original design. This is typical of most projects constructed before that time as the seismic hazard in the region was thought to be minimal at the time. However, the current understanding of the seismic hazard in the area indicates significant seismic hazard from both crustal and Cascadia subduction zone sources. Therefore, owners and agencies are identifying which of these dams are high hazard and require mitigation from seismic hazard in the next decade. This presentation will focus on procedures used for screening level geotechnical seismic evaluation of these dams that are currently used in engineering practice, using case studies. Evaluation of the potential for slope instability, settlement, and lateral movement; and identification of other potential seismic hazards that are associated with design earthquake(s) will be discussed. Mitigation measures to limit the potential for seismically induced ground displacement are discussed.



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Seismic Performance Assessment of Framed Building with Base Isolators of Special Configurations

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ABSTRACT

Several dams in the Pacific Northwest were constructed prior to the 1990s. Seismic performance of these dams was not considered in the original design. This is typical of most projects constructed before that time as the seismic hazard in the region was thought to be minimal at the time. However, the current understanding of the seismic hazard in the area indicates significant seismic hazard from both crustal and Cascadia subduction zone sources. Therefore, owners and agencies are identifying which of these dams are high hazard and require mitigation from seismic hazard in the next decade. This presentation will focus on procedures used for screening level geotechnical seismic evaluation of these dams that are currently used in engineering practice, using case studies. Evaluation of the potential for slope instability, settlement, and lateral movement; and identification of other potential seismic hazards that are associated with design earthquake(s) will be discussed. Mitigation measures to limit the potential for seismically induced ground displacement are discussed.

**AI/ML-based methods for liquefaction susceptibility of soil due to seismic
excitation: Present Developments and Future challenges**

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ABSTRACT

Earthquake-induced soil liquefaction is a major geotechnical hazard that not only affects the existing infrastructure but also causes danger to lifeline. With massive construction of waste containment impoundment to store the industrial wastes has further necessitated the accurate and real-time monitoring of the soil liquefaction. The use of artificial intelligence and machine learning (AI/ML) techniques to predict the liquefaction susceptibility of soil. These data-driven AI/ML-based methods have been proved to be very efficient in handling large datasets to capture the non-linear relationship involved in liquefaction phenomenon.

This study comprehensively presents a review on the recent advancements in the application of AI/ML-based methods for earthquake-induced soil liquefaction for deterministic and probabilistic methods. The study discusses the AI/ML-based methods in context of field and laboratory tests including Standard Penetration Test (SPT), Cone Penetration Test (CPT) and shear wave velocity (V_s) data. The key challenges and limitations that restrict the widespread adoption of AI/ML models in liquefaction analysis is highlighted. The issues related to availability of high-quality data, interpretability of the models and their generalization capabilities, and their practical applicability. Furthermore, the study directs towards future research to improve the physical interpretability, model transparency and reliability of data-driven AI/ML-based techniques with physics-informed neural network (PINN) and deep neural networks are discussed. Finally the integration of physical space with virtual reality through data connectivity in the framework of digital Twin (DT) for earthquake-induced liquefaction susceptibility assessment is presented.

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**Invited
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Sustainable Construction Techniques for Tunnels and Deep excavations

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ABSTRACT

Recently there has been a marked increase in the construction of major highway and railway tunnels and deep excavations due to increase in Infrastructure growth in transportation sector. Present practice of construction mostly relies heavily on traditional techniques and conventional materials, leading to increase in pollution levels, CO₂ emissions and global warming Tunneling projects and the associated deep excavations involve consumption of high levels of energy and conventional material with little or no significant concern about the environment or ecological systems. To counter this trend, new techniques of construction are emerging in tunnel infrastructure sector which ensure infrastructure development duly safeguarding sustainability requirements of environmental protection, resource efficiency and social responsibility. This study examines the principles, challenges, and emerging practices of sustainable tunnel construction and sustainable material with emphasis on minimizing environmental impact while ensuring safety, durability, and economic viability. Key aspects discussed include optimized design of tunnel alignment and approaches, cross-section of tunnel to reduce excavation volumes, adoption of energy-efficient methods such as mechanized tunneling, design blasting and use of sustainable material that involve low-carbon emissions in tunnel linings, shotcrete, support systems and the protection measures of deep excavations. Advanced ground investigation, real-time instrumentation, and digital technologies such as Building Information Modeling (BIM) and digital twins are highlighted for their role in improving design accuracy, reducing uncertainties, and minimizing construction risks and rework. Sustainable management of excavated material, groundwater control, ventilation, and waste is also addressed, along with measures to protect biodiversity and nearby communities. A case study of the author in NF Railway is also discussed where surplus soil from deep excavations was converted to usable soil-cement blocks, thereby effecting considerable saving on cost as per life-cycle costing and reduction in CO₂ levels as per life cycle analysis, providing employment to locals and



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enhancing the aesthetic appeal to ensure sustainability of tunnels and high cuttings. The study concludes that sustainable tunnel construction is achievable through a holistic approach combining engineering excellence, and policy support, making it a cornerstone for resilient and future-ready transport infrastructure worldwide.



Self-Centering Precast Post-Tensioned Shear Walls in Seismic Areas

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ABSTRACT

Self-centring precast post-tensioned (PT) shear walls represent an innovative seismic-resistant structural system aimed at minimising damage and residual deformation during strong earthquakes. Unlike conventional reinforced concrete shear walls that dissipate seismic energy through yielding and cracking, PT shear walls are designed to rock at the base, with post-tensioning tendons providing restoring forces that enable re-centering after seismic events. This presentation discusses numerical and experimental studies evaluating the seismic performance of PT shear walls in comparison with conventional shear wall systems. Key response parameters such as strength, stiffness degradation, hysteretic behavior, energy dissipation, and residual drift are examined. The inherently low energy dissipation of pure self-centering systems is addressed through the incorporation of external energy dissipating devices, such as replaceable steel fuses. Results demonstrate that hybrid PT shear wall systems achieve an effective balance between self-centering capability and energy dissipation, offering a resilient, repairable, and performance-based alternative for construction in high seismic regions.



Nano-Silica Modified Cement Composites for Resilient Infrastructure

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ABSTRACT

Material performance is fundamental to achieving seismic-resilient infrastructure. This invited talk presents the development of nano-silica modified multi-blended cementitious composites designed to enhance strength, durability, and microstructural stability under demanding service conditions.

Colloidal nano-silica (0.5-3.5%) was incorporated into binary, ternary, and quaternary blended systems containing fly ash (FA) and ultrafine fly ash (UFFA). An optimum dosage of 3% nano-silica was identified based on compressive strength performance. Advanced characterization techniques (TGA, XRD, SEM-EDX) revealed that nano-silica significantly accelerates hydration kinetics, enhances pozzolanic reactivity, and refines pore structure, leading to a denser and mechanically robust matrix.

The synergistic incorporation of FA, UFFA, and nano-silica, guided by particle packing principles, resulted in improved early-age strength development, enhanced durability characteristics, and reduced microstructural defects. The quaternary blended system demonstrated superior performance compared to conventional mixes, indicating its suitability for high-performance structural applications.

The findings highlight that optimized nano-silica based multi-blended cementitious composites offer a sustainable and high-strength material solution for seismic-resilient infrastructure in hazard-prone regions.



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Plasticity-Based Stress Characteristics Approach for Geotechnical Stability Analysis

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ABSTRACT

Accurate evaluation of earth pressures and stability of geotechnical structures under static and seismic loading remains challenging due to the presumption of failure surfaces in many conventional theories. Plasticity-based formulations provide a rigorous alternative by allowing failure mechanisms to develop naturally from stress equilibrium and yield conditions. This invited talk presents a semi-analytical stress characteristics framework based on the theory of plasticity, in which the governing hyperbolic stress equations are solved using a stress characteristics and finite difference scheme. The approach enables direct computation of stress fields and emergent failure surfaces without predefined geometry, offering high accuracy with computational efficiency. The proposed methodology is semi-analytical in nature and is capable of addressing a wide range of geotechnical problems, including earth pressure calculation and stability analysis of retaining structures and foundations under static and seismic conditions.



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Indian Institute of Technology (BHU) Varanasi, India
13th- 15th March, 2026

Hybrid Simulation: Theory and Applications

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ABSTRACT

Hybrid simulation (HS) is an accurate and cost-effective method of simulating the seismic response of structural systems. In this simulation, a complete system is discretized into coupled domains of numerical and physical substructures, and the dynamic response of the system is determined by solving the equations of motion using a direct integration algorithm. The method integrates the benefits of computational simulation and physical testing. Real-time hybrid simulation (RTHS), i.e., HS conducted in real time, is particularly useful for the performance assessment of structures with rate-dependent devices. This talk will begin with the theory of HS and RTHS and their implementation in the Pseudo-Dynamic Testing Facility (PDTF) at IIT Kanpur. Key challenges in large-scale RTHS of complex structural systems, along with means to overcome them, will be highlighted. Several examples of completed and ongoing HS and RTHS involving not only earthquakes, but also other hazards will be presented.



Re-Engineering Earth Block Construction for Seismic-Resilient Low-Rise Housing in India: Development of Ultra-Compressed Masonry Systems

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ABSTRACT

Masonry is the dominant residential construction system in India, with nearly 70–80% of buildings constructed using load-bearing masonry walls, as reported in the Government of India Housing Census. A significant portion of this construction is non-engineered, primarily driven by affordability constraints. Such construction typically relies on locally produced, non-standardized masonry units such as fired clay bricks, concrete blocks, or sun-dried bricks. These conventional masonry units require energy-intensive manufacturing processes that contribute significantly to carbon emissions and demand considerable production time and storage space. Fired clay bricks involve high-temperature kiln firing and require time for both firing and cooling. Concrete blocks require cement (which is energy- and carbon-intensive) and require curing time before they can be used in construction. In this presentation, the development of ultra-compressed stabilized earth block (UCSEB) masonry for seismic-resilient housing in India is presented. Ultra-compaction improves the mechanical and physical properties of the blocks and provides sufficient green strength to allow their use in masonry construction immediately after fabrication. The long-term properties of the blocks demonstrate that masonry built with such blocks can achieve sufficient performance for seismic-resilient low-rise buildings. The UCSEB masonry system provides a practical alternative for low-rise housing that is affordable, environmentally responsible, and suitable for rapid construction.

Micromechanical insights on the flow-liquefaction phenomena of granular soil: Effect of particle morphology, loading rate and its direction

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ABSTRACT

Undrained shearing response of saturated loose granular soil usually depicts a sudden loss in shear strength marking the emergence of flow-liquefaction type undrained or solid-fluid instability. For real field cases, such solid-fluid instability leads to catastrophic failure of geotechnical structures resulting in loss of life and property. In case of earthquake induced liquefaction, the loading is generally displacement/strain controlled with existence of a generalized strain state. Consequently, consideration of various strain paths becomes crucial while analysing the mechanical response of saturated loose sand subjected to undrained shearing. Additionally, loading rate can also significantly affect the mechanical behavior and undrained instability response of such soils, even for other geotechnical applications like pile driving, dynamic compaction and underground blasting involving loading of medium to high strain-rate range. For such cases, the interplay between drainage scenarios and loading rate will critically govern the generation of excess pore-water pressure and its subsequent dissipation process. The inherent material rate-sensitivity may further add complexities to it. This presentation delves into the micro-mechanics associated with flow-liquefaction phenomena in granular soil with a particular focus on particle morphology, loading rate and its direction. In this regard, 3D Discrete Element Method (DEM) based simulations of constant volume true-triaxial test have been carried out for loose granular soils at different strain rates and along various strain paths by controlling the intermediate strain ratio. A rolling resistance type contact model has been employed to indirectly cater the particle shape effects within the numerical framework. With increasing strain rate, significant reduction in the generation of pore-water pressure has been observed owing to the underlying suppressed particle rearrangement at higher rates. This leads to a delayed onset of complete liquefaction for the specimen in conjunction with enhanced peak deviatoric stress. Further, such a rate-sensitive response has been observed



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to be more significant for granular assembly of higher rolling resistance mimicking more irregular shaped particles. Additionally, a reduction in liquefaction susceptibility becomes evident with increasing intermediate strain ratio, which is attributed to enhanced particle contacts in the major and intermediate principal stress direction, leading to increased mean confinement.



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Sustainable Performance Enhancement of Masonry Walls with Textile- and Wire-Reinforced Mortar Composites

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ABSTRACT

An experimental overview is presented on the sustainable performance enhancement of unreinforced masonry (URM) walls using textile-reinforced mortar (TRM) and wire-reinforced mortar (WRM) composite systems. Masonry specimens strengthened with externally bonded composite layers are evaluated under out-of-plane bending conditions to examine the effectiveness of these retrofitting interventions. The lecture will discuss the role of reinforcement configuration, material compatibility, and reinforcement ratio in improving the structural response of masonry walls. Particular emphasis will be placed on strength enhancement, stiffness improvement, crack control, ductility, and energy absorption capacity. The session will further highlight the potential of textile- and wire-reinforced mortar composites as sustainable, cost-effective, and compatible strengthening solutions for both existing and heritage masonry structures.



Seismic Safety Strategy of Masonry Structures: Challenges and Way Forward

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ABSTRACT

Poor seismic performance of masonry (most preferred housing of common people in most of the developing countries and the prime constituents of ancient/heritage structures) is well documented in literature. The brittle failure of such structures during earthquake events (even in moderate earthquakes) lead to huge casualties, loss of economy and potential damage to ancient/heritage structures. Wide variations of material characteristics (brick/stone and mortar) and presence of bond between the materials (head joint and bed joint), makes the behaviour of masonry a complex phenomenon. Predominant nature of failure includes; shear, tension, diagonal and junction. Most of the strengthening strategy are focussed on application of composite materials. However, its availability and cost makes it far beyond the reach of common people. A few sustainable, cost-effective, easily applicable and straight forward strategy are also applied towards the seismic safety of masonry successfully. However, most of these are limited to the laboratory application. It's the need of the hour to popularize the same among the users and technical community for extending the applicability from lab to land. Effort may be made towards its standardization and availability of design guidelines. The policy makers and the technical community may have to play crucial role with the researchers for successful transformation of the strategy from lab to land, which may lead to sustainable infrastructure.



Smart Rainwater Utilization and Drone-Enabled Monitoring for Seismic-Resilient Educational and Public Infrastructure

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ABSTRACT

Urban educational institutions and public buildings are increasingly vulnerable to both water scarcity and seismic disruptions. Conventional centralised municipal water supply systems are highly susceptible to earthquake-induced failures, leading to functional paralysis of critical infrastructure such as sanitation systems, fire safety reserves, and emergency utilities. This lecture proposes a decentralized, smart rainwater utilization framework integrated with UAV (drone)-based inspection and monitoring systems to enhance sustainability and seismic resilience in institutional infrastructure.

This lecture emphasizes rooftop rainwater harvesting (RWH) systems designed specifically for non-potable applications, including toilet flushing, landscape irrigation, cleaning operations, and emergency water reserves.

To enhance operational efficiency and post-disaster rapid assessment, the system integrates drone-enabled technologies for roof catchment inspection, blockage detection, crack identification in overhead tanks, thermal leak detection, and GIS-based campus drainage mapping. UAV-supported inspections reduce manual risk exposure and allow rapid condition assessment immediately following earthquakes, thus accelerating recovery timelines.

The proposed integrated system contributes to seismic functional resilience, water security, climate adaptation, and sustainable infrastructure development. The framework aligns with SDG 6 (Clean Water), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action). This interdisciplinary approach bridges water resource engineering, structural resilience, smart infrastructure, and UAV-based monitoring technologies, offering a scalable model for campuses, hospitals, and public facilities in seismic-prone regions.

Seismic Stability of Slopes Subjected to Foundation Loads: Threshold Load Behaviour and Failure Mechanisms - A Case Study

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ABSTRACT

The construction of buildings on sloping ground significantly alters slope stability, particularly under seismic excitation. Conventional slope stability analyses typically consider free slopes; however, the presence of foundation loads acting as surcharge can fundamentally modify failure mechanisms and available safety margins. This study presents a detailed case study investigating the seismic stability of a natural hill slope subjected to foundation loads. Finite Element Limit Analysis (FELA), in conjunction with the Strength Reduction Method, is employed to evaluate the variation of Factor of Safety (FOS) with increasing footing load under pseudo-static seismic conditions. The results reveal a characteristic response: the FOS remains nearly constant at low loading intensity, followed by a sudden reduction beyond a critical value defined as the threshold load. This transition corresponds to a shift in failure mechanism from global slope instability to localized failure beneath the footing. The study further demonstrates the influence of slope angles, seismic coefficient, footing width, and edge distance on both the threshold load and overall seismic stability. Design charts and empirical relationships developed from the investigation are applied to the selected site to estimate allowable foundation loads and associated seismic safety margins. The findings emphasize that neglecting foundation surcharge in seismic slope analysis may lead to unconservative assessments. The proposed framework provides a rational and mechanics-based approach for evaluating the stability of slopes supporting structural loads in earthquake-prone regions.

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Participants

Paper ID: 04

A Study on Seismic Risk Analysis using Machine Learning

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

Seismic resilience in high-density urban areas is often compromised by the complex interplay between local soil conditions and structural dynamics. This study proposes a Machine Learning (ML) framework designed to quantify seismic risk by integrating spatial hazard data with building-specific resonance analysis. The methodology utilizes an ensemble learning approach to map regional seismic risk levels and predict site-specific soil classifications. Central to this research is the development of a predictive "Resonance Index", which synthetically combines building natural frequencies derived from height and structural systems with the fundamental frequency of the underlying soil strata. By identifying zones where soil-structure resonance is likely to occur, the model provides a high-fidelity assessment of potential structural collapse beyond traditional shaking intensity metrics. The framework was tested using historical seismic catalogs and geotechnical borehole data, demonstrating a significant improvement in identifying high-vulnerability structures compared to standard screening methods. The results offer a scalable tool for urban planners and engineers to prioritize seismic retrofitting and disaster mitigation strategies in high-seismic zones.

Keywords: *Seismic Resilience, Resonance Index, Urban Risk Mapping, Soil-Structure Resonance, Seismic Vulnerability.*

Paper ID: 08

Reliability-Based External Stability Evaluation of Gravity Retaining Walls under Seismic Conditions Using LHC-MCS

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

The performance of gravity retaining walls (GRWs) is strongly influenced by inherent uncertainties in soil properties, which are not adequately addressed using conventional deterministic design approaches. To overcome this limitation, the present study employs a probabilistic and reliability-based framework using Latin Hypercube based Monte Carlo Simulation (LHC-MCS) for external stability of GRWs assessment under latest seismic zone of India. Furthermore, system level of reliability analysis was investigated using approximate series reliability method. Random samples of geotechnical parameters were generated using specified mean values and coefficients of variation (COVs) to capture the inherent variability in soil behavior. A total of 8000 samples were generated for probabilistic simulations, with the sample size selected based on the convergence of the probability of failure curves to ensure statistical stability of the results. The study systematically investigates the influence of soil uncertainty by considering four combinations of COVs, where the friction angle varies between 3% and 4%, unit weight between 4% and 6%, and cohesion between 10% and 30%. The probabilistic responses corresponding to sliding, overturning, and bearing capacity failure modes are evaluated, followed by a system reliability assessment using a series-system configuration. The results demonstrate the effectiveness of the proposed MCS-based reliability framework in realistically quantifying the stability performance of GRWs under parametric uncertainty.

Keywords: *Seismic Analysis, Reliability, Probability of Failure, MCS, Retaining Wall*

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Paper ID: 09

Reliability-Aided Soft Computing Approach for Evaluating External Stability of Reinforced Soil Retaining Walls Under Static and Seismic Conditions

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

This study proposes an integrated framework for evaluating the external stability of reinforced soil (RS) retaining walls under static and seismic conditions by combining probabilistic analysis with system reliability concepts and soft computing techniques. The assessment considers three governing failure modes sliding, overturning, and bearing capacity under static and seismic conditions using deterministic formulations followed by probabilistic evaluation through the First Order Second-Moment method. To capture the interaction among individual failure mechanisms, a sequential compounding approach is adopted for system reliability assessment under multiple loading scenarios. Uncertainty in soil and structural parameters is incorporated through statistical characterization, enabling realistic estimation of reliability measures beyond conventional FOS-based design. In addition, soft computing models, including the Generalized Regression Neural Network and Probabilistic Neural Network, are developed to predict FOS and corresponding reliability indices, thereby reducing computational effort while maintaining consistency with probabilistic principles. The proposed framework provides a systematic and efficient tool for system-level stability assessment of RS retaining walls under static and seismic conditions, offering enhanced insight into failure mechanisms and supporting reliability-informed geotechnical design practices.

Keywords: *System Reliability, Retaining Wall, External stability, Machine Learning*

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Paper ID: 11

Vibration based Monitoring of Steel Pile considering Soil Nonlinearity

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THEME: Seismic soil-structure interaction

ABSTRACT

Vibration based health monitoring (VHM) of piles depend on the analysis of dynamic signals, where the role of soil–pile interaction is often significant but commonly simplified in numerical studies. To address this, a three-dimensional finite element model (FEM) is developed to investigate the dynamic response of steel piles subjected to exponentially increasing harmonic (EIH) loading, with emphasis on the effect of soil nonlinearity. Soil behaviour is represented using Linear Elastic (LE), Mohr–Coulomb (MC), and Hardening Soil-small (HS-small) constitutive models. Localized pile damage is introduced in the form of thin half-circular and full-circular stiffness reduction zones with reduced Elasticity. The EIH load is applied at the pile top, while viscous boundary conditions are maintained along the lateral and bottom boundaries with the top surface remaining free. The pile response is analysed through velocity time histories, force response, frequency content and impedance characteristics. The results show that nonlinear soil behaviour alters wave attenuation and dynamic response when compared to the LE assumption. Among the models considered, the HS-small model captures the highest energy dissipation and more realistic signal decay due to strain-dependent stiffness degradation which help us differentiate intact pile from damaged pile conditions. Overall, the results show that realistic nonlinear soil behaviour and damping must be considered to obtain reliable predictions of steel pile response under VHM loading.

Keywords: *Steel pile, VHM, EIH, FEM, Dynamic soil–pile interaction, Soil nonlinearity*

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Effect of Nonlinear Soil Behaviour on Pile Integrity Test

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THEME: Seismic soil-structure interaction

ABSTRACT

Pile integrity test (PIT) is a commonly used method for the damage assessment of pile foundations; however, the interpretation of test results is strongly influenced by soil–pile interaction effects that are often simplified in numerical analyses. Hence, a three-dimensional finite element analysis (3D FEA) of the dynamic response of concrete piles subjected to impulse loading is studied, with particular emphasis on the role of soil nonlinearity and damping. Linear Elastic (LE), Mohr–Coulomb (MC), and Hardening Soil-small (HS-small) constitutive models are employed to represent soil behaviour, while localized pile damage is modeled as thin half-circular and full-circular stiffness reduction zones with reduced Young's modulus. An impulse load is applied at the pile head with viscous boundary conditions maintained across all sides while top free. The pile response is examined in terms of velocity time histories, force response, frequency content, and impedance characteristics. The outcomes demonstrate that nonlinear soil behaviour significantly changes wave attenuation and dynamic response with respect to LE model. The HS-small model represents a better signal decay through strain-dependent stiffness, allowing clearer identification of damage effects in piles. The findings highlight the importance of incorporating nonlinear soil behaviour and damping mechanisms for reliable numerical interpretation of steel PIT responses.

Keywords: *Concrete pile, PIT, FEA, Dynamic soil–pile interaction, Soil nonlinearity*

Paper ID: 14

System reliability assessment of geotextile retaining wall using artificial neural network

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

This study explores the integration of artificial neural networks and system reliability analysis to assess the stability of geotextile-reinforced retaining walls under seismic loading. The research combines a simple feed-forward artificial neural network (ANN) model with reliability-based methods to address the uncertainties inherent in geotechnical problems. The primary objective is to evaluate the stability of retaining walls under various failure modes, including sliding, overturning, bearing capacity, tensile rupture, and pullout, by incorporating earthquake effects using a pseudo-static seismic approach. In the analysis, soil parameters are considered as stochastic variables, while geometric and reinforcement parameters are treated as deterministic. The ANN model is developed to predict the factor of safety by capturing the complex nonlinear relationships between input parameters such as soil friction angle, unit weight, cohesion, geotextile tensile strength, and seismic acceleration coefficient. The results demonstrate that the ANN model provides reliable predictions for all failure modes. Furthermore, the First-Order Second Moment (FOSM) method is employed to quantify the reliability of geosynthetic retaining structures considering multiple seismic failure mechanisms. The system reliability analysis demonstrated the influence of seismic loading on overall structural performance. The proposed ANN-FOSM based framework provides a simple, efficient, and practical tool for probabilistic seismic stability assessment of geotextile-reinforced retaining walls.

Keywords: *Reliability, Retaining Wall, System Reliability, Artificial Neural Network*

Paper ID: 16

Use of Waste Tire Rubber Chips as a Partial Replacement to The Coarse Aggregates in Concrete

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THEME: Miscellaneous

ABSTRACT

The control of vibration in concrete structures is a critical requirement for improving structural durability, serviceability, and occupant comfort, particularly in structures subjected to dynamic loads such as machinery foundations, bridges, and buildings in seismic or traffic-prone zones. In recent years, disposal of the scrap tire is of great concern in many countries across the globe, and the utilization of waste materials in construction has gained significant attention due to environmental and sustainability concerns. Used tires are recommended for usage in a variety of sectors due to their durability. The usage of derivatives, used tire is reported in many recent researches for a variety of civil engineering applications. Partial replacement of coarse aggregate with rubber chips raises the concrete's damping capacity but reduces a larger amount of strength. Waste tire rubber chips were introduced into the concrete mix in varying percentages, and their effect on mechanical properties and dynamic behavior was experimentally assessed. Laboratory tests were conducted to determine compressive strength, split tensile strength, and flexural strength, while vibration characteristics were analyzed using damping ratio, and vibration amplitude under dynamic loading circumstances. The results show that the addition of rubber chips improves the energy absorption capacity and damping characteristics of concrete, The damping ratio of rubberized concrete is much better than that of PC. Rubberized concrete can absorb more vibrational energy than PC. However, a marginal reduction in strength properties was observed with increasing rubber content.

Keywords: *Concrete structures, structural durability, dynamic loading*

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Paper ID: 17

A NURBS-Augmented Finite Element Approach for Flexural Vibration of Orthotropic Plates

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THEME: Miscellaneous

ABSTRACT

The free vibration response of plates is mainly affected by their geometric configuration and material properties. Isogeometric Analysis (IGA) is a powerful numerical tool where Non-Uniform Rational B-Splines (NURBS) are used to describe both the geometry and the solution fields. Nevertheless, a significant challenge arises from the non-interpolatory nature of NURBS basis functions, which lack the Kronecker-Delta property. This drawback makes it difficult to directly apply the essential boundary conditions. To address this problem, the current study uses the NURBS-Augmented Finite Element Method (NAFEM). In this coupled method, geometry and solution variables are described separately using NURBS and conventional finite element shape functions, respectively. The latter have the advantage of satisfying the Kronecker-Delta condition, thus making it easy to enforce boundary constraints accurately. The current study generalizes the NAFEM approach for the free flexural vibration analysis of orthotropic plates. The approach takes into account the direction-dependent material properties, and the eigenvalue problem is solved to determine the natural frequencies and modes. Numerical studies involving different geometries and boundary conditions are used to validate the accuracy and effectiveness of the approach. The results show that the natural frequencies are in close agreement with the exact solutions reported in the literature. Moreover, new results for arbitrarily shaped orthotropic plates are provided and can be used as a reference solution in future studies.

Keywords: *Orthotropic Plates, Free Vibration*

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Influence of Perforated Interlayers on Wave Transmission Characteristics in Multi-Layer Structures

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Multilayer structures provide a versatile framework for achieving broadband wave insulation and absorption through layering of materials. By designing the layer sequence and interfacial characteristics, these systems enable effective control of acoustic wave propagation. In this study, the sound transmission loss characteristics of double leaf and triple leaf multilayer structures are investigated by incorporating perforated plates. The analysis is carried out under diffuse incidence conditions using the transfer matrix method (TMM). Initially, it is formulated for infinite panels over incidence angles ranging from 0° to 78° . To capture the finite panel effects, the infinite TMM formulation is extended through the incorporation of radiation efficiency which introduces geometric dependency in the transmission loss. This enables the evaluation of transmission loss over a wide frequency range, with a Gaussian weighting function applied to obtain more realistic results. The acoustic impedance of the perforated plate is governed by the characteristic impedance of air and acoustic resistance of the panel, sound quality and the perforation ratio defined as the area of hole to area of the surface area of plate. The acoustic performance of different multilayer configurations is compared based on sound transmission loss and sound transmission class (STC) in accordance with ASTM E413 for each configuration. A detailed parametric study is conducted to examine the influence of panel thickness for both solid and perforated plates, the perforation ratio and the air gap between adjacent layers. The effects of these parameters on sound transmission are analyzed to examine the performance improvements across different structural configurations.

Keywords: *Sound Transmission Loss, Sound Transmission Class, Multi-Layer Structures, Perforated Panels, Transfer Matrix Method, Sound Insulation*

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Paper ID: 25

An experimental Study on Evolution of Correspondence between California Bearing Ratio (CBR) and Dynamic Cone Penetrometer (DCP) Test

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

The subgrade soils of Kashmir Valley exhibit significant spatial variability due to diverse geological formations and are further influenced by frequent seismic activity, making reliable evaluation of subgrade strength essential for flexible pavement design. The California Bearing Ratio (CBR) test is conventionally used for this purpose; however, it is time-consuming and often impractical for extensive in-situ evaluation in mountainous and seismically sensitive regions. The Dynamic Cone Penetrometer (DCP) test offers a rapid and economical alternative, provided reliable correlations with CBR values for local conditions. Such a database can facilitate rapid subgrade evaluation for resilient pavement design and post-earthquake damage assessment.

The objective of this study is to establish a correlation between CBR values and DCPT results for subgrade soils of Kashmir Valley. Field and Laboratory investigations were carried out at twelve field locations comprising alluvial and lacustrine soil deposits. Field testing included DCP and core cutter tests, while laboratory investigations included soaked and unsoaked CBR tests, grain size analysis, Atterberg Limits, moisture content, specific gravity and Standard Proctor Compaction tests. Empirical correlations between DCPT results and CBR values were developed by simple and multivariate parametric regression analysis using MS-Excel tool. The developed correlations showed strong predictive capability with correlation coefficients (R^2) >0.90 . The results demonstrate a clear inverse and consistent relationship between CBR and DCPI for the soils studied. The study concludes that DCPT can be reliably used for rapid subgrade strength evaluation and preliminary pavement design in Kashmir region, significantly reducing dependence on conventional CBR testing.

Keywords: *Dynamic Cone Penetrometer (DCP), California Bearing Ratio (CBR), Subgrade*

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Paper ID: 26

Machine Learning Based Assessment of Charnockite Rock Strength for Structural Engineering via Non-Destructive Evaluation

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

The Uniaxial Compressive Strength (UCS) of the rock is a key geo-mechanically parameter to be use in the design of foundations, tunnels, slopes, and other civil and mining engineering structures. Direct determination of UCS through laboratory testing is often constrained by sample quality, availability, and high cost, especially for anisotropic and weathered rocks. As a solution, this study explores indirect estimation of UCS using advanced machine learning models. Specifically, two deep learning architectures Convolutional Neural Network (CNN) and Deep Neural Network (DNN) were developed in Python to predict the UCS of Charnockite rocks based on 100 experimentally collected samples from Chennai. The input variables used were Ultrasonic Pulse Velocity (UPV), Schmidt Hammer Rebound Number (N), Brazilian Tensile Strength (BTS), and Point Load Index (PLI). The performance of the models was evaluated using multiple statistical indicators, including Mean Absolute Error (MAE), Coefficient of Determination (R^2), Root Mean Square Error (RMSE), Nash–Sutcliffe Efficiency (NS), Performance Index (PI), Root Square Residual (RSR), Willmott Index (WI), and Weighted Mean Absolute Percentage Error (WMAPE). The CNN model demonstrated superior performance with $R^2 = 0.9746$, MAE = 0.0193, and RMSE = 0.0342, followed closely by the DNN model with $R^2 = 0.9720$, MAE = 0.0173, and RMSE = 0.0398. Among the influencing factors, UPV emerged as the most significant parameter in UCS prediction. These findings affirm that deep learning methods offer a reliable and efficient alternative for estimating UCS, minimizing the need for destructive testing and enhancing decision-making in geotechnical engineering.

Keywords: *Uniaxial Compressive Strength, Ultrasonic Pulse Velocity, destructive testing*

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Cyclic Response of Agar Gum-Stabilised Black Cotton Soil

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THEME: Dynamic properties of soil and ground response

ABSTRACT

The vulnerability of black cotton soils (BCS) to cyclic degradation makes them a major risk to infrastructure in seismically active areas. The aim of this research is to investigate if agar gum, a natural biopolymer, has any effect on the cyclic/dynamic properties of BCS. The cyclic/dynamic tests were conducted on soil samples with varying concentrations of agar gum (0%, 0.5%, 1.0%, 1.5%, and 2.0% by dry weight) at the maximum dry density and the optimum moisture content. The soil samples were cured for 7 days before being subjected to 100 cycles of cyclic loading at 0.5 Hz, with a confining pressure of 50 kPa and a cyclic stress amplitude of ± 30 kPa. Axial strain accumulation, energy dissipation, excess pore pressure, resilience modulus, and shear modulus degradation were assessed as key dynamic characteristics. The findings show that agar gum considerably increases cyclic resilience. After 100 cycles, axial strain decreased by 76.5% (from 5.10% to 1.20%), permanent strain decreased by 35.7%, and peak excess pore pressure decreased by 67.1% at 2.0% agar content in comparison to untreated soil. The damping ratio dropped and the robust modulus showed noticeably higher retention, suggesting improved elastic recovery under repeated loading. The development of hydrogel networks, which bind particles and limit the flow of pore fluid, is responsible for these advancements. According to the study, agar gum shows promise as an environmentally safe addition for applications involving seismic ground enhancement.

Keywords: *Black Cotton Soil, Agar Gum, Cyclic Loading, Seismic Ground Improvement*

Paper ID: 28

Enhancing Seismic Safety of Structures Using Base Isolation Technology

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THEME: Earthquake disaster mitigation and management

ABSTRACT

Earthquakes are one of the major classes of natural hazards, very often resulting in significant damage and even structural collapses due to severe shaking of the ground. In conventional fixed base buildings, the transmission of ground motion from the foundation to the superstructure may cause significant distress in both structural and non-structural elements. Thus, effective earthquake disaster mitigation and management need for an advanced strategy toward improving seismic resilience and reducing vulnerability. Base isolation technology has been identified as one of the best seismic mitigation measures of safeguarding structures against the effects of earthquakes. In this type of structure, isolators are placed between the substructure and the superstructure as an inserted component, isolating the building and the ground motion. Lead Rubber Bearing (LRB) is one of the most effective system by which a structure adds more horizontal flexibility, increases the fundamental time period of the structure and offers energy-dissipation processes by damping the isolators. Accordingly, seismic structural responses (displacement, velocity and acceleration) of the building are substantially reduced and thus the inter-story drifts can also be minimized, thereby safeguarding the lives and properties within the buildings. This paper focuses on the application and numerical evaluation of base isolation systems with regard to earthquake disaster mitigation. The work emphasizes the value of isolation technologies in modern earthquake-resistant structure and the need to integrate it into overall disaster management systems.

Keywords: *Base Isolation, Lead Rubber Bearing, Earthquake Disaster Mitigation, Seismic Response reduction*

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Paper ID: 29

Performance evaluation of buried pipe on slope subjected to vehicular loading

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THEME: Seismic safety of pipelines, underground & buried structures

ABSTRACT

This research focused on cyclic loading from traffic (associated loading) on geo-synthetic reinforced embankments and overlaid flexible HDPE pipes. This work used PLAXIS 3D to create three-dimensional finite element models of unreinforced and geogrid-reinforced sand beds that were geo-synthetically reinforced, the verification aspect was the 3D calculations. The models were developed considering cyclic loading intensity, the rate of the geogrid reinforcement, and rate (depth) of the piping installation. The geogrids were idealized using elastic perfectly plastic models that described their interaction with surrounding soil under load transfer mechanisms such as interlocking and passive resistance. The primary focus of the numerical analysis was to describe the response of pipes and the geological settlement, accounting for the 2000 cycles of trapezoidal, laden loads as set out in IRC 37:2018 Traffic Control Devices. The models were also tested at different slope angles (10°, 20°, and 30°) as well as different pipe locations (crest, mid-slope, and toe). The results highlighted that a lateral 30° slope with a pipe resulted in over 39 mm lateral displacement. The surface settlement was over 30.17 mm when the pipe was placed on the bearing 30° slope. In addition, using geogrid layers yielded a beneficial outcome in terms of lateral soil displacement and settlement of the structure, as it allowed for an improved response towards variational dynamic load applications on buried pipelines.

Keywords: *soil-pipe interaction, lateral displacement, vertical settlement, 1-way trapezoidal cyclic loading, load multipliers, finite element method*

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Paper ID: 33

Comparative Response of Connected and Disconnected Piled Raft Foundations in Sand under Pseudo-Static Seismic Loading

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THEME: Seismic soil-structure interaction

ABSTRACT

Disconnected piled raft (DPR) foundations have emerged as a promising alternative to conventional connected piled raft (CPR) systems by modifying the load transfer mechanism between the raft, piles, and supporting soil. While the pseudo-static seismic behaviour of CPR systems has been widely investigated, the response of DPR foundations under varying seismic demand remains inadequately understood, and direct comparative studies between CPR and DPR within a simplified pseudo-static framework are limited.

In this study, a three-dimensional finite element investigation is carried out to comparatively evaluate the seismic response of CPR and DPR foundations embedded in sand under pseudo-static loading. Numerical analyses are performed using PLAXIS 3D for a baseline piled raft configuration subjected to combined vertical load and equivalent static horizontal loads corresponding to three representative peak ground acceleration (PGA) levels of 0.16 g, 0.2 g, and 0.4 g, representing moderate to strong seismic demand associated with the Nepal (2015), Sikkim (2011), and Uttarkashi (1991) earthquake events. The DPR system is modelled by introducing a granular cushion layer between the raft and pile heads, enabling indirect load transfer and partial decoupling of pile head rotation.

The response of CPR and DPR systems is evaluated in terms of horizontal load–displacement behaviour, raft inclination, pile–raft load sharing, pile’s lateral deflection, and structural demand in piles. Broadly, the results indicate that the cushion in DPR plays a key role in defining the lateral response and inclination of the raft. The pile load proportion and the maximum pile bending moment in DPR are significantly reduced as compared to CPR for all moderate to strong PGA values. Interestingly the peak bending moment location is found to shift from the pile head in CPR to $z/L \approx 0.2$ in DPR due to cushion-induced moment release. The shear force at the pile head in DPR is observed to decrease significantly for higher PGA values when compared with CPR system.

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International Conference on Seismic Resilient Infrastructure (ICSRI)-2026
Department of Civil Engineering,
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13th- 15th March, 2026

Overall, the results demonstrate that DPR foundations act as an effective force-modifying system under pseudo-static seismic loading and offer a more economical and resilient solution when pile structural demand governs design.

Keywords: *Disconnected piled raft, Connected piled raft, Finite element analysis, Pseudo-static seismic loading, Granular cushion*

Paper ID: 35

A Numerical Study on Seismic Response Mitigation of Structures Using Tuned Mass Dampers

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

The behavior of building structures under dynamic loading continues to attract significant attention in structural engineering. In this context, seismic vulnerability and risk govern the extent of damage during earthquake events by representing the inherent susceptibility of structures to hazard-induced loading and the associated anticipated losses to exposed elements. In contemporary construction, the use of flexible and slender members has directly influenced seismic risk. Reducing seismic response remains a key objective in mitigating earthquake risk, which could otherwise lead to huge human casualties and economic losses.

A resilience-based, passive vibration control strategy using Tuned Mass Dampers (TMDs) is investigated through numerical simulation. A TMD is tuned to a dominant vibration mode of the primary structure, causing out-of-phase motion that reduces the dynamic response, thus assisting earthquake resilience control. A Python-based framework is developed to model the behavior of structural systems, encompassing both single-degree-of-freedom (SDOF) and multi-degree-of-freedom (MDOF) configurations. The equations of motion are solved using the constant-average-acceleration Newmark- β scheme. For MDOF systems, mass and stiffness matrices are developed, modal characteristics are extracted using eigen-value analysis and Rayleigh damping coefficients are calculated. The TMD is then integrated into the system, enabling direct comparison of vibration behavior with and without the absorber. Time-history responses of displacement, velocity and acceleration demonstrate significant reduction in peak characteristics due to TMD implementation.

The study extends evaluating TMD effectiveness under dynamic loading, and explores optimization under high-rise building applications.

Keywords: *seismic response, Newmark- β , modal characteristics, Rayleigh damping coefficients, Time-history responses*

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Paper ID: 37

Influence of Geometry and Material Properties on Ground motion Amplification of Hill Slopes

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THEME: Dynamic properties of soil and ground response

ABSTRACT

In India, 15 percent of the land is covered under mountainous region and mostly are under high seismic zones V and VI as per IS 1893. The Sikkim, Nepal, Assam, Chamoli, and Uttarkashi earthquakes are the best evidence of the severity of the damage in these regions. World with in some of the earthquake records exposes significant ground motion amplification due to hill slope topography. In the past researcher observed that the ground motion gets amplified up to 2 to 3 times due to slope topography. However, the geometric effect is mostly dominant, whereas the influence of material behavior is limited. Therefore, the present study investigates the topographic amplification of a hill slope subjected to the real earthquake horizontal component of ground motion using two-dimensional finite element analysis. The free-field boundary condition is assigned at the lateral sides, whereas complaint boundary condition is applied at the base. Northridge-Burbank Howard Rd (1994) ground motion horizontal component is used with a peak ground acceleration of 0.112g in the present study and applied at the base of the model. The dynamic response of the slope is presented in terms of Seismic Slope Topographic Amplification Factor (S-STAF), which is the ratio between the seismic response of the slope and flat ground with comparable height. The variation of S-STAF along the slope surface is recorded from the present numerical analysis. The effect of soil non-linearity is examined by considering different constitutive models (Linear Elastic, Mohr-coulomb and HS-Small). These findings highlight that the magnitude of S-STAF is significantly influenced by considering slope geometry and material nonlinearity in seismic slope analysis. The constructive and destructive interference effect due to hill slope topography is presented.

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International Conference on Seismic Resilient Infrastructure (ICSRI)-2026
Department of Civil Engineering,
Indian Institute of Technology (BHU) Varanasi, India
13th- 15th March, 2026

Keywords: *2D FEA, Soil non-linearity, Slope topography, Seismic slope response*

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Paper ID: 38

Assessment of Time and Frequency Domains of Toggle-Brace Dampers for Seismic Loading on Multi-Storey Steel Structures

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Passive energy dissipation systems such as toggle-brace dampers (TBDs) have gained significance with increased importance of seismic resilient structures. The seismic response of a three-storey steel moment-resisting frame subjected to scaled earthquake loading is investigated for both the original undamped configuration and systems equipped with toggle-brace dampers (TBDs). The structural formulation was made using mass and stiffness matrices with inherent Rayleigh damping representation. The governing equations of motion were solved using the Newmark-Beta method. Equivalent damping coefficients (representing TBD) were assigned to each storey based on modal properties and incorporated into the global damping matrix, yielding a coupled mass–damping–stiffness (MDS) system. The TBD configurations were examined to evaluate the influence of damper placement on seismic performance. In addition to conventional time-history analysis, Fourier Amplitude Spectrum (FAS) analysis and Power Spectrum (PS) analysis were performed on displacement responses to examine the frequency-domain characteristics due to damper installation. These results indicate a significant decrease in peak response for the TBD-equipped system compared to the undamped frame. Moreover, the results from FAS and PS reveal substantial reduction of spectral amplitudes near the fundamental frequency, which demonstrates how effective TBDs are in suppressing resonant response.

Keywords: *Toggle-Brace Dampers, Seismic Response Control, Passive Energy Dissipation, Time-Domain Analysis, Fourier Amplitude Spectrum*

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Paper ID: 41

Life-Cycle Seismic Resilience Assessment of Riverine Bridges Under Multi-Hazard Scenario Incorporating Long-Term Climatic Variations

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Riverine bridges are exposed to continuously evolving environmental and hydraulic conditions that can progressively intensify the seismic vulnerability over their service life. Climate-driven variations in river discharge may accelerate foundation scour, while aggressive exposure conditions can promote corrosion-induced deterioration of reinforced concrete components, leading to significant reductions in structural capacity and post-earthquake functionality. This study presents a multi-hazard, life-cycle framework for seismic resilience assessment of riverine bridges by explicitly incorporating long-term climate records to capture time-dependent deterioration mechanisms, such as corrosion and scour, and their coupled influence on seismic performance. The proposed corrosion deterioration model accounts for site-specific environmental exposure, non-uniform pitting characteristics, and corrosion-induced concrete cracking, while the temporal evolution of scour depth is estimated from long-term historical river discharge records. To represent the combined effects of degradation on seismic response, a detailed three-dimensional numerical bridge model incorporating soil–pile–structure interaction is developed in OpenSees and employed for nonlinear dynamic analyses under multiple deterioration scenarios. Seismic fragility curves are developed for different damage states and ground motion intensities using probabilistic seismic demand and capacity limits, which are updated to reflect progressive deterioration. System-level resilience is then evaluated by integrating fragility outcomes with seismic loss estimation and recovery-based functionality models. The findings show that the simultaneous presence of corrosion and scour can substantially impair performance, resulting in up to a 62% decrease in the seismic resilience of a 75-year-old bridge.

Keywords: *Bridges, Scouring, Corrosion deterioration, Seismic resilience*

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Paper ID: 43

Machine Learning–Based Prediction of the Fundamental Period of Vertically Irregular Buildings

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

Accurate estimation of the fundamental period of buildings is a critical requirement for seismic design and vulnerability assessment. Buildings constructed on hill slopes exhibit complex dynamic behaviour due to irregular geometry and varying stiffness distribution. This study proposes a machine learning–based framework for estimating the fundamental period of buildings located on hill slopes. A comprehensive dataset is developed using finite element software, considering the key structural and topographical parameters, including building height, number of storeys, and slope angle. Multiple machine learning models are trained and evaluated to capture the nonlinear relationships between these parameters and the fundamental period. The predictive performance of the models is assessed using statistical error metrics and compared with existing code-based and empirical formulations. Results demonstrate that machine learning models significantly improve prediction accuracy and robustness, particularly for buildings with pronounced geometric and elevation irregularities. The proposed approach offers a reliable and efficient alternative for preliminary seismic analysis and can support performance-based design of hillside buildings.

Keywords: *Seismic design, vulnerability assessment, machine learning*

Paper ID: 48

**Environmental Risk-Informed Assessment of Urban Road
Infrastructure Expansion Using Advanced GIS and Remote Sensing:
Implications for Seismic-Resilient Planning in Karad, Maharashtra**

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THEME: Seismic-Resilient Transportation Infrastructure and Urban Systems

ABSTRACT

Urban road infrastructure expansion plays a vital role in enhancing connectivity and economic growth; however, in seismically sensitive regions, such developments can significantly influence environmental stability and disaster resilience. This study presents an environmental risk-informed geospatial assessment framework to support seismic-resilient urban infrastructure planning, using the rapidly developing road and flyover corridor near the Koyna River in Karad, Maharashtra, a region located close to the Koyna seismic zone. Multi-temporal Sentinel-2 Level-2A satellite imagery was processed using the cloud-based Google Earth Engine (GEE) platform to evaluate land-use/land-cover (LULC) dynamics and vegetation health before and after major road infrastructure expansion. A supervised Random Forest classification algorithm was employed to map LULC classes, while the Normalized Difference Vegetation Index (NDVI) was used to quantify vegetation loss and surface alteration. A 1 km buffer around the road alignment was analyzed to capture both direct and indirect environmental impacts relevant to seismic vulnerability, such as increased impervious surfaces and reduced ecological buffering. The results indicate a substantial increase in built-up and transport surfaces (over 100%) accompanied by a significant decline in vegetation cover (approximately 21%). These changes may exacerbate seismic risk by intensifying surface runoff, reducing soil stability, and increasing post-earthquake recovery challenges. The proposed GIS- and remote-sensing-based framework demonstrates strong potential for integration into Environmental Impact Assessment (EIA) and seismic resilience planning, offering a scalable and evidence-based decision-support tool for sustainable and disaster-resilient urban infrastructure development.

Keywords: *Seismic-Resilient Infrastructure; Urban Roads; GIS; Remote Sensing;*

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International Conference on Seismic Resilient Infrastructure (ICSRI)-2026
Department of Civil Engineering,
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13th- 15th March, 2026

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Evaluation of Alternative Fill Materials to Mitigate Lateritic Cavities

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THEME: Tunnels and rock mechanics

ABSTRACT

Lateritic cavities are formed due to the leaching of minerals, such as carbonates and silicates, caused by fluctuating water tables and changes in pH under specific environmental conditions. These cavities decrease collapse loads and cause shear failures. This study reviews the materials that can be used to fill cavities and restore strength, thereby preventing failures. The materials used for the study include expanded clay, lean concrete, and lateritic soil. The analysis is performed using FEM based software OPTUM G2 2020 v2.0.53.0 academic version. Finite element limit analyses were performed to analyze rocky lateritic strata with cavities using numerical models, namely, the Hoek-Brown, Drucker-Prager Basic, and Mohr-Coulomb models. Of these models, lateritic strata were represented using the Hoek-Brown model, while the others were used to represent fill materials. The fill materials analysed included lightweight concrete, lateritic soil, and expanded clay aggregates. This study reviews the soil models and provides a comprehensive report on their suitability for fill materials. The results also throw light on the best-suited materials for cavity mitigation through filling.

Keywords: *Minerals, shear failures, FEM, Hoek-Brown model*

Paper ID: 51

FEM analysis of Euler beam considering material and geometric nonlinearity

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THEME: Miscellaneous

ABSTRACT

Linear elastic beam theory is widely used for structural analysis; however, it becomes inadequate when beams experience large deflections or material yielding. Under such conditions, stiffness evolves during deformation due to geometric and material nonlinearities, resulting in significant deviation from linear predictions. In this study, a nonlinear finite element investigation of Euler-Bernoulli beams is carried out considering elastic-plastic material behavior with strain hardening and large-deflection geometric effects. Cantilever and simply supported beams subjected to concentrated loads, uniformly distributed loads, and end moments are analyzed using an incremental-iterative Newton-Raphson scheme implemented in commercial finite element software ANSYS. Model validation is performed by comparing numerical results with classical solutions. Numerical results show that linear analysis underestimates deflection by more than 20-30% at higher load levels, while geometric nonlinearity alone contributes up to 15-18% additional deflection before yielding. The study assures that nonlinear analysis is essential for accurate serviceability assessment of slender beams subjected to high loads.

Keywords: *Euler-Bernoulli beam, Material nonlinearity, Geometric nonlinearity, Nonlinear finite element analysis, Large deflection*

Paper ID: 54

**Instability evaluation of road-cut slopes in a seismic Himalayan region:
A case study of slopes along National Highway (NH)-7 between
Rudraprayag and Joshimath, Uttarakhand, India**

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THEME: Earthquake disaster mitigation and management

ABSTRACT

The Himalayan region of Uttarakhand features steep landscapes, intricate geological formations, and frequent seismic activity, resulting in road-cut slopes that are highly prone to instability. The National Highway NH-7, which connects Rudraprayag and Joshimath, runs through rock masses affected by seismo-tectonic forces. The rock mass comprises phyllite, schist, quartzite, and heavily weathered shear zones, where frequent slope failures impede transportation and pose significant risks to life and infrastructure. The area lies in Seismic Zones IV and V, the highest seismic hazard zones in India, where earthquakes have repeatedly caused major disasters, mainly through ground shaking, which has induced various kinds of slope failures like landslides, avalanches, debris slides, rockfalls, etc. Such instabilities are responsible for damage of road network and infrastructures. This research offers an empirical evaluation of the instability of road-cut slopes in this corridor for proper evaluation slopes and mitigating measures. Comprehensive field studies were conducted on five road-cut slopes to define lithology, structural discontinuities, slope geometry, weathering conditions, drainage patterns, possible impact of earthquake and human-induced alterations. Empirical and geometrical methods such as Rock Mass Rating (RMR), Slope Mass Rating (SMR), and kinematic analyses, were used to assess the instability of critical road-cut slopes of the area.

The results may be useful for highway authorities and disaster management organizations for proper planning and design of slopes as well as mitigations measures to enhance the stability of road-cut slopes and ensure the proper transportation and safety of infrastructure located in the earthquake-prone Himalayan region.

Keywords: *RMR, SMR, Kinematic analysis, Seismic zones.*

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Paper ID: 55

**Seismic Response of Discontinuities on Geotechnical Characterization
of Rock Masses: - An example from Upper Vindhyan Sandstone of Son
Valley, Central India**

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THEME: Tunnels and rock mechanics

ABSTRACT

The geoground is commonly categorized into hard ground and soft ground. In these the hard ground is made up of rocks. Such ground made up of rocks is traversed by varieties of structural elements. The micro to macro level such structural elements inherited in rocks are responsible for discontinuous and inhomogeneous anisotropic nature of hard geoground. Thus, geotechnically, it is suitable to describe the rock mass as constituent of such ground in place of rocks. Hence practically a rock mass is comprised of intact rock blocks and separating discontinuity. Discontinuities in rock mass commonly support open, biochemical systems that influence production of geothermal fluids, oil and gas, helpful in the maintenance of environmental quality and influence the geotechnical response of rock mass. Thus, the inhomogeneity and anisotropy assisted by discontinuities contribute in various field related to earth sciences.

The present study is based on the geotechnical characterization of rock masses exposed along a road-cut sandstone strata of Upper Vindhyan Supergroup exposed in Son Valley, Central India with special emphasis on seismic response of discontinuities and its bearing on the geotechnical response of rock masses empirically and experimentally.

The Upper Vindhyan Sandstone strata is comprised on brownish red coloured Scarp Sandstone and milky white coloured Dhandraul Quartzite (Quartz arenite). Keeping in view the importance discontinuity which prominently traversed in such sandstone strata is selected for the study. The selected sandstone strata were evaluated in terms of Rock Mass Rating (RMR) and Geological Strength Index (GSI) and velocities of seismic wave i.e longitudinal (P) and transverse (S) waves. A interrelationship was developed to understand the seismic response of discontinuity and its control on geotechnical attributes of sandstone rock mass.

The outcome of the work reveals a pronounce control of seismic response of discontinuity on

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International Conference on Seismic Resilient Infrastructure (ICSRI)-2026
Department of Civil Engineering,
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13th- 15th March, 2026

geotechnical characteristics of sandstone rock masses. This study may be helpful in understanding of the behaviour of hard geoground during any natural or anthropogenic seismic activities.

Keywords: *Seismic, Response, RMR, GSI, Rock mass, Vindhyan*

Paper ID: 60

Numerical Investigation of Structural Response under Blast Loading Using SAP2000 and AUTODYN

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THEME: Miscellaneous

ABSTRACT

The increasing threat of accidental and intentional explosions has heightened the need to assess the blast resistance of civil engineering structures. This study looks at how reinforced concrete structures respond to explosions by using both math and computer simulations. Linear and nonlinear structural analyses are conducted with SAP2000 to understand how the entire structure behaves, while AUTODYN is used to simulate the blast load and create pressure–time histories in detail. The blast loading factors are set using equivalent TNT charge weights and distances from the explosion, and the resulting pressure patterns are used on the structural models to check for movement, stress levels, and damage patterns.

The study compares the response of structural elements under varying blast intensities, highlighting the influence of blast load magnitude and proximity on structural performance. Key response parameters, such as peak displacement, time-history responses, and stress concentration zones, are analyzed to identify critical components vulnerable to blast effects. The results show that blast loading causes major temporary reactions, with most damage focused on the main parts that support the structure, highlighting the need for designs that can withstand blasts.

Using SAP2000 and AUTODYN together creates an effective way to assess how the entire structure responds and how it is affected by blasts in specific areas. The findings provide useful insights into how reinforced concrete and steel structures behave during blasts and support using numerical simulation tools for designing buildings that can resist blasts and for safety evaluations.

Keywords: *Blast loading, Structural response, SAP2000, AUTODYN, Dynamic analysis*

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Paper ID: 61

**Impact of repetitive vibrations and water flow on geotechnical
attributes of road-cut Upper Kaimur Sandstone strata in and around
Markundi Ghat, Sonbhadra, India.**

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THEME: Earthquake disaster mitigation and management

ABSTRACT

The geotechnical instability of rock-cut rock strata is commonly observed throughout the world due to effects of vibration generated from the traffic and flow of water during rainy season. Among the various forces influencing the stability of road-cut strata, the heavy vehicles movement induced vibrations technically changing the effective dynamic stress acting on road-cut strata. The changes in geotechnical characteristics under such dynamic stress in water saturated conditions often reducing stability and accelerates the failure of rock strata. Therefore, the frequent failure of road-cut strata are common problem along roads just after rainy seasons. Technically vibration generated due interaction of tires of vehicles with road irregularities like depression, potholes, joints, damage spots, are responsible for initiation and propagation of road-ground-borne waves through the rock strata. The change in geotechnical response of strata under such wave propagated condition is commonly led to failure of such cut slopes. Further, such effect of waves in water saturated road-cut strata may accelerate in reduction of strength and caused the frequent failure of rock strata

Keeping in view of such critical instability problem frequently observed along road-cut slopes in after rainy seasons, the present study is tried to emphasize the changes in geotechnical characteristics of sandstone strata exposed along road-cut slopes in Son Valley, Central India.

The sandstone strata of area is comprised of sandstone blocks and discontinuities due to the traverse of a variety of structural elements through the strata. Stratigraphically, studied sandstone strata is belonging to Upper Kaimur Group. Broadly, such sandstone strata can be divided into Scarp Sandstone and Dhandraul Quartzite. In view of above said aspects, the sandstone strata exposed along the road in and around Markundi Ghat, Sonbhadra, Uttar Pradesh were geotechnically evaluated from highly vibration affecting zone and without vibrating effecting zones to quantify the impact of such kinds of vibration effect both in dry and

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water saturated conditions.

The results demonstrate the potential effect of traffic induced vibration accelerated during water saturated condition due to change in geotechnical characteristics sandstone strata. The outcomes of the study may be relevant to suggest proper measures for stability and safety of road-cut rock strata. The study may be helpful in the proper planning and design of new alignments in any area in view of traffic induced vibration and water flow.

Keywords: *Vibration, Traffic, Geotechnical Characteristics, Road cut, Sandstone strata, Upper Kaimur Group, Son Valley*

Paper ID: 63

Effect of Water Table on the Seismic Response Performance of Municipal Solid Waste (MSW) Fines Deposit

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THEME: Dynamic properties of soil and ground response

ABSTRACT

In the present study, one-dimensional site-response analyses were conducted using Cyclic1D software to evaluate the influence of increasing groundwater table depth on the seismic response performance of a municipal solid waste (MSW) fines deposit. Two input motions (an idealized 0.2g sinusoidal excitation and a recorded time history from the 2015 Nepal earthquake-Mw 7.8) were employed for the seismic response analysis of the MSW fines deposit. The increase in peak ground acceleration (PGA) value was noticed with the increase in water table depth from the ground surface under the excitation of both the input motions. However, significant increase in PGA value has been noticed under the excitation of Nepal earthquake motion. The municipal solid waste (MSW) fines deposit was found to be safe against liquefaction under the excitation of both the considered input motion.

Keywords: *MSW fines, Seismic response, Nepal earthquake, Liquefaction*

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Assessing the Influence of Soil Moisture Uncertainty on GRACE-Derived Groundwater Storage over India

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THEME: Dynamic properties of soil and ground response

ABSTRACT

Groundwater storage estimation using GRACE satellite observations has become a widely adopted approach for monitoring groundwater variability at regional to global scales. However, the accuracy of GRACE-derived groundwater estimates strongly depends on the reliable removal of soil moisture contributions from total water storage. A major limitation in current GRACE-based groundwater studies is the uncertainty associated with land surface model-derived soil moisture, particularly in regions with high hydroclimatic variability such as India. The extent to which these model uncertainties propagate into the GRACE groundwater signal remains insufficiently quantified, representing a critical knowledge gap. In this study, we investigate the dependency and anomalies between GRACE-derived groundwater storage and soil moisture by integrating extensive in situ soil moisture observations. Observed soil moisture data from 200 locations across India, obtained from the India Meteorological Department (IMD), are used to evaluate the accuracy of GLDAS soil moisture simulations. Spatial and temporal comparisons are conducted to identify discrepancies between observed and modeled soil moisture and to assess their influence on GRACE groundwater estimation. The results reveal significant regional and seasonal deviations in GLDAS-simulated soil moisture, which directly affect the magnitude and variability of GRACE-derived groundwater storage. These findings demonstrate that inaccuracies in modeled soil moisture can lead to systematic biases in groundwater estimates. This study represents a pioneering large-scale assessment over India linking in situ soil moisture observations with GRACE and GLDAS datasets. The outcomes provide a pathway to improve groundwater estimates from GRACE, which is extensively used for groundwater assessment worldwide.

Keywords: *Groundwater storage, Soil moisture, GLDAS, In-situ observation, Land surface models*

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Paper ID: 69

Prediction of Breach parameters for Overtopped Embankments by Regression Technique

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

The failure of an embankment causes loss of lives, massive damage to infrastructure and the interruption of basic facilities; it has thus drawn increasing attention from researchers. When compared to other types of embankment disasters, overtopping-related embankment breaches are much more frequent. The study of the breach mechanism of embankments due to overtopping is becoming more and more essential for developing evacuation plans, early warning systems and damage assessment. To recognize the breach activities of embankments, it is necessary to find out discrete breach considerations like breach depth, breach initiation, breach width, etc. The present paper analyzes the results of the design for forty experiments carried out in two different laboratory water channels (flumes). Different embankment models are overtopped with the objective of studying the breach behavior during overtopping. The study was inspired by reports in the open literature of embankment failures that resulted in catastrophic conditions. With experimental data, an efficient model is developed for predicting breach peak outflow (Q_p) by correlating with other independent embankment breach parameters for cohesive as well as non-cohesive embankments. The model is validated with historical and laboratory data compiled in the past. For the validation of current investigational work, the experimental data of the present study are compared with the model already developed by other researchers. From the study and analysis, it is observed that breach peak outflow depends upon hydraulic, geometric, and geotechnical parameters of embankments. Being a phenomenon that is active for a short duration only, the manual measurement of various parameters of the modeling process poses some limitations under laboratory conditions. also, the trials were carried out in a narrow flume under constant hydraulic conditions, which are two of the study's limitations.

Keywords: *Embankment disasters, breach peak outflow, flumes*

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Paper ID: 71

One-Dimensional ground response analysis of black cotton soil stabilized with fly ash

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THEME: Dynamic properties of soil and ground response

ABSTRACT

As earthquakes are unpredictable, the importance of ground response analysis became necessary. In this study, a non-linear 1D-ground response analysis of black cotton and stabilized black cotton soil with fly ash has been analyzed using Cyclic1D software. Cyclic1D is a non-linear one-dimensional ground response analysis program used to simulate soil behaviour under cyclic earthquake loading. The seismic analysis of black cotton and stabilized black cotton soil with fly ash was conducted under the excitation of Nepal earthquake input motion. The outcomes of the present numerical study are illustrated by acceleration, displacement and excess pore pressure responses. The outcomes of the present research could prove useful in the earthquake resistant design of foundations constructed with black cotton and stabilized black cotton soil with fly ash deposits.

Keywords: *Black cotton soil, Fly ash stabilization, Liquefaction, Cyclic 1D, Nepal earthquake*

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Paper ID: 72

Seismic Performance Evaluation of a Building using Optimum Tune Mass Damper Inerter (TMDI)

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

The tuned mass damper inerter (TMDI) is designed as a passive energy dissipating system for better seismic resilience of buildings. While conventional tune mass dampers (TMDs) are widely used, their performance is often limited by mass constraints and sensitivity to frequency detuning effect. TMDI overcomes the limitations of TMD by coupling the conventional TMD with an inerter. Inerter is a two terminal device which resist the relative acceleration between its terminals, when arranged in its optimal configurations by providing supplemental apparent mass and enhanced damping breadth. This paper analyses the optimal design and seismic performance evaluation of a building with TMDI. A multi-degree-of-freedom (MDOF) model with TMDI is taken and optimised using Genetic Algorithm (GA) to tune the frequency ratio, damping ratio, and inertance ratio of the control system. Here, robust control of the building is achieved by minimizing the H_2 and H_∞ norm with GA for the roof displacement transfer function. Moreover, this paper investigates the reliability-based approach for the optimum design of TMDI in MDOF linear shear building under seismic excitation. Numerical results demonstrate that the TMDI system significantly outperforms the conventional TMD. The findings suggest that GA-based optimization process is crucial for preventing performance degradation and ensuring occupant comfort in high-rise structures subjected to seismic excitation.

Keywords: *Tune Mass Damper Inerter, Genetic algorithm, H_2 and H_∞ optimisation, seismic performance, Vibration Control, robust control*

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Paper ID: 73

ML-Based Seismic Response Prediction of RC Buildings Using Indian Ground Motions

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

Nonlinear time history analysis (NLTHA) has been widely recognized as the most reliable method for evaluating the seismic response of reinforced concrete (RC) buildings. However, its application becomes computationally intensive when a large number of earthquake records are considered. In this study, a tree based machine learning framework was proposed for rapid prediction of seismic response of RC frame buildings using a uniformly processed Indian strong ground motion database representing earthquakes recorded across the Indian subcontinent. The selected ground-motion records were used to capture region specific seismic characteristics relevant to Indian seismic conditions. Regular and vertically irregular RC building models were developed, and NLTHA was performed using the Indian earthquake records to generate benchmark response data in terms of maximum drift ratio. Key ground motion intensity measures provided in the database were employed as input features for advanced tree based machine learning models, including Random Forest and Extreme Gradient Boosting. The trained models successfully captured the nonlinear relationship between Indian ground-motion characteristics and structural response, enabling accurate prediction without repeated dynamic analyses. The findings demonstrated high predictive accuracy with a significant reduction in computational effort, highlighting the effectiveness of tree-based machine learning as an efficient surrogate for NLTHA in seismic assessment of RC buildings under Indian seismic conditions. The proposed framework provides a computationally efficient solution for rapid seismic assessment and supports preliminary design decisions in engineering practice.

Keywords: *Machine Learning, Nonlinear Time History Analysis, RC Buildings, Indian Ground*

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International Conference on Seismic Resilient Infrastructure (ICSRI)-2026
Department of Civil Engineering,
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13th- 15th March, 2026

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Paper ID: 77

**Prediction of Ultra Low Cycle Fatigue life (ULCF) in IS:2062 grade
steel under asymmetric cyclic loading based on a cyclic void growth
Model**

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THEME: Earthquake disaster mitigation and management

ABSTRACT

Disaster mitigation in seismic prone regions is highly dependent on the development of resilient structural systems capable of preventing collapse during strong ground motions. Under earthquakes, steel structures are subjected to severe reverse cyclic loading, often resulting in rapid degradation of material strength and premature failure within a few cycles due to ultra low cycle fatigue (ULCF). While structural response at the system level may vary from ductile to brittle depending on detailing, fracture at the material scale is predominantly ductile. Hence ULCF behavior poses a significant challenge to performance based seismic design due to the complex triaxial stress states. Hence, accurate prediction of ductile fracture becomes important for seismic safety and effective disaster risk reduction.

In this study, an uncoupled, triaxiality dependent damage model based on void growth and coalescence is employed to predict fracture initiation in mild steel under ULCF conditions. The model, derived from the Rice Tracey's Void growth model framework (and extended to account for asymmetric cyclic loading), is applied to coupon-level components representative of seismic fuse elements in special moment resisting frames. The material under consideration is IS2062 grade mild steel since it is the most commonly used steel in Indian construction industry. Cyclic loading histories are obtained from experimental and numerical simulations of beam-to-column sub-assemblages, thus incorporating realistic seismic deformation demands. Coupons of three different lengths are analyzed, with geometric nonlinearity in the finite element simulations. Model parameters are calibrated using experimental data and complementary numerical studies by comparing with experimental fracture response. The proposed framework accurately predicts ULCF life under seismic loading. The model framework can be employed for development of seismic resilient steel structures.

Keywords: *Disaster mitigation, structural response, Cyclic loading*

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Paper ID: 78

Role of Vertical and Horizontal Bands in Seismic Performance of Confined Masonry Walls with Openings

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Confined masonry (CM) walls are widely used in low-rise construction in seismic regions; however, their seismic performance is strongly affected by the presence of door and window openings. This study numerically investigates the influence of different configurations of horizontal and vertical seismic bands on the nonlinear response of confined masonry walls with openings. Ten three-dimensional finite element models were developed using the commercial finite element software Abaqus and analyzed under monotonic displacement-controlled pushover loading up to a target displacement of 20 mm. The response was evaluated in terms of ultimate lateral capacity, secant stiffness at target displacement, energy dissipation capacity, and damage evolution.

The results demonstrate that the inclusion of seismic bands significantly enhances lateral strength and deformation capacity while reducing damage concentration around opening corners. Walls without seismic bands exhibited early diagonal cracking and rapid stiffness degradation, whereas banded configurations promoted more uniform crack distribution and delayed damage progression. Configurations incorporating both horizontal and vertical seismic bands provided the most effective improvement in load transfer across openings and energy dissipation performance. The findings highlight the critical role of seismic band detailing in improving the seismic resilience of confined masonry walls with openings and provide valuable insights for design of confined masonry housing in earthquake-prone regions

Keywords: *Confined masonry, Energy dissipation capacity, finite element analysis, Lateral load capacity, Seismic performance.*

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Paper ID: 86

Variability in Modal Data due to Uncertainty in Measured Acceleration Responses under Ambient Vibration Survey

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THEME: Earthquake disaster mitigation and management

ABSTRACT

It is well-known that different vibration-based damage detection algorithms may yield varied outcomes for assessing post-earthquake conditions in presence of significant measurement uncertainties. This is because, unlike force vibration survey, the response accelerations are usually feeble in case of ambient vibration survey of civil structures and often significantly contaminated owing to measurement errors and noise. In literatures, varied levels of uncertainties are considered for measured acceleration response data and estimated modal data while applying various damage detection algorithms. This study provides qualitative and quantitative ideas on how uncertainties in acceleration response data under ambient vibration survey result in variability in modal parameters estimated through well-known frequency domain decomposition technique and thus, may influence in post-earthquake damage assessment. A theoretical basis is derived for this purpose considering the measurement uncertainties to be uncorrelated zero mean Gaussian white noise and characterized by root mean square (r.m.s) error. It has been shown that for low r.m.s errors in measured response acceleration, the identified modal frequencies are immune to sensor noise. Further, the r.m.s errors in mode shapes are much smaller compared to the r.m.s error in the measured acceleration. These r.m.s errors in mode shapes increase with increase in mode number from the fundamental mode to higher modes. A numerical study has been conducted with a shear building. The results of the numerical study verify the theoretical understanding and demonstrate that there is a significant reduction of r.m.s error in mode shape with respect to the noise level.

Keywords: *Vibration-based damage detection, post-earthquake, response accelerations*

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Paper ID: 87

Multi-level Data Fusion Framework for Damage Assessment under Unknown Input Conditions

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

A reliable assessment of earthquake-induced structural damage is essential for ensuring life safety, enabling quick decision-making, and improving the seismic resilience of civil infrastructure. Structural Health Monitoring (SHM) has become an important component in this aspect. However, practical implementation of SHM for seismic applications is challenged by measurement errors, modelling uncertainty, sparse instrumentation, and, in many cases, the absence of information for reliable input force. This study proposes a multi-level data fusion framework with a specific focus on damage assessment under unknown input conditions. The framework combines data-level, feature-level, and decision-level fusion schemes, while adopting a common Optimal Sensor Layout (OSL) for all fusion levels. The OSL is determined using the Fisher Information Matrix (FIM). At the data level, measured responses are fused using the Unscented Kalman Filter (UKF), enabling state and parameter estimation without explicit knowledge of excitation forces. The inclusion of inter-story drift measurements in the UKF framework allows direct estimation of stiffness parameters, providing enhanced robustness and physical interpretability compared to single-response filtering approaches. At the feature level, natural frequencies and mode shapes extracted from measured responses are used as damage-sensitive features to predict storey stiffness parameters. Feature-level fusion is performed using probabilistic Bayesian framework which explicitly incorporates uncertainty through likelihood functions, with posterior estimation carried out using Laplace approximation method. At the decision level, outputs from both models are combined to improve damage classification reliability. Decision-level fusion reduces sensitivity to individual model bias and enhances robustness under sparse instrumentation and uncertain seismic environments.

Keywords: *Structural Health Monitoring, Inter-Story Drift, Unknown Input, Fisher Information Matrix, Multi-Level Data Fusion, Unscented Kalman Filter, Bayesian Inference*

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Paper ID: 88

Greedy Optimization of MR Damper Placement in MDOF Building for Seismic Risk Mitigation

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THEME: Earthquake disaster mitigation and management

ABSTRACT

For seismic risk mitigation of structures, use of supplemental damping devices is well-known. Optimal placement of supplemental damping devices in multi-degree-of-freedom (MDOF) structures is a combinatorial optimization problem, where exhaustive search rapidly becomes computationally infeasible as system size increases. This study investigates an efficient sequential greedy optimization strategy for the placement of magneto-rheological (MR) dampers in planar MDOF structures, formulated within a structural dynamics and computational mechanics framework. The objective is to minimize a combined drift-acceleration-based global response metric, capturing both deformation- and inertia-driven performance demands under dynamic excitation. The structure is modeled as a two-dimensional shear building, and the damper placement problem is posed as a discrete optimization task in which candidate locations are evaluated based on their incremental contribution to global response reduction. The greedy algorithm proceeds by iteratively selecting damper locations that yield the maximum marginal improvement in the objective function, without requiring evaluation of all possible placement combinations. The results of damper placement configurations are compared to a benchmark damper layout commonly used in practice. The study demonstrates that the proposed greedy strategy achieves response reductions comparable to the benchmark configuration while requiring significantly fewer function evaluations. The study highlights the potential of greedy optimization as a computationally efficient alternative for similar problems as the proposed approach is general and can be extended to larger structural models, alternative response objectives, and other classes of energy-dissipating devices, making it attractive for practical applications in structural control and optimization.

Keywords: *Greedy optimization; MR damper placement; Multi-degree-of-freedom systems; Structural dynamics*

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Paper ID: 89

Noise-Resilient Feature-Based Structural Health Monitoring Using Gradient Boosting: A Machine Learning Approach

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

In earthquake-prone regions, reliable post-earthquake structural damage assessment is essential for ensuring safety and resilience. This work focuses on using recorded seismic response data for such purpose. A noise-resilient structural health monitoring (SHM) framework is presented in this work by using robust, multi-domain signal features and machine learning for reasonable damage detection. A broad set of features such as statistical, dynamic, frequency-domain, energy-based, higher-order, and complexity measures to capture diverse aspects of a signal's variability, structure, and frequency content are extracted. These features are evaluated for robustness against noise to determine an optimal feature configuration for accurate detection of damage. Comparative analyses between baseline and optimized features show improved reliability under noisy conditions. After denoising and usage of optimal parameters for acceleration data with defined damage levels to a 12-storey shear building model in OpenSees, feature extraction was considered. A gradient boosting classifier is trained on the resulting data using the extracted features. Detailed floor-wise and feature-wise importance analyses are conducted to examine the spatial distribution of damage-relevant information. The classification results showed high accuracy at low damage levels (10%) but a noticeable decline beyond 20% damage due to increased feature overlap and noisy signal. Also, the most influential features, with the highest importance scores, were found to be primarily associated with floors 1–3. The findings show the potential of robust features in enhancing the resilience, interpretability and localized damage identification of SHM systems under real-world noise conditions.

Keywords: *Earthquake, structural health monitoring, damage detection*

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Paper ID: 91

Resilient Retrofit Design: Physics-Informed Machine Learning for Shear Strength Prediction of FRP-Strengthened RC Members under Seismic Vulnerability

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THEME: Application of machine learning and deep learning in seismic resilience

ABSTRACT

The seismic resilience of aging reinforced concrete (RC) infrastructure is frequently compromised by shear-critical vulnerabilities in transfer girders and bridge piers. While Fiber-Reinforced Polymer (FRP) retrofitting provides a potent strengthening solution to prevent brittle shear failure, current design codes (ACI 440.2R, fib Bulletin 90) rely on simplified, highly conservative semi-empirical formulations that fail to capture the complex, non-linear mechanisms of FRP debonding and aggregate interlock under varied shear span regimes. This study introduces a robust, data-driven framework utilizing advanced Machine Learning (ML) techniques to enhance the reliability of seismic shear retrofit designs. Leveraging a comprehensive database of over 1000 experimental specimens consolidated from recent high-impact studies, we evaluate the efficacy of Gradient Boosting (CatBoost), Gene Expression Programming (GEP), and Artificial Neural Networks (ANN) against traditional code provisions. The proposed CatBoost model, optimized via Bayesian Hyperparameter Tuning, demonstrates a predictive accuracy ($R^2 \approx 0.90$) significantly superior to code formulations ($R^2 < 0.30$), reducing Root Mean Square Error (RMSE) by over 50%. Crucially, the study integrates SHAP (SHapley Additive exPlanations) analysis to enforce physics-consistent monotonicity, ensuring that the ML models correctly reflect the governing mechanics of shear transfer—specifically the critical influence of shear-span-to-depth ratio (a/d) and competitive interaction between internal stirrups and external FRP. By providing a transparent, interpretable, and highly accurate prediction engine, this research bridges the gap between black-box AI and structural reliability, offering a pivotal tool for performance-based seismic design and the resilient rehabilitation of critical infrastructure.

Keywords: *Seismic Resilience, FRP Retrofitting, Physics-Informed ML, Shear Strength, CatBoost*

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Paper ID: 103

Cost Effective Liquefaction Mitigation in Layered Soils: Comparative FEM Study of Ground Improvement Methods

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THEME: Seismic soil-structure interaction

ABSTRACT

Layered soil profiles in earthquake-prone areas like Kadapa (Cuddapah Basin), featuring loose sandy silt over silty clay with karstic voids, suffer rapid liquefaction and excessive settlements during seismic events. While effective, traditional mitigation methods remain cost-prohibitive for regional infrastructure. This study evaluates cost-effective ground improvement through comparative finite element method (FEM) analysis, with particular emphasis on vibro stone columns (VSC) as the optimal solution.

A typical 25m Kadapa soil profile was modelled using PLAXIS 2D. Seismic excitation with PGA of 0.22g is applied. The groundwater table is located at a depth of 4 m. The existing soil deposit showed critical liquefaction, moderate surface settlements, and a reasonable factor of safety. Exonomical methods like Vibro stone column, Compaction grouting, and permeation grouting was employed, studied and compared.

Results state that Vibro stone columns demonstrated superior effectiveness, reducing excess pore pressure ratio, limiting settlements to very minimal, and enhancing the factor of safety. Vibrostone column's dual drainage-reinforcement mechanism excelled particularly near sinkholes. The method maintained high performance even at reduced area replacement ratios.

Vibrostone column emerges as the most cost-effective liquefaction mitigation for Kadapa's layered karstic soils, supporting IS code revisions and infrastructure resilience planning.

Keywords: *Vibro stone columns, liquefaction mitigation, layered soils, finite element analysis, PLAXIS 2D, Kadapa Cuddapah Basin*

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Enhancing Playground Soil Permeability: A Review of Practical Economical Ground Improvement Methods

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Playground soils in seismic zones require enhanced permeability not only for drainage but also to mitigate liquefaction risks through improved pore pressure dissipation and ground response modification. This review evaluates economical methods such as core aeration (INR 50-100/m²), sand topdressing (INR 200-400/m²), compost amendments (INR 100-200/m²), and gravel slit drains (INR 500-800/m²) etc., that boost infiltration rates from less than 20 mm/hr to greater than 80 mm/hr while elevating liquefaction safety factors ($FS > 1.3$).

These techniques shorten drainage paths ($L_{dr} < 15$ cm), reducing excess pore pressure ratios (ru) by 40-70% under cyclic loading (PGA 0.1-0.3g), as validated by Idriss-Boulanger CRR correlations adjusted for high hydraulic conductivity ($k > 10^{-4}$ m/s). Core aeration fractures compaction layers, increasing small-strain shear modulus (G_{max}) by 20-30%; sand-compost mixes enhance relative density (Dr 50-70%) and cyclic resistance ratio (CRR) via improved gradation and root reinforcement. Several numerical studies of playground profiles confirm 50-65% settlement reduction post-treatment, with turf macropores delaying excess pore water pressure peaks by 2-4 cycles compared to untreated clays or silty clays.

Case studies from Christchurch (2011) and Bhuj (2001) reveal permeable playground amendments limited lateral spreads to <30 cm versus 80+ cm in native soils. Socio-economic benefits include reduced maintenance (60% less puddling-related repairs) and enhanced community resilience through safer recreational spaces. The economic strategies bridge geotechnical engineering with disaster management, ensuring playground functionality and human safety in seismic-prone regions.

Keywords: *Liquefaction risks, pore pressure dissipation, hydraulic conductivity*

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Paper ID: 105

Towards Resilient Campuses: A Review of Integrated Rainwater Harvesting, Greywater Recycling

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THEME: Preparedness, public awareness and their participation

ABSTRACT

Educational campuses in seismically active and drought-prone regions of India, such as Andhra Pradesh's Anantapuramu-Chittoor belt (Zone III), experience groundwater over-exploitation, inducing anthropogenic seismicity, monsoon deficits of up to 50%, and liquefaction risks in silty soils and silty alluvial soils. Conventional water extraction using deep borewells concentrates pore pressure changes, leading to an increase in seismic vulnerability; this review highlights integrated rainwater harvesting (RWH) and greywater recycling as transformative strategies. These decentralized systems such as shallow recharge pits, vegetated wetlands, disperse subsurface loads, stabilize soil moisture gradients, and mitigate liquefaction triggers while securing non-potable water (flushing, irrigation) during post-quake disruptions when pipelines breakdown.

Review of several case studies shows real-world success. JNTUA Anantapuramu's rooftop rainwater harvesting cut groundwater use by 40%, collecting 40-100 liters per square meter each year using simple gutters, first-flush filters, and recharge pits. Mewar University's Rajasthan project combined rainwater harvesting with reed bed filters for 50-70% water savings. Anna University's greywater plant treats 50,000 liters per day and recycles 95% of it (BOD below 20 mg/L, meeting CPCB standards). Site adaptations like local gravel filters and shallow recharge trenches cut costs by 20-25%. Using campus-native plants and simple gravel media saves 15-20% over commercial filters

These site-optimized systems pay back in 3-5 years, saving ₹30-80 per 1,000 liters. They reduce municipal water demand by 40-60%, saving ₹8-15 lakh annually for 2,000 students through local material sourcing (gravel, laterite instead of imported media), shallow pits matching campus soil permeability, native vegetation minimizing pumping/maintenance, modular sizing avoiding over-design.

Keywords: *Seismic resilience; Rainwater harvesting; Greywater recycling; Liquefaction mitigation; Campus water security*

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From Collision Physics to Seismic Safety: Modeling and Efficiency of Impact Damper

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

This study investigates the effectiveness of an impact-based vibration control device in reducing the seismic response of multi-degree-of-freedom building structures. Conventional Tuned Mass Dampers (TMDs) are widely used for vibration control but are generally tuned to a single dominant mode, typically the fundamental mode. During earthquakes, however, ground motions contain broadband frequency content that activates higher modes, which can reduce the effectiveness of single-mode tuned TMDs. Under such multimodal excitation, detuning may occur, leading to reduced control efficiency or increased structural response. This highlights the need for vibration mitigation approaches capable of maintaining stable performance under uncertain and broadband seismic excitation.

To address this limitation, a comparative investigation is conducted between conventional TMD and Pounding Tuned Mass Damper (PTMD) systems for a multi-storey shear building subjected to earthquake loading. Numerical simulations are performed in OpenSees. In the PTMD configuration, impact behavior between the auxiliary mass and rigid constraints is explicitly modeled. The pounding mechanism is represented using available OpenSees impact material models, including the Jankowski viscoelastic impact model and other formulations to capture contact stiffness and energy dissipation during collisions.

The performance of PTMD is evaluated through comparison with the conventional TMD under identical ground motions. Structural response measures, including peak floor displacement, inter-storey drift, and acceleration, are used for assessment. The influence of impact-induced energy dissipation on vibration reduction is quantified, with emphasis on robustness under multimodal excitation. Parametric studies varying auxiliary mass, impact gap, and coefficient of restitution are performed to identify effective design combinations. Results demonstrate the potential of PTMD systems to improve seismic vibration mitigation beyond conventional single-mode tuning strategies.

Keywords: *Impact-based vibration, Structural response, Multi-storey shear building*

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Paper ID: 110

MAPPING GROUNDWATER POSSIBILITY AREAS USING REMOTE SENSING AND GIS FOR CHEYYERU RIVER BASIN OF ANDHRA PRADESH, INDIA

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THEME: Preparedness, public awareness and their participation

ABSTRACT

This study used GIS and remote sensing techniques to identify high groundwater potential areas in the Cheyyeru river basin, Annamayya district, Andhra Pradesh, India. The research employed ArcGIS 10.8.2 along with remote sensing data from sources such as USGS Earth Explorer, FAO/UNESCO Soil Map of the World, Geological Survey of India, DIVA-GIS, and Hydro SHEDS. To predict groundwater potential, the study considered factors such as geology, lineament density, slope, drainage density, soil, and land use/land cover. The land use/land cover map showed that 38% of the area is covered by vegetation and 17% by water bodies. The soil map indicated that 76% of the region consists of Lithosols and 24% of Chromic Vertisols. The geology map revealed that the entire study area is composed of the Cumbum formation. The lineament density map indicated a minimum of 5% high lineament density and a maximum of 55% low lineament density. The slope map showed that 53% of the area has slopes between 0-20%, while only 4% falls within the 80-100% slope range. Finally, the drainage density map revealed a maximum of 26% low drainage density and a minimum of 7% high drainage density in the region. The Analytical Hierarchy Process (AHP) technique was employed to rank and assign weights to each factor based on their relative importance. The study area was categorised into groundwater potential zones, with 18.87% classified as high potential, 37.91% as medium potential, and 43.22% as low potential. These results provide a valuable decision support tool for effective water resource management, promoting sustainable and equitable groundwater use, and can serve as a benchmark for future studies.

Keywords: *Remote sensing, Groundwater potential, GIS*

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Paper ID: 113

Seismic Assessment and Strengthening of an Existing Non-Code Compliant RC Building

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THEME: Seismic vulnerability, risk, and resilience assessment

ABSTRACT

Many reinforced concrete (RC) buildings constructed prior to the implementation of modern seismic codes were designed primarily for gravity loads and may not satisfy current earthquake-resistant design requirements. This study presents a detailed seismic assessment and strengthening strategy for an existing 1980s government administrative building located in Nagpur, India. The structure comprises a Main Building and an Annex Building, separated by an expansion joint, and was originally designed without explicit seismic considerations. Due to the unavailability of original structural drawings, member dimensions and reinforcement details were established through site measurements, non-destructive testing (UPV and rebound hammer), and rebar locator surveys. A three-dimensional finite element model was developed in ETABS v22.3.0 to represent the as-built condition. The building was first verified for gravity load adequacy as per IS 456:2000 and subsequently evaluated under seismic loading in accordance with IS 1893:2025. Results indicate that while the structure remains adequate under gravity loads, several columns exhibit significant reinforcement deficiency under updated seismic demands. Critical members were identified based on a rational deficiency criterion using the ratio of required to provided reinforcement. Carbon Fiber Reinforced Polymer (CFRP) wrapping was proposed as a targeted retrofitting measure to enhance confinement, strength, and ductility of deficient columns. The study demonstrates a systematic and practical framework for upgrading non-code-compliant RC buildings to meet present-day seismic performance requirements.

Keywords: *Seismic Assessment and Strengthening, Non-code compliant buildings, RC Frame Structure, CFRP retrofitting, IS 1893:2025, ETABS v22*

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Paper ID: 114

Optimized and realistic design methods of Post-Installed Anchors against high seismic shear loads

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THEME: Earthquake disaster mitigation and management

ABSTRACT

The construction industry is evolving rapidly, driven by changing design requirements, productivity demands, regulatory updates, and on-site constraints. These conditions often require engineers to revise designs repeatedly and provide solutions that accommodate modifications without compromising safety or code compliance. Post-installed connections have become a widely accepted method for attaching structural and non-structural elements to existing reinforced concrete, offering flexibility when original cast-in provisions are absent or must be adapted. With over four decades of development, post-installed anchor systems now provide reliable performance for both new construction and interventions in existing buildings. Beyond new installations, post-installed anchors play a key role in repair and retrofitting, helping enhance the safety, durability, and strength of aged structures. This paper focuses on design of post-installed anchors to connect new steel member to an old or existing concrete structure. The abstract outlines the relevance of such solutions using different design approaches in modern engineering practice and highlights their importance in meeting current structural, seismic, and operational challenges. The paper also examines design aspects that fall outside codal limits using more representative shear distribution across multiple anchors (SOFA method), reflecting actual load-sharing behaviour to achieve optimized design. It discusses realistic evaluation methods to enhance the prediction of connection performance considering realistic behaviour of structural baseplate using Component Based Finite Element Method (CBFEM).

Keywords: *Steel-to-Concrete, Post-installed anchor, Structural baseplate, Non-rigid baseplate, CBFEM, Shear distribution*

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Paper ID: 116

Impact of IS875 (Part 3):2015 Revisions on Wind Load Estimation for High Rise Structures in Kolkata

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THEME: Seismic safety of pipelines, underground & buried structures

ABSTRACT

In this paper, the wind load design procedure of a 60m tall commercial structure is compared utilizing the 1987 and 2015 versions of IS 875 (part 3) by assuming the location of that building at various parts of Kolkata based on various category suggested as in the code. The paper emphasizes how the Indian code has changed in response to urbanization, regional and hazard profiles, and advancements of structural engineering. We look at important factors like fundamental wind speed, design wind speed coefficient, and the 2015 revisions addition of the k4 component for cyclonic zones. The analysis shows differences in lateral force, gust factor, and resulting wind pressure as determined by both code provisions using the same bending and sites, specific data. Due to the updated wind speed map, altered risk and terrain consideration, and a greater emphasis on cyclone resilience, the 2015 regulations significantly increased design stringency, according to the results. The study highlights the influences of code evolution on high rise building design in a crucial urban expansion zone by exposing significant variations in structural response and safety margins. In order to attain the best safety, performances and regulatory compliance in wind-sensitive areas, the study in with recommendations for practitioners, highlighting the importance of implementing the most recent codal practices.

Keywords: *IS 875 (Part 3), Cyclone-prone region, Basic wind speed, Design wind pressure*

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Paper ID: 117

Seismic Vulnerability Assessment of Built Infrastructure in Varanasi District using a Multi Criterion Decision Analysis

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THEME: Preparedness, public awareness and their participation

ABSTRACT

Varanasi is an ancient, densely populated city in northern India, located in Earthquake Zone III. It spans 82.10 km², divided into 90 wards, and lies within a moderate to high seismic risk zone. Moreover, unplanned urbanization and aged, unengineered structures contribute to a highly vulnerable built environment. Therefore, a holistic appraisal of seismic risk in built-up areas is essential.

This study presents a seismic vulnerability assessment of Varanasi district using GIS-based Multi-Criteria Decision Analysis (MCDA), incorporating multiple factors such as roof, floor, and wall building materials, road density, and land use land cover (LULC). This information is derived from high-resolution satellite imagery, field surveys, and census records. Spatial dataset layers are overlaid on a base GIS map using weighted overlay analysis to generate a combined vulnerability index. Each factor is assigned a weight based on its relative impact on seismic performance.

The results indicate that areas with multi-story, non-engineered buildings are highly vulnerable, particularly in core commercial zones with limited open space and complex road networks. In contrast, peripheral residential areas exhibit lower risk due to lower building density and smaller building heights. The final vulnerability map delineates very high, high, moderate, low, and very low-risk zones, providing a spatial framework for prioritized seismic risk mitigation.

Keywords: *Seismic Vulnerability, Earthquake, GIS, Multi Criteria Decision Analysis*

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ICSRI-2026

Published by

Department of Civil Engineering

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