

International Conference
on
TENETS FOR GEOSYSTEM SURETY
TGS 2026

Sustainable Infrastructure Through Hazard Analysis, Resilience and Management

To Felicitate

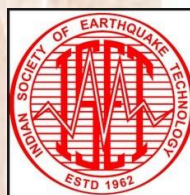
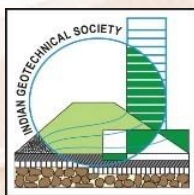
Prof TG Sitharam

Organised by

**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF SCIENCE, BENGALURU**



In Collaboration with



INDIAN GEOTECHNICAL SOCIETY (BENGALURU CHAPTER)

Date: July 17–18, 2026

Venue: JN Tata Auditorium, IISc Bengaluru, India

About the Conference

The Department of Civil Engineering, Indian Institute of Science (IISc) Bengaluru, proudly organizes the International Conference on **Tenets for Geosystem Surety (TGS) 2026**. This prestigious gathering is specially convened to honor the exemplary three-decade career, visionary leadership, and superannuation of Prof. T.G. Sitharam, Professor of Civil Engineering at IISc and past Chairman of the All India Council for Technical Education (AICTE). Centered around the vital theme of ***Sustainable Infrastructure Through Hazard Analysis, Resilience and Management (SITHARAM)***, the conference provides a premier platform for participants to showcase their cutting-edge work, exchange transformative ideas, and deliberate on modern geotechnical challenges before an eminent assembly of scholars and engineering leaders.

TGS 2026 serves as a high-signal intellectual forum, drawing together a diverse and eminent assembly of participants from across the globe. The conference brings together:

- **Distinguished Invitees & Scholars:** Leading global researchers, foundational thinkers in civil engineering, and academic pioneers driving technical innovation.
- **International & Local Delegates:** Registrants from premier global and national institutions presenting cutting-edge advancements across six specialized technical themes.
- **The Geotechnical Fraternity & Practitioners:** Industry consultants, contractors, manufacturers, and policy analysts navigating real-world infrastructure challenges.
- **Prof. Sitharam's Academic Lineage:** A proud contingent of his former Ph.D. scholars and students who have gone on to shape modern engineering practices worldwide.
- **Bonafide Students:** The next generation of researchers and engineering minds presenting breakthrough insights before an accomplished assembly of peers.

Through dedicated technical deliberations, peer reviews, and an active industrial exhibition, TGS 2026 bridges the gap between sophisticated geomechanical theory and field practice, forging the path for resilient global infrastructure.



Professor Ganapati D. Yadav

B. Chem. Eng., Ph.D.(Tech.), D.Sc. (Hon. Causa, DYPU Kolhapur), D. Eng. (Hon. Causa, NIT-A)
NAE (US), FNAI (US), FTWAS, FNA, FASc, FNASc, FNAE, FISTE, FRSC (UK), ChE, FIChemE (UK), FIChE, FICS FMASc, FIChE
Bhatnagar Fellow (CSIR) & Former National Science Chair (ANRF/DST/GOI)

Emeritus Professor of Eminence

Former Vice Chancellor & R.T. Mody Distinguished Professor
and Tata Chemicals Darbari Seth Distinguished Professor of Leadership & Innovation

INSTITUTE OF CHEMICAL TECHNOLOGY

Deemed to be University under Section 3 of UGC Act 1956

Category I Institute UGC

ICT IOC Campus Bhubaneswar, ICT Marathwada Campus, Jalna

Elite Status & Centre of Excellence, Govt. of Maharashtra

Foreword

It gives me immense pleasure to write this foreword for the *International Conference on Tenets for Geosystem Surety (TGS 2026): Sustainable Infrastructure Through Hazard Analysis, Resilience and Management*, organized by the Department of Civil Engineering, Indian Institute of Science, Bengaluru, in honour of Professor T. G. Sitharam on the occasion of his superannuation. The conference rightly celebrates an exceptional engineer, educator, institution builder, and visionary leader whose contributions have left an indelible mark on geotechnical engineering and technical education in India.

My association with Prof. Sitharam goes back more than four decades. During the later part of mid-1980s, when I was a Post-Doctoral Fellow in Chemical Engineering at the University of Waterloo, Canada, Prof. Sitharam joined the same university to pursue his doctoral studies in Civil Engineering. Although we belonged to different disciplines, we shared the stimulating academic environment that Waterloo was renowned for. It has been gratifying to witness his remarkable professional journey since those formative years.

Many years later, it was a pleasant surprise to meet him again when he was serving as the Director of IIT Guwahati, where I had the privilege of being appointed as a Distinguished Adjunct Professor. Our interactions became even more frequent during his tenure as Chairman of the All India Council for Technical Education (AICTE), where I had the opportunity to serve as Chairman of five AICTE committees.

Prof. Sitharam's tenure as Chairman of AICTE will be remembered as one of transformational leadership. He introduced several innovative initiatives aimed at enhancing the quality, inclusivity, and relevance of technical education across the country. He recognized that India's vast network of private engineering institutions required not only regulatory oversight but also active academic support. His emphasis on strengthening doctoral and post-doctoral research, faculty development, innovation, entrepreneurship, industry-academia collaboration, and outcome-based education has significantly enriched the technical education ecosystem. These initiatives have empowered

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Vice President, Indian National Science Academy (INSA)

President, Indian Chemical Society

Honorary Professor, JNCASR, Bangalore

Distinguished Adjunct Professor, IIT Guwahati

Adjunct Professor, University of Saskatchewan, Saskatoon, Canada

Distinguished Visiting Professor SOA University, Bhubaneswar

Padmashri Awardee (2016)



Dr. H R Nagendra, ME, PhD, DSc
Padma Shri - 2016
President
S-VYASA Society



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Anusandhana Samsthana (S-VYASA)
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e-mail: president@svyasa.edu.in
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FOREWORD

It is a privilege to extend my warm greetings to the organizers and participants of the International Conference on Technologies for Geotechnical Solutions (**TGS 2026**).

The conference addresses a theme of great importance as the world strives to build resilient, sustainable, and safe infrastructure. By bringing together researchers, academicians, industry experts, and policymakers, TGS-2026 provides an excellent platform for exchanging knowledge, fostering innovation, and promoting solutions to the geotechnical challenges of the future.

I am particularly delighted that this conference celebrates the outstanding contributions of **Prof. T. G. Sitharam**, one of India's most distinguished geotechnical engineers. His pioneering research in foundation engineering, earthquake engineering, soil dynamics, landslide hazard mitigation, and geotechnical modelling has significantly advanced the science and practice of geotechnical engineering. Equally noteworthy has been his visionary leadership in engineering education and institution building, inspiring generations of engineers and researchers.

A landmark contribution of Prof. Sitharam has been his role in the construction of the **Shri Ram Temple at Ayodhya**. As a member of the expert technical team, he contributed to the development and validation of the temple's innovative foundation system, helping create a robust, durable, and earthquake-resistant foundation designed to stand the test of time. This historic achievement beautifully demonstrates how scientific excellence and engineering innovation can preserve and support India's timeless cultural and spiritual heritage.

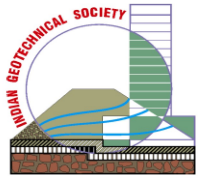
I congratulate the Organizing Committee for this commendable initiative and wish TGS-2026 every success. I am confident that the deliberations and outcomes of this conference will advance geosystem engineering and inspire future generations to build a safer, stronger, and more sustainable world.

Dr. H. R. Nagendra
President, S-VYASA Deemed-to-be University
Guest of Honour, TGS-2026

INDIAN GEOTECHNICAL SOCIETY

Registered under Societies Act vide Regn. No. S/18957 dated 16.05.1988)

(Affiliated to INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING)



President: Dr. Anil Joseph
Hon. Secy. Dr. A.P. Singh



It gives me immense pleasure to extend my warm greetings to the organizers, delegates, speakers, researchers, and industry professionals participating in the International Conference on Tenets for Geosystem Surety (TGS-2026) being held at the Indian Institute of Science (IISc), Bengaluru.

The theme of TGS-2026 aptly reflects the growing need for resilient, sustainable, and reliable geosystems in addressing the challenges of modern infrastructure development. As geotechnical engineers, we carry the responsibility of ensuring that our designs and practices contribute to the safety, durability, and sustainability of the built environment. Conferences such as TGS-2026 provide an invaluable platform for the exchange of innovative ideas, cutting-edge research, and practical experiences among academicians, researchers, practitioners, policymakers, and students.

The Indian Geotechnical Society has always been committed to fostering excellence in geotechnical engineering through knowledge dissemination, professional collaboration, and capacity building. I am delighted to witness IISc Bengaluru bringing together distinguished experts from India and abroad to deliberate on contemporary advancements and emerging challenges in geotechnical engineering.

I congratulate Prof. P. Anbazhagan, the Organizing Committee, faculty members, students, sponsors, and all those who have worked tirelessly to make this conference a reality. I am confident that the technical sessions, keynote lectures, and discussions will inspire meaningful collaborations and contribute significantly to the advancement of geotechnical science and engineering.

I wish TGS-2026 every success and hope that all participants have a rewarding academic and professional experience.

Dr. Anil Joseph

Vice President for Asia

International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)

President

Indian Geotechnical Society (IGS)

Secretariat :

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Prof. Deepak Kumar Srivastava

Former - Vice Chairman

UNIVERSITY GRANTS COMMISSION, NEW DELHI
(Ministry of Education, Govt. of India)

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Date: 15.7.2026

MESSAGE

At the outset, I must congratulate the Department of Civil Engineering at IISC, Bengaluru for hosting an International Conference on “Tenets for Geosystem Surety (TGS 2026)” hosted at IISC, Bengaluru. The theme is very relevant for *VIKSIT BHARAT 2047*. The domain of civil engineering is making the journey of Viksit Bharat a true reality. I wish that conference will certainly benefit other domains like humanities and social sciences.

The conference will also release the book **AI Sakti AI Bharat** authored by Prof. T.G. Sitharam. AI has been reaching to every walk of our life – not that machines become intelligent, but that dignity and opportunity can finally reach people the system has historically left behind. Whether that promise is kept will not be decided by the technology, it will be decided by the choices we make today. Prof. T.G. Sitharam is known for his passion and commitments towards high impact research and innovation. He is a civil engineer by academic discipline but a social engineer by practice. This is very well reflected from his academic and professional journey so far. His contributions to the larger society will certainly add value to the academicians and researchers participating in this conference.

I am confident that outcome of this conference will take the discourses to the next level of the orbit.

I wish all the best to the organisers, participants and Prof. T.G. Sitharam for a great success in future.

Jai Hind ... Jai Bharat !!



(Prof. Deepak Srivastava)



N Revanasiddappa

“Congratulations T.G Seetharam! You have reached a stage where you have to be a pathfinder for future of engineering education in India. When the technologies are rapidly evolving, I hope you will do your best. I am proud to be one of the faculties of Civil Engineering B.D.T college of engineering from 1960s-1990s. Many alumni have contributed for excellence in their own way like engineer G.H Basavaraj. As another alumni of B.D.T has become R & D scientist and contributed to cement technology . I wish all the alumni Good Luck. Thanks to Sri Parthasarthy for giving me this opportunity.”

About Prof T G Sitharam



Prof. T. G. Sitharam is the Chairman, Board of Governor (BOG) of The National Institute of Food Technology Entrepreneurship and Management, Thanjavur, Tamil Nadu. NIFTEM-T is a premier higher education and research institute and an Institution of National Importance (INI) under India's Ministry of Food Processing Industries (MoFPI). It focuses on food science, technology, and entrepreneurship (NIFTEM-T) and offers undergraduate, postgraduate, and Ph.D. programs in food technology and management. He is a distinguished academic leader, institution builder, and national policy expert with over 35 years of transformative contributions to India's technical education, research, skilling, innovation, and infrastructure ecosystem. With strong academic foundations at the Indian Institute of Science (IISc), Bengaluru, and Director of IIT Guwahati, combined with extensive international exposure, he uniquely blends scientific excellence, policy vision, and people-centric governance. He is the co-chair of Human capital theme for AI impact summit 2026 which was held during 19-20, Feb 2026. Prof. Sitharam focuses on bridging the skill mismatch caused by rapid automation, highlighting that while routine jobs are at risk, AI creates new roles in development, ethics, and governance. His efforts aim to generate a "National Enhancing Human Capital Report" as a key contribution to the Summit, promoting a shift in technical education to prioritize critical thinking and AI integration, and ensuring that India leads in developing a "trusted and responsible" AI ecosystem.

Until Dec 20,2025, he was the Chairman of the All India Council for Technical Education (AICTE) since December 2022, Prof. Sitharam has played a pivotal role in reshaping technical education through reforms in curriculum, digital learning, emerging technologies, and institutional capacity building. His leadership has emphasized transparency, accountability, and outcomes, alongside the establishment of Centers of Excellence in AI, drones, cybersecurity, quantum, semiconductors and other frontier technologies, impacting millions of learners and educators across the country. Prior to this he was the Director of IIT Guwahati and also Chairman of Research council of CSIR-CBRI and many other organizations. He was the former Council Member of Indian Institute of Science, Bengaluru

for 3 years. He was the Chairman, Executive committee, Visweswaraya Industrial and Technological Museum (VITM), NCSM, Ministry of Culture 2016-2022 and Member, National council of Science Museums(NCSM), Ministry of Culture. He was a Member of SERB (2019- 2022), IOE committee, NASSCOM Future Skills, DST, IITG Research Park, Anuvadini Foundation (section 8 Companies) etc., Prof. T. G. Sitharam possesses an outstanding academic and professional educational background. He earned his Bachelor of Engineering from Government BDT College of Engineering, Davanagere, affiliated to the University of Mysore. He completed his Masters at the Indian Institute of Science, Bengaluru (1984–1986), followed by a Ph.D. from the University of Waterloo, Canada (1987–1991).



He further advanced his research expertise as a Postdoctoral Scientist at the University of Texas at Austin, USA (1991–1994). He was conferred the Doctor of Science (Honoris Causa) by Vel Tech University in 2023 and Jawaharlal Nehru Technological University (JNTU), Hyderabad in 2025. He has authored over 500 research publications and 20 books, guided 40 Ph.D. scholars, and executed 120+ consultancy projects, with several innovations translated into practice. His scholarly impact is reflected in his ranking among the top 2% of scientists worldwide by Stanford University for multiple consecutive years.

He is the Fellow of INAE, ASCE (USA), ICE (UK), IGS, ISTE, ISET and Honorary Fellow of Indian Geotechnical Society, 2015. He is the chief editor of the International Journal of Geotechnical Engineering (IJGEE) USA and Chief Editor; of Springer Civil & Environmental Book Series, Singapore, and also the Editorial board member of many prestigious Journals in India and Abroad. Beyond academia, he has contributed to landmark national projects, including the Ram Temple foundation works at Ayodhya, the Chenab Railway Bridge, and Sarovar Mala, demonstrating how engineering solutions can harmonize with tradition, ecology, and sustainability. He has also held numerous high-level governance roles across IITs, IISc,

CSIR laboratories, and national science institutions, and has been actively involved in mobilizing CSR and philanthropic resources for research and innovation. Widely honoured with national and international awards including Sir M. Visvesvaraya Lifetime Achievement Award 2023 and Sir C.V. Raman Award from Govt of Karnataka, 2002, STTAR SHIKSHA GARIMA PURASKAR sept 27, 2025; IGS-Kueckelmann Award 2015; Prof. Gopal Ranjan Research Award 2014; Recipient of 1998 S. P. Research Award, and Dr Pritam Singh Academic Transformation Leader Award 2025 from Dr. Pritam Singh Foundation. Prof. Sitharam stands out as a rare leader who bridges academia, government, industry, and society, combining scientific depth with a compelling vision for nation-building and sustainable development. He was the President of Indian Society for Earthquake Technology (ISET) for two terms, and Vice President ISET for two terms. In addition, he is the founder President of International Society for Coastal Reservoir Research (IACRR).



Presently, he is the mentor for the Green TERRE Foundation (GTF). He has authored many books on Artificial Intelligence including “AI Shakti-AI Bharat”, Challenges into opportunities and dreams into realities, Wireframe document on AI for all (authors: T G Sitharam, Dr. M. Verma, Mr. Kochhar, 2025), Khanna Book Publishing Co (P) Ltd., New Delhi, pp. 164, 2025; The Road Ahead 2.0 (2 volumes 750 pages), Education world, 2024 (by prof. T G Sitharam and Yogesh Kochhar -2 volumes: ISBN 978-93-341-9461-6 & ISBN NO-978-93-341-9750-1, 2025; and Unlocking the potential of Technical education to shape India’s Future – Fueling Innovation, Growth and Inclusion, by Prof. T G Sitharam, ISBN 978-

93-6194-306-5. 2024; “Empowering Minds: the Transformation of IIT Guwahati” by Prof. T. G. Sitharam, 2025 and Building a Future Ready India: Vision plan & Strategy for Technical education during Amrit Kaal (enhancing the role of technical education for vikasit Bharat, by: T. G. Sitharam, 2025, ISBN 978-93-55386-11-3”). He emphasizes lifelong learning, adaptability, and human-centered AI, preparing people for job transformation rather than elimination, and integrating national efforts into the global summit framework.

Awards and Honors



Proud Alumnus of UBDT College of Engineering, Honoured by the Vice Chancellor of VTU, Belagavi on 29th May 2026, in the honorable presence of the Vice President of India and Honorable Governor, and many Ministers of the Government of Karnataka at Davanagere during the Platinum Jubilee celebration of UBDCE.

Patents

- **In-Vehicle Road Signs and Live Traffic Lights Using Direction Sensitive Short Range Wireless Communication,**

RFID-IPA09120001

Title: Direction Sensitive Wireless Communication Application No. 4873/CHE/2012;

Date of filing: 23 November 2012;

Applicant: Indian Institute of Science, Bangalore; Our Ref: IPA09120001 Applicants: Aritra Paul, T G Sitharam, Venkatesh.

- **A System and method for fracking of shale rock using shock wave**

Date of filing in India: 15.10.2013

Patent Application no.: 4633/CHE/2013

Deferment filed for six months April 08, 2015 4633/CHE/2013 April 09,2015; PCT/IN2015/000166.

The proposed technique intends to produce new fractures in the oil-bearing shale rock formation using the shock waves. A shock tube is a tool which generates shock waves which can be placed either inside the wellbore or on the ground surface. Applicants: G Jagadeesh, T G Sitharam; KPJ Reddy and KB Akhilesh (IISc, Bangalore).

- **A System and method for fracking of shale rock using shock wave**

Date of filing in India: 15.10.2013

Patent Application no. PCT/IN2015/000166. (Filed in US)

- **A System And Method For Increasing Yield Of A Depleted Borewell By Using Shock**

Applicants: KPJ Reddy, T G Sitharam and Vivek,P. Patent

Application no: IP -1371-IN-10960-PPA-2014:

Many borewells get abandoned due to low yield or dry out. The efficiency of the wells gets reduced over time by indicating a low specific capacity or yield. It is economically not feasible and practically impossible to abandon them and start with a new borewell. It is possible that these borewells can be rejuvenated. A new technique is proposed here to increase the yield of a well with the application of shock waves. Shock waves are generated using a shock tube on the surface and directed into the borewell. The high pressure behind the shock wave traveling into the borewell acts normal to the walls of the borewell and helps in clearing the clogged up water channels (fissures, fractures, etc.) present in rock formations and thereby allowing the water to flow easily into the well

- **Smart water network to store river flood water in sea-based reservoirs and a method of interlinking these reservoirs (Sarovar Mala™),**

India patent no. TEMP/E-1/44294/2016-CHE,2016. Thallak Gundurao Sitharam;

Copyright and Trademark

- Smart water network to store river flood water in sea-based reservoirs and a method of interlinking these reservoirs (Sarovar Mala™), Thallak Gundurao Sitharam, India Copyright Registration number L-72417/2018 dated 16.01.2018
- Efficacy of coastal reservoirs to address India's water shortage by impounding excess river flood waters near the coast, Copyright Registration number L-72419/2018 dt. 16.01.2018.

List of Publications

Consolidated Details of Publications

Sl. No.	Details	Entire period 1986 - 2015
1	Journal Publications	156
2	Geotechnical Special Publications	3
2	Books	6
3	Book Chapters	6
4	Edited Proceedings and Journals	14
5	Conference Papers	251
Total		436

List of Students – T G Sitharam

PhD Thesis Submitted

1. Bala Reddy Muthanna, “Liquefaction behavior of clayey soils (*Submitted 2017*). (external)

PhD Thesis awarded

2. Vivek P, (2018) "The Behaviour of Granular Materials under Shock and Blast Loading - A Shock Tube Investigation".. *Status* : Degree awarded.
3. Deendayal Rathod (2017), “Analyses of Laterally loaded piles in clayey soils with sloping ground” . *Status* : Degree awarded.
4. Devaraj H., (2016) “Socio-economic impact analyses of improvement of roads in around Bangalore”, (*Awarded*)- *Jointly with Prof. Parthasarathy Ramachandran. Status* : Degree awarded.
5. Naveen B P (2016), Static and dynamic behavior of solid wastes (*Awarded*).(Jointly with prof. P V Sivapullaiah) *Status* : Degree awarded.
6. Resmi Sebastian (2015), "Low strain dynamic properties of jointed rock mass" *Status* : Degree awarded.
7. Raviraj H. Mulangi (2015) “Performance evaluation of public bus transport operations in Karnataka by using non-parametric and multivariate analysis”. *Status* : Degree awarded.
8. Amarnath Hegde (2015), "Ground improvement using 3D cellular confinement systems: Experimental and numerical studies". *Status* : *Awarded*
9. Naveen James (2014), "Site characterization and assessment of various earthquake hazards for micro and macro-level seismic zonations of regions in the peninsular India". *Status: Awarded*
10. Arjun Sil (2014), "Seismic Hazard Assessment of Tripura and Mizoram States along with microzonation of Agartala and Aizawl cities". *Status: Awarded*
11. Partho Choudhury (2013), "Intelligent models for prediction of blast induced ground vibration parameters based on explosive and geotechnical characteristics". *Status: Awarded (jointly with prof. Madhavi latha)*

12. S D AnithaKumari (2013), "Effect of Particle shape on the mechanical behaviour of granular media: Discrete Element Simulations". *Status: Awarded*
13. SreevalsaKolathayar (2013), "Comprehensive Seismic Hazard Analysis of India".*Status: Awarded*
14. Abhishek Kumar (2013), "Seismic microzonation of lucknow based on region specific GMPE's and geotechnical field studies".*Status: Awarded (Jointly with Dr. P. Anbazhagan)*
15. M Raji (2013), "Endochronic Constitutive Model for sands and its application to geotechnical problems". *Status: Awarded*
16. More Ramulu (2010), "Behaviour of subsurface structures in jointed rock mass subjected to repeated loading" *Status: Awarded. (jointly with prof. Madhavi latha)*
17. K.S. Vipin (2010), "Assessment of seismic hazard with local site effects: Deterministic and probabilistic approaches" *Status: Awarded.*
18. Dash, Hemanta Kumar (2008). "Undrained Cyclic and Monotonic Response of Sandsilt Mixtures". *Status: Awarded.*
19. PijushSamui (2007), "Geotechnical Site Characterization and Liquefaction evaluation using Intelligent models". *Status: Awarded.*
20. Maaji Vidya Bhushan (2007), "Strength and Deformation Behaviour of Jointed rocks: An Equivalent continuum model". *Status: Awarded.*
21. Anbazhagan, P. (2007). "Site characterization and Seismic hazard Analysis with local site effects for Microzonation of Bangalore". *Status: Awarded.*
22. Ravishankar, B.,V., (2006), "Cyclic and monotonic undrainedbehaviour of Sandy soils", *Status: Awarded.*
23. Vinod.J.S. (2006), "Liquefaction and dynamic properties of granular materials: A Discrete element approach". *Status: Awarded.*
24. Sireesh S. (2006), "Behaviour of Geocell Reinforced Foundation Beds". *Status: Awarded.*
25. Govindaraju, .L (2005), "Liquefaction and Dynamic Properties of Sandy Soils". *Status: Awarded.*

26. Dinesh, S.V. (2003), "Discrete element simulation of static and cyclic behaviour of granular materials". *Status: Awarded.*
27. Sridevi, B., (2000), "Numerical modeling of jointed rock mass". *Status: Awarded.*
28. K. Nagendra Prasad (1997), "Constitutive modeling of soft cemented soils". *Status: Awarded.*
29. H.B. Raghavendra (1997), "Some studies on the analysis of reinforced soil beds". *Status: Awarded.*
30. Sameed Kumar Patil, "A Laboratory Study on Liquefaction and Post Liquefaction Behavior of Soils from Indo-Gangetic Basin" (*Thesis writing in progress*).
31. Monalisa Naik, "Seismic hazard analyses for North India Region" (*Joined in 2014*).
32. Vaishali Wayal, "Electrical resistivity Tomography: Laboratory and Field Assessment of Soil Properties using Electrical Resistivity Technique", (*Joined in 2016*).
33. Dhanaji Chavan, "Liquefaction mitigation using air-injection techniques", (*Joined in 2016*).
34. Hemanth, "Twin tunnel interference effect" (*Joined in 2017*).

MSc (Engg) thesis

1. Susan Kurien, (1999) Shear Strength and Volume Change Characteristics of Granular Materials and Aggregate Mixtures, Status: *Awarded.*
2. P.V. Nagaraja Rao, (1998) "Discrete element simulation of liquefaction behavior of sands", *Status: Awarded-coguide*
3. Mandar S. Nimbkar (1996), "Constitutive behavior of coarse grained granular media A discrete element approach" *Status: Awarded.*
4. Naveen B.P. (2012), "Ageing effects on municipal Solid Waste". *Status: Awarded.*
5. Akash Gupta, (*Joined 2016*) "Interference effect of closely spaced square footing on clay and sand deposits-experimental and numerical studies" *Status: In Progress*

TECHNICAL PROGRAMME SCHEDULE – TGS 2026

Venue: National Science Seminar Complex, Indian Institute of Science, Bangalore

Day 1: 17/07/2026 (Friday)

09:30 – 10:30	Inauguration Venue: J N Tata Auditorium	Coordinator: Dr. C.R. Parthasarathy (SGES Pvt Ltd) Volunteers: Sivani Sangeetha Dikshitha Shreyas Yadunandan Bronson Arun Kumar Singh Kukutla Sai Shivanand Vanishree
10:30 – 11:00	Tea Break & Exhibition Visit	
11:00 – 12:00	Theme 1: Geosynthetics and Ground Improvement Presenters: Prof. Sireesh Saride (IIT Hyderabad); Dr. Amarnath Hegde (IIT Dharwad); Dr. Deendayal Rathod (NIT Tiruchirapalli). Expert Panel: Prof. A. Murali Krishna (IIT Tirupati); Prof. Dasaka Murthy (IIT Bombay); Prof. H.N. Ramesh (UVCE, Bengaluru University).	Chair: Prof. Jyant Kumar (IISc, Bangalore) Volunteers: Ankit, Surya Prakash
12:00 - 13:00	Theme 2: Geotechnical Investigation and Site Characterization Presenters: Dr. Abhishek Kumar Sharma (IIT Guwahati); Dr. Naveen James (IIT Ropar); Dr. L. Govindaraju (UVCE, Bengaluru); Dr. B.V. Ravishankar (Cambridge Institute of Technology). Expert Panel: Prof. Vasant Matsagar (IIT Delhi); Prof. T. Thyagaraj (IIT Madras); Prof. A.P. Singh (Explore Engineering Consultants).	Chair: Prof. Sekhar Muddu (IISc, Bangalore) Volunteers: Yadhunandan, Hrithick
13:00 – 14:00	Lunch & Exhibition Visit	
14:00 – 15:30	Felicitation of MP Nagaraj by TGS Special guest address: Shri M Nagaraj, Member of Parliament, Rajya Sabha	

	Theme 3: Seismology, Earthquake Geotechnical Engineering and Microzonation Presenters: Dr. Sreevalsa Kolathayar (NIT Surathkal); Dr. Abhishek Kumar (IIT Guwahati); Dr. Dhanaji Chavan (KLSGIT, Belagavi); Prof. Anbazhagan P. (IISc, Bangalore); Dr. Monalisha (L&T Construction); Dr. Ramakrishnan (FRI, Dehradun); Dr. Balreddy Muttana S. (SIT, Tumkur). Expert Panel: Shri M Nagaraj, Member of Parliament, Rajya Sabha Prof. S.K. Prasad, (IGS Mysuru chapter) Prof. A. Boominathan (IIT Madras); Prof. G.R. Dodagoudar (IIT Madras); Prof. K. Premalatha (Anna University, Chennai); Prof. Hazarika Hemanta (Kyushu University, Japan)	Chair: Prof. KV Vijayendra (AIT, Bengaluru) Volunteers: Ayush Kumar, Rishab Kumar, Yogarish NR
15:30 – 16:00	Tea Break & Exhibition Visit	
16:00 – 17:30	Parallel Technical Session 1 (Hall A) (Details are provided on Page 4-9)	Chairs: Dr. Ramakrishna Bag (IIT Patna) Volunteers: Yadhunandan ME; Sourav Sarkar; Hirtheek
	Parallel Technical Session 2 (Hall B) (Details are provided on Page 4-9)	Chair: Dr. G V Ramana (NIT Warangal) Volunteers: Zeeshan; Deepak; Ankit
	Parallel Technical Session 3 (Hall C) (Details are provided on Page 4-9)	Chair: Dr. K Manjunatha (UBDTCE, Davangere) Volunteers: Ayaz Mehmood; Surya Prakash; Vishnu
18:00 – 20:00	Cultural Programme Venue: J N Tata Auditorium “Echoes of the Earth” by Laasya Academy of Dance and Shivapriya School of Dance Artists: Dr. Lakshmi Rekha Arun Founder-Director, Laasya Academy of Dance Dr. Sanjay Shantaram Artistic Director, Shivapriya School of Dance	Coordinator: Dr. C R Parthasarathy Volunteers: Sivani Sangeetha
20:00 onwards	Dinner Venue: Dining Hall	
Day 2: 18/07/2026 (Saturday)		
08:00 – 09:00	Breakfast	

09:00 – 10:00	Theme - 4 Computational Methods and Geomechanics Presenters: Prof. Pijush Samui (NIT Patna); Prof. J S Vinod (University of Wollongong); Dr. Vipin (Swiss Re); Prof. Dinesh SV (SIT, Tumkur); Prof. Anitha SD (MSRUAS, Bengaluru). Expert Panel: Prof. Muthukkumaran K (NIT Tiruchy); Prof. Ravi S. Jakka (IIT Roorkee). Shri Sriram, GEMS software	Chair: Prof. Debraj Ghosh (IISc, Bangalore) Volunteers: Harish Thakur, Panjami K
10:00 – 11:00	Theme 5: Rock Mechanics, Tailing Dams and Mining Presenters: Prof. VB Maji (IIT Madras); Dr. Reshmi Sabastian (IIT Ropar); Dr. Vivek P (IIT Guwahati). Expert Panel: Prof. Mahendra Singh (IIT Roorkee); Dr. H.S. Venkatesh (NIRM, Bengaluru); Dr. More Ramulu (AICTE, New Delhi)	Chair: Dr. P Raghuveer Rao (IISc, Bangalore) Volunteers: Zeeshan, Pranjal, Ayaz
11:00 – 11:30	Tea Break & Exhibition Visit	
11:30 – 13:00	Parallel Technical Session 4 (Hall A) (Details are provided on Page 4-9)	Chair: Dr. Lohitkumar Nainegali (NITK Surathkal) Volunteers: Panjami; Hirthick; Surya Prakash
	Parallel Technical Session 5 (Hall B) (Details are provided on Page 4-9)	Chair: Dr. Prabhakar (NIT Tiruchy) Volunteers: Harish Thakur; Deepak; Yogarish
	Parallel Technical Session 6 (Hall C) (Details are provided on Page 4-9)	Chair: Dr. Arvind Kumar Jha (IIT Patna) Volunteers: Yadhunandan ME; Rishabh Kumar
13:00 – 14:00	Lunch & Exhibition Visit	
14:00 – 15:00	Theme 6: Sustainability, Social Impact and Education Presenters: Dr. CR Parthasarathy (Sarathy Geotech), Dr. Deepankar Choudhury (IIT Bombay) Dr. Raviraj H.M. (NITK, Surathkal); Dr. More Ramulu (AICTE, New Delhi).	Chair: Prof. V V Srinivas (IISc, Bangalore) Volunteers: Sourav, Vishnu

	Expert Panel: Padmashree Dr. Prahalada Rama Rao (Former Director, DRDL Bengaluru); Dr. HK Ramaraju (The Institute of Engineers (India)).	
15:00 – 16:00	Parallel Technical Session 7 (Hall A)	Chair: Dr. Aditya Parihar (TIET, Patiala) Volunteers: Ayush Kumar; Hirthick; Maneet
	Parallel Technical Session 8 (Hall B)	Chair: Dr. Kunjari Mog (IIEST, Shibpur) Volunteers: Sourav Sarkar; Deepak
	Parallel Technical Session 9 (Hall C)	Chair: Dr. Manoj N. Bagde (CSIR-CIMFR, Nagpur) Volunteers: Zeeshan; Surya Prakash; Vishnu
16:00 – 16:30	Tea Break & Exhibition Visit	
16:30 onwards	Valedictory Function	Coordinator: Dr CR Parthasarathy Volunteers: Sivani Sangeetha

Inaugural Function Programme Schedule

International Conference on Tenets for Geosystem Surety: TGS-2026

Date: 17 July 2026

Venue: J. N. Tata Auditorium, IISc Bangalore

09:30 AM – 09:33 AM	Opening Note	Opening remarks and invitation to the dignitaries to occupy the dais: Chief Guest – Dr. S. Vidyashankar, <i>Vice Chancellor, VTU</i> Presided by – Prof. Ananth Ramaswamy, <i>Chairman, Department of Civil Engineering, IISc</i> Guests of Honor – Padma Shri Dr. H.R. Nagendra Guruji, <i>President, S-VYASA Deemed-to-be-University</i> – Shri. Janardhana Swamy, <i>Former Member of Parliament, 15th Loka Sabha, Chitradurga constituency</i> – Padma Shri Prof. Ganapati D. Yadav, <i>Emeritus professor of Eminence, Institute of Chemical Technology</i> – Prof. Deepak Kumar Srivastava, <i>TISS, Former Vice Chairman UGC</i> Host Dignitaries – Prof. T. G. Sitharam and Mrs. Sitharam; – Dr Anil Joseph, <i>President IGS, Vice President-Asia, ISSMGE</i> – Prof. Anbazhagan, <i>Convenor, TGS 2026</i> – Prof S.K Prasad, <i>Organizing member, TGS 2026</i>
09:33 AM – 09:35 AM	Invocation	Invocation song
09:35 AM – 09:40 AM	Welcome Address	Prof. Ananth Ramaswamy
09:40 AM – 09:43 AM	About the Conference	Brief introduction and overview of TGS-2026 by the Prof. Anbazhagan
09:43 AM – 09:48 AM	Lighting of the Lamp	
09:48 AM – 09:58 AM	Felicitation of Teachers	by Prof. T. G. Sitharam, Felicitation of esteemed teachers including – Dr. K. N. V. Rao, <i>Retd. Professor UBDT CE</i> – Shri K. V. Prasad, <i>Retd. Professor UBDT CE</i> – Shri D. S. Prakash, <i>Retd. Professor UBDT CE</i> – Prof. S. K. Narayan, <i>Retd. Professor UBDT CE</i> – Prof. Rama Rao, <i>Retd. Professor UBDT CE</i> – Prof. Achuta, <i>Retd. Professor UBDT CE</i> – Prof. N. Somashekar, <i>Retd. Professor UBDT CE</i> – Prof. P. V. Sivapulliah, <i>Retd. Professor IISc</i> – Prof. A. Sridharan, <i>Retd. Professor IISc</i>
09:58 AM – 10:00 AM	Felicitation of Chief Guest	by Prof. T. G. Sitharam

10:00 AM – 10:10 AM	Felicitation of Guests	By the organizing committee; Dr. Nagendra Guruji Shri Janardhana Swamy Dr. G. D. Yadav Prof. Deepak Kumar Srivastava
10:10 AM – 10:15 AM	Address by the Chief Guest	Dr. Vidyashankar
10:15 AM – 10:20 AM	Address by Guests of	Dr. Nagendra Guruji, Distinguished Guest
10:20 AM – 10:25 AM	Honor	Prof. Deepak Kumar Srivastava
10:25 AM – 10:27 AM	Souvenir release	
10:27 AM – 10:29 AM	Felicitation of Prof. T. G. Sitharam	by Dr Anil Joseph, IGS President
10:29 AM – 10:32 AM	Address by Guests of	Dr Anil Joseph, IGS President
10:32 AM – 10:37 AM	Honor	Mr. Janardhana Swamy
10:37 AM – 10:42 AM		Dr. G. D. Yadav
10:42 AM – 10:44 AM	TGS book release (AI Sakti AI for Bharat)	
10:44 AM – 10:47 AM	Special Address by Prof. T. G. Sitharam	Prof. T. G. Sitharam
10:47 AM – 10:50 AM	Vote of Thanks	Vote of thanks by Prof. S. K. Prasad
NATIONAL ANTHEM		

Cultural Evening

Venue: J N Tata Auditorium

18.30 to 19.30hrs

“Echoes of the Earth”

by Laasya Academy of Dance and Shivapriya School of Dance

Artists:

Dr. Lakshmi Rekha Arun

Founder-Director, Laasya Academy of Dance

Dr. Sanjay Shantaram

Artistic Director, Shivapriya School of Dance

Dinner 19.30 Onwards

Host Dignitaries

- Prof TG Sitharam and Mrs TG Sitharam;
- Dr CR Parthasarathy, IGS Bengaluru Chapter
- Prof KV Vijayendra, IGS Bengaluru Chapter

Valedictory Function Programme Schedule

International Conference on Tenets for Geosystem Surety: TGS-2026

Date: 18 July 2026, 16.30hrs

Venue: J. N. Tata Auditorium, IISc Bangalore

04:30 PM – 04:32 PM	Opening note	Invitation to the dignitaries to occupy the dais: Chief guest – Dr Anil Joseph, <i>President IGS, Vice President-Asia, ISSMGE</i> Guests of Honor – Padmashri Prof. Prahlada Ramarao, <i>Former Distinguished Scientist, DRDO, Ministry of Defence, Former Vice Chancellor, DIAT, Ministry of Defence</i> – Dr. B. E. Rangaswamy, <i>Vice Chancellor, Davangere University</i> – Dr A. P. Singh, <i>Secretary, IGS</i> Host Dignitaries – Prof. T. G. Sitharam and Mrs. Sitharam – Prof Raghuveer Rao, <i>Vice-Chairman, IGS Bangalore chapter</i> – Prof. Anbazhagan, <i>Convenor, TGS 2026</i> – Prof HN Ramesh, <i>IGS Bengaluru Chapter</i>
04:32 PM – 04:35 PM	Welcome Address	Prof Raghuveer Rao
04:35 PM – 04:40 PM	Honouring of Guests	
04:40 PM – 04:43 PM	About IGS	By Dr A. P. Singh, Hon Secretary, IGS
04:43 PM – 05:02 PM	Technical Presentation	by Prof. T. G. Sitharam
05:02 PM – 05:06 PM	Address by Chief Guest	By Dr Anil Joseph, President, IGS
05:06 PM – 05:10 PM	Address by Guests of honour	Padmashri Prof. Prahlada Ramarao,
05:10 PM – 05:14 PM	Address by Guests of honour	Dr. B. E. Rangaswamy
05:14 PM – 05:24 PM	Felicitation by IGS Chapters	Felicitation by representatives of various IGS chapters: – IGS Bengaluru. – IGS Suratkal – IGS Mysuru – IGS Hubballi-Dharwad
05:24 PM – 05:34 PM	General Felicitation	Felicitation by well-wishers, colleagues, and invited members (if any, requested during the conference)
05:34 PM – 05:36 PM	Release of books written by TGS (Road ahead 2.0, AImagineering)	
05:36 PM – 05:51 PM	Special Address	by Prof. T. G. Sitharam

05:51 PM – 05:54 PM	Closing Remarks	Prof. Anbazhagan
05:54 PM – 05:57 PM	Vote of Thanks	Prof HN Ramesh
NATIONAL ANTHEM		

Snacks and Tea – 18.00hrs

DETAILS OF PARALLEL SESSIONS

Parallel Session 1 - Geosynthetics & Ground Improvement		
Day 1 17-07-2026; Venue: Hall A; 16:00 - 17:30		
Chair: Dr. Ramakrishna Bag (IIT Patna)		
Volunteers: Yadhunandan M E; Sourav Sarkar; Hirthick		
1	TH02P01	Innovative Geocell and Geogrid Composite Foundation to Support Dry Zinc Tailings over Existing Wet Tailings Deposits by Amarnath Hegde, Peddireddy Sreekanth Reddy, TG Sitharam, MK Arha, SN Gupta
2	TH02P02	Interaction of 3D-Printed Geomembranes with Sand: A Comparison of Different Polymers by Maralappa Kadimani, Amarnath Hegde
3	TH02P03	Strength Performance of Natural and Cement-Admixed Soils Modified with Nano clay by M. Kirithika, VK Stalin
4	TH02P04	Strength Behaviour of Soil Stabilized with Red Mud-based Geopolymer by Sandeep Kumar Chouksey, Hari Naga Prasad. Chenna
5	TH02P05	Stabilization of Expansive Black Cotton Soil Using Copper Slag as a Sustainable Subgrade Material: A Microstructural and Mineralogical Study by DM Suman, MS Ramya
6	TH02P06	Experimental and Analytical Investigation on Sand Bed Reinforced with Coir Geocell and Basal Planar Reinforcement by Renu N, Anjana Bhasi, Anil Kumar
7	TH02P07	Stabilization of Expansive Soil Subgrade through Lime-Sand Admixture for Flexible Pavement by Dharmendra Barman, Sujit Kumar Dash
8	TH02P08	Study on Performance of Red and Black Soil with and without application of Geo-textile by Rajeshwari B
9	TH02P09	Effect of Sawdust Ash on the Geotechnical Properties of Marine Clay by Sana Fathima MA, Hariraj R, Nandana R, Fabiyan Augustine
10	TH02P10	Experimental Study on improvement of Soil Strength using Geofoam and Sawdust based on California Bearing Ratio Test by Kinkhikar, R
11	TH02P11	Experimental Investigation of Enzyme-Induced Calcite Precipitation Using Soybean-Derived Urease for Strength Improvement of Fine-Grained Soils by Mohammad Rajin Zaki Anwar, Raheena M, Resmi Sebastian
Parallel Session 2 - Computational Geomechanics and AI/ML		
Day 1 17-07-2026; Venue: Hall B; 16:00 - 17:30		
Chair: Dr. G V Ramana (NIT Warangal)		
Volunteers: Zeeshan; Deepak; Ankit		
1	TH01P03	Z-Score Normalization in Random Forest for Standard Penetration Test Value Prediction by Swaroopa Sail
2	TH01P07	Effect of Loading Waveform and Drainage on the Cyclic Triaxial Response of Granular Sand: A DEM Study by Abhinandan Thakur, Kunjari Mog
3	TH04P01	Comparison of LEM 3D and FEM 2D for slope stability analysis in a part of Western Ghats by Anant Gawhade, Priyajit Kundu, Sreevalsa Kolathayar
4	TH04P02	Reliability-Based Slope Stability Analysis of Embankment Using Machine Learning Techniques in Pune Region by Momin Abuzar, Saurav Shekhar Kar, Rahul Ray
5	TH04P04	A Review of Probabilistic Methods for Landslide Hazard by Radha Rao, Pradnya Singbal, Nisha Naik

6	TH04P06	Numerical Investigation of Impedance Characteristics of Adjacent Strip Footings on Dense Sand under Cyclic Loading Using the HS small Model by Anupkumar G. Ekbote, Lohitkumar Nainegali
7	TH04P07	Reliability-Based Design Optimization of Pile Foundations via Machine Learning under Stochastic Uncertainty by Karthikeyan M, Manish Kumar
8	TH04P09	Load Sharing and Settlement Reduction Analysis of Piled Raft Foundations on Soft Black Cotton Soil by Aruna T Raju, K
9	TH04P10	Influence of Embankment Height and Train Speed on the Dynamic Behaviour of Railway Embankments over Soft Coastal Clay by Roy R. Anil Kumar
10	TH04P11	Intelligent Modelling of Underground Structures Using Computational Geomechanics and Deep Learning by R. Sridhar, Kiran KK
11	TH04P12	Machine learning-based V_{s30} and fo mapping for seismic site characterization of the Himalayan region by Harish Thakur and P. Anbazhagan
Parallel Session 3 - Geotechnical Investigation & Site Characterization		
Day 1 17-07-2026; Venue: Hall C; 16:00 - 17:30		
Chair: Dr. K Manjunatha (UBDTCE, Davangere)		
Volunteers: Ayaz Mehmood; Surya Prakash; Vishnu		
1	TH01P01	Correlation of Hydraulic Conductivity with Index Properties of In-situ Polymerized Bentonites Under Diverse Chemical Environments by S. Keerthana
2	TH01P04	Strength and Energy Absorption Characteristics of High-Plasticity Clay Stabilized with Cow Dung Ash and Fly Ash by Anjana R Krishnan, L Abhijith, Kodi Rangaswamy
3	TH01P05	Estimation of Erosion Rate in Goa using Hole Erosion Test by Vanessa Fernandes, Savoikar, P
4	TH01P06	Shear Strength Behaviour of Vetiver Grass Root Reinforced Clayey Sand by Sakeri Ashutosh, Purvi Sabar, Suchismita Biswal, Aditya Kumar Bhoi, Nabeen Bage
5	TH01P08	Geophone Directionality Effects on Surface Wave Amplitudes over Slopes by Prabhakar Vishwakarma and P. Anbazhagan
6	TH01P09	Evaluation of Deformability Characteristics and Correlation between In-situ and Geophysical Moduli in a Stylolitic Limestone Terrain by Aakash Baheti, Singh, S, Sarwade, D, Gupta, M
7	TH01P10	Unified Properties of the Stone Masonry Dam for Stability Analysis by Senthil S. and P. Anbazhagan
8	TH01P15	Settlement Analysis of Transformer Yard Foundation in Thin Layer Soil by Lenin K R, Rishabh K, P Anbazhagan
9	TH03P07	Deflection behaviour of piles on sloping terrain by Veeresh Rudrappa Koti, Naveen A
10	TH01P12	Subsurface Profiling Using Multi-Parameter Ensemble and Fuzzy Clustering from GPR Data by K. Panjami, P Anbazhagan, Arun Kumar M N
11	TH01P14	Nearshore Karst Hazards in Coastal Sediments: Geophysical Delineation from the Coromandel Coast, India by Yogarish Narasinga Raja A and P Anbazhagan
Parallel Session 4 - Sustainability, Social Impact & Education		

Day 2 18-07-2026; Venue: Hall A; 11:30 - 13:00		
Chair: Dr. Lohitkumar Nainegali (NITK Surathkal) Volunteers: Panjami; Hirthick; Surya Prakash		
1	TH02P14	Biostimulation of Indigenous Soil Microbes and Implications for CO ₂ Mineralization: A preliminary study by Bhavitha Kamasani, Resmi Sebastian, Sakshi Rohilla
2	TH04P05	Enhancing Engineering Students' Engagement Through an Experience-Based Approach in The Era of Artificial Intelligence by Aditya Parihar
3	TH04P08	Sustainable Environmental Flow Analysis of the Puthimari River Using Flow Duration Curve (FDC) And Tennant Method by Nilakshi Devi, Triptimoni Borah
4	TH05P07	Waste-to-Resource Subgrade Materials for Low-Carbon Pavement Infrastructure by N S Chandanshree, Anitha Kumari S D, Sanjay Nimbalkar
5	TH06P01	Numerical Analysis of Coir Geocell-Reinforced Pavements for Enhanced Structural Performance by Vikash J, Dhanya Raveendran, Sreevalsa Kolathayar
6	TH06P02	Structural Performance of Recycled Polypropylene Mattress-Reinforced Base Layers by Jain, S, Ram, A, Saride, S, Rao, P
7	TH06P04	Biopolymer-Based Sustainable Subgrade for Pavement Applications by Evangelin Ramani Sujatha, Pratheeba V, Abirami, Pavithraa S, Shri Janani R
8	TH06P05	Sustainable Stabilization of Expansive Soils Using Microbially Induced Calcite Precipitation (MICP) and Biopolymers: A Critical Review by Barman, T
9	TH06P06	The study on the significance of sugarcane bagasse Ash as a supplementary cementitious material in concrete by Soumya, T, Kumar, G
10	TH06P07	Synergistic Stabilization of Contaminated Dump-yard Soil via Gradation-Optimized C&D Waste and GGBS-based Geopolymer Binders for Pavement Infrastructure by Shriram Marathe, Pushparaja, Naik, Anoop Rai M
Parallel Session 5 - Sustainability, Social Impact & Education		
Day 2 18-07-2026; Venue: Hall B; 11:30 - 13:00		
Chair: Dr. Prabhakar (NIT Tiruchy) Volunteers: Harish Thakur; Deepak; Yogarish		
1	TH06P08	Removal of Chromium from Paint Industry Effluent Using Marigold Flower Waste as a Biosorbent – Batch and Column Studies by Brunda G S
2	TH06P09	Column Leaching Study on the Removal of Nickel from Paint Industry Effluent Using Orange Peel Powder as a Biosorbent by Brunda G S, Punya C P, Sandhya M, Poorvika M, Puneeth Kumar M
3	TH06P10	Parametric Assessment of Soil Quality and Geochemical Variations Induced By Effluent Irrigation: Implications for Agro-Environmental Sustainability by Bhagyashree H N, D P Nagarajappa, P Shivakeshava Kumar
4	TH06P11	Dynamic Split Tensile Behaviour and High Strain Rate Anisotropy of 3D Printed Concrete under SHPB by Shivam Kumar, Vivek P, Biranchi Panda
5	TH06P12	Sustainable approach for infrastructure development: A State-of-the-Art Review by Sandhya Mathapati, Sanju Phulpagar, Varsha More, Lipsa Mishra
6	TH06P13	Analytical Evaluation of Subgrade-Controlled Rutting in Flexible Pavements: A Case Study of Soft Clay Strata in Jhalawar, Rajasthan by Shailendra Singh, Acharya, B

7	TH06P15	Planning and Design of Reinforced Earth Wall for Approaches of Major Bridge on Complex Hilly Terrain: Sustainable Perspective by Gondu Venkata Ramana, Prudhviraaj Vysaraj, Sudheer Kumar Yamsani
8	TH06P16	Utilization of Industrial Waste Materials for Enhancing Subgrade Soil Properties: A Comprehensive Review by Patel, S
9	TH06P17	Integrated Traffic Flow Congestion Mitigation Strategies Using IRC And INDO-HCM Standards In PMC, Pune by Vivek P. Gajpure, Rajshekhar G. Rathod, Sagar K. Sonawane
10	TH06P18	Sustainable Road Construction Using Bamboo Fiber in Subgrade Soil Stabilization by Lade V, Rathod R, Sonawane S
Parallel Session 6 - Rock Mechanics, Tailing Dams & Mining		
Day 2 18-07-2026; Venue: Hall C; 11:30 - 13:00		
Chair: Dr. Arvind Kumar Jha (IIT Patna) Volunteers: Yadhunandan ME; Rishabh Kumar		
1	TH01P02	Dynamic Tensile Strength and Fragmentation Characteristics of Cemented Sandstone under Impact Loading by Abass Z, Padmanabha V
2	TH05P01	Infrared Thermographic Signatures of Rock Damage: A Focused Review from a Rock Mechanics Perspective by Revuru P, Sebastian R
3	TH05P02	Characterization of Gold Ore Tailings and Assessment of Mechanical Properties of Geopolymer Concrete Produced Using Gold Ore Tailings by Eshwarayya Bolluru Loksha, Mangalpady Aruna
4	TH05P03	Utilization of Geogrids for Improving the Strength of Coal Tailings by Hema Gurappa Pol, Amarnath Hegde
5	TH05P04	A Physics-Informed Digital Twin for Early Detection and Localization of Toxic Seepage in Tailings Dams by Mehul Khanna, Prachit Agarwal, Kinshuk Jain, Rudraksh Rajpurohit, Gowtham Padmanabhan
6	TH05P05	A Physics-Informed Digital Twin Driven by Real-Time Radar Data for Weak Zone Detection and Slope Failure Prediction in Open-Pit Coal Mines by Prachit Agarwal, Mehul Khanna, Kinshuk Jain, Debjit Mandal, Gowtham Padmanabhan
7	TH05P06	Comparative Evaluation of Empirical Rock Slope Stability Methods Along Dedicated Freight Railway Corridor in Aravalli Hills, India by A. Mohd. Masroor Alam, Sadique M Waheed
8	TH05P08	Fracture & Fragmentation Analysis using Fragalyst Software of Failed Rock Samples subjected to Cyclic Loading in Uniaxial Compression by MN Bagde and AK Raina
9	TH05P09	Evaluation of Seepage-Induced Softening in Earthen Dams Using ERT and MASW by Sourav Sarkar and P. Anbazhagan
10	TH05P10	Performance Assessment of Underground Tunnels Under Missile Penetration and Blast: Effect of Liner Material by Ibraheem Rais, Md Rehan Sadique, Mohd Masroor Alam, Zaid Mohammad
Parallel Session 7 - Seismology, Earthquake Engineering & Microzonation		
Day 2 18-07-2026; Venue: Hall A; 15:00 - 16:00		
Chair: Dr. Aditya Parihar (TIET, Patiala) Volunteers: Ayush Kumar; Hirthick; Maneet		

1	TH02P17	Probabilistic Seismic Hazard Analysis for Salem District, Tamil Nadu. by R.Tharani, K.Premalatha
2	TH03P01	Site-Specific Probabilistic Seismic Hazard Assessment of the Mullaperiyar Dam in Peninsular India by Abdusamed A, Sankar A, Bhat G, Kolathayar S
3	TH03P02	Physics-Informed Earthquake Early Impact Forecasting Using Digital Twin and Unreal Engine by Mohamed Naveed, Rithwik Ganesh, Debjit Mandal, Gowtham Padmanabhan
4	TH03P03	Static and Seismic Stability Assessment of Black Cotton Soil – Construction and Demolition Waste Mixture Slopes by Madhumita Mohanty, Abhishek Kumar Singh, G Lokesh Tharun Kumar, Tejavath Pravalika
5	TH03P04	Numerical Investigation of Seismic Response of RC Buildings on MSW Landfill Sites Considering Soil–Structure Interaction Effects by Pruthviraj S R
6	TH03P05	Seismic Performance of Soil Foundation Structure Interaction and structure soil structure interaction in Dense Urban AreaS by Shaik Kabeer Ahmed
7	TH03P06	Experimental Investigation of Shock Wave Propagation in Sand Using a Vertical Shock Tube by Deka N, Padmanabha V
Parallel Session 8 - Computational Geomechanics and AI/ML, Geosynthetics & Ground Improvement, Geotechnical Investigation & Site Characterization, Seismology, Earthquake Engineering & Microzonation		
Day 2 18-07-2026; Venue: Hall B; 15:00 - 16:00		
Chair: Dr. Kunjari Mog (IEST, Shibpur) Volunteers: Sourav Sarkar; Deepak		
1	TH01P13	Critical Evaluation of IS 8009 Settlement Correlations for Foundations on Compressible Soils by Rishabh K. and P. Anbazhagan
2	TH01P11	Application of Nonlinear Iterative Inversion in Downhole Seismic Tomography by Ayush Kumar, Panjamani Anbazhagan
3	TH04P13	Thermal Performance Analysis of Geothermal Energy Pile Using Deep Learning Techniques by Ashutosh Kumar, Ramakrishna Bag
4	TH04P14	Numerical Analysis of Non-Linear Consolidation by Pushkar Nath Chaurasia, Manash Chakraborty
5	TH06P03	A Distributional PPO Framework for Sustainable and Energy-Aware Cloud Task Scheduling by Ratnakumari Neerukonda, Sahil Ali Akbar, Sudipta Sundar Pal, Asmath Abbas, Anupama CG
6	TH02P12	Embankments over Soft Soils Improved by Stone Columns with and without Geogrid Encasement under Seismic Excitations by Patel R, B R
7	TH03P09	Evolution of Seismic Zonation and Design Response Spectra in IS 1893: A Critical Review by Shimna Manoharan and P. Anbazhagan
Parallel Session 9 - Geosynthetics & Ground Improvement, Geotechnical Investigation & Site Characterization		
Day 2 18-07-2026; Venue: Hall C; 15:00 - 16:00		
Chair: Dr. Manoj N. Bagde (CSIR-CIMFR, Nagpur) Volunteers: Zeeshan; Surya Prakash; Vishnu		
1	TH03P08	Cost-effective Geophysical Approaches for Resilient Infrastructure. An Integrated Framework for Geotechnical Hazard Assessment and Risk-Based Design Decisions, by Ayaz Mohmood Dar, P Anbazhagan

2	TH01P16	Energy-Dependent Behaviour of SPT N-Values: Insights from Simultaneous Measurement of Hammer Efficiency and Shear Wave Velocity by Yadhunandan M E, Anbazhagan P
3	TH02P13	Investigations on the Influence of Antecedent Rainfall on Rainfall-Induced Landslide Initiation with and Without Geosynthetic Stabilization by Hariom Pathania, Ganesh Kumar, Mahesh Sharma
4	TH02P15	Experimental Investigation on Geogrid Reinforced retaining structure under sequential seismic loading: A Shaking-table study by G Sakthivel, S Ganesh Kumar
5	TH02P16	Encased Stone Column Technology by Starina J. Dias
6	TH04P03	Strength and Hydraulic Stability Enhancement of Sandy Soil Using Biochar-Assisted MICP by Ambuj Kumar Shukla, Anil Kumar Sharma

Cultural Evening, TGS 2026 at J.N Tata Auditorium, 6.30pm – 7.30pm

Laasya Academy of Dance and **Shivapriya School of Dance** present “**Echoes of the Earth**”, a deeply evocative Bharatanatyam presentation that celebrates Mother Earth while reminding us of our shared responsibility towards her preservation. Through the grace, rhythm, and expressive depth of classical dance, the performance journeys from the Earth’s pristine and divine origin, shaped by the harmony of the five elements, to the ecological imbalance caused by human excess and neglect. Yet, at its heart, “Echoes of the Earth” is not a tale of despair, but one of awakening.

The presentation leaves us with a message of hope: that through mindful living, sustainable choices, and renewed respect for nature, humanity can still honour Mother Earth’s compassion and restore balance for generations to come.

Dr. Lakshmi Rekha Arun

Founder-Director, Laasya Academy of Dance

Dr. Lakshmi Rekha Arun is an acclaimed Bharatanatyam artist, scholar, philanthropist, trained Carnatic vocalist, and dentist by profession. A prominent exponent of the Vasundhara style, she is widely admired for her thoughtful integration of Yoga into classical dance. As the Founder-Director of Laasya Academy of Dance, she has contributed significantly to cultural education and inclusive artistic outreach over the past two decades.

Her initiatives, including *Laasya Sambhrama*, *Laasya Saadhaki*, *Laasya Purusha*, and *Halliyedege Lasya*, reflect her commitment to taking classical arts, education, and wellness to diverse communities, including children with disabilities and rural learners.

A

Gold Medalist in Dentistry and a B-High Graded Doordarshan Artist, Dr. Lakshmi has performed on prestigious stages in India and abroad. She has also been honoured with recognitions such as Nritya Shiromani, Natya Vaidya, and Seva Ratna.

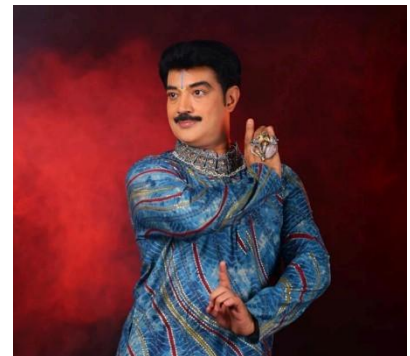


Dr. Sanjay Shantaram

Artistic Director, Shivapriya School of Dance

Dr. Sanjay Shantaram is an accomplished classical dancer, choreographer, vocalist, actor, lyricist, and dentist by profession. He is among the rare artists to have attained mastery in both Bharatanatyam and Kuchipudi, having trained under eminent gurus including G. S. Rajalakshmi, Narmada, and Manju Bhargavi. With over 500 performances across 24 countries, he has represented Indian classical dance on prestigious national and international stages.

As the artistic force behind Shivapriya School of Dance, Dr. Sanjay has nurtured the institution into a reputed centre for performing arts over the past three decades. His acclaimed productions, including *Matsya Kanya*, *Wodeyar Vaibhava*, and *Nada Prabhu Kempegowda*, reflect his depth as a creative director and choreographer. A Doordarshan-graded and ICCR-recognized artist, he has also been honoured with several awards, including the Aryabhata Best Actor Award, Ananya Puraskara, and Mysuru District Rajyotsava Award.



Theme: Geosynthetics and Ground Improvement

The Role of Geosynthetics in Indian Infrastructure Development: Current Practices and Beyond...A journey with Prof. TGS

Sireesh Saride, Amarnath Hegde & Deendayal Rathod

ABSTRACT

India's rapidly expanding infrastructure sector, driven by urbanization, industrialization, and increasing investments in transportation and urban development, demands innovative and sustainable engineering solutions. Geosynthetics, including geogrids, geocells, and geocomposites, have emerged as indispensable materials for enhancing the performance, durability, and cost-effectiveness of civil engineering infrastructure. Their versatile applications in foundations, roadways, railways, embankments, and retaining structures have significantly improved infrastructure performance while reducing construction time, maintenance requirements, and environmental impacts.

This presentation provides a comprehensive overview of the research contributions made by Prof. T.G. Sitharam and his research students in the field of geosynthetics over the past 25 years. It highlights the evolution of their research through systematic laboratory investigations, analytical and numerical studies, design developments, and successful field implementations. The early phase of the research focused on evaluating the performance of geogrids and laboratory-fabricated geocells through medium to large-scale plate load tests. These investigations were subsequently extended to commercially available geocells, followed by comprehensive three-dimensional numerical analyses to better understand stress distribution, confinement effects, and load-transfer mechanisms in reinforced foundation systems. Based on these studies, analytical design methodologies were developed to predict failure strain and bearing capacity of geosynthetic-reinforced foundation beds.

Building on these foundational studies, the research expanded to several innovative applications of geosynthetics in civil engineering. These include reinforced pavements, buried pipelines, vibration isolation systems, geosynthetic-encased stone columns, and other ground improvement techniques. Recognizing the importance of sustainable infrastructure, the group also explored the use of natural geosynthetic materials such as bamboo, jute, and coir as environmentally friendly alternatives to conventional polymeric products. In addition, the presentation showcases several field case studies that demonstrate the successful translation of research findings into engineering practice, validating the effectiveness of the proposed methodologies under real-world conditions and finally development of code of practices.

Overall, the research contributions of Prof. T.G. Sitharam and his group have significantly advanced both the scientific understanding and practical application of geosynthetics in India. Their work has contributed to the development of rational design methodologies for reinforced foundations and ground improvement systems, expanded the range of geosynthetic applications in infrastructure engineering, and promoted sustainable construction practices. These contributions continue to serve as valuable references for researchers, practicing engineers, and policymakers working toward the development of resilient, durable, and sustainable infrastructure.

Theme: Geotechnical Investigation and Site Characterization

Importance Of Site Characterization Based On In-Situ Investigation And The Lesson Learnt

Abhishek Kumar Sharma, Naveen James, Govindaraju, B V Ravihankar

ABSTRACT

Seismic site characterization in India has evolved significantly over the last two decades, from conventional geotechnical investigations to integrated, multi-scale assessment of subsurface conditions and local site effects. A major impetus to systematic research in this area was provided by ****Prof. T. G. Sitharam at the Indian Institute of Science (IISc), Bangalore****, who initiated pioneering research on seismic microzonation and site characterization by integrating geology, geotechnical investigations, geophysical measurements, site response analysis, and spatial hazard mapping. The comprehensive seismic microzonation studies of Bangalore provided one of the early frameworks for understanding how local soil and rock conditions modify earthquake ground motions in Indian geological settings. This research subsequently expanded through investigations led by his students, extending site characterization studies to urban regions, the Indo-Gangetic Basin, shallow bedrock terrains of Peninsular India, and the Kalpakam Nuclear Power Plant site. Extensive use of Standard Penetration Test (SPT) data, Multichannel Analysis of Surface Waves (MASW), seismic borehole testing, and other geophysical techniques enabled the development of regional correlations, engineering bedrock maps, and improved subsurface models. These investigations also raised fundamental questions regarding the universal applicability of conventional site classification parameters, particularly Vs30, to Indian shallow bedrock conditions and demonstrated the importance of soil thickness, engineering bedrock depth, impedance contrast, and spatial variability in realistic assessment of local site effects.

The lessons learnt from this continuing research journey demonstrate that reliable site characterization cannot depend on a single parameter, empirical correlation, or investigation technique. The initial research framework established at IISc has progressively evolved into integrated investigations combining SPT, MASW, downhole and crosshole seismic testing, electrical resistivity, Ground Penetrating Radar, and advanced laboratory characterization using resonant column and cyclic triaxial testing. Field and laboratory studies have further highlighted the importance of measurement quality, particularly the influence of SPT hammer energy on N-values and their correlations with shear-wave velocity and maximum shear modulus. Recent innovations involving automated P- and S-wave arrival-time identification, improved seismic downhole interpretation and ray-path analysis, resolution of high impedance contrasts, non-contact visual measurement of SPT hammer energy, and region-specific shear modulus and damping models represent important advances towards reducing uncertainties in subsurface characterization. The progression from the pioneering microzonation initiatives of ****Prof. T. G. Sitharam at IISc Bangalore**** to the present generation of advanced field, laboratory, and computational investigations illustrates the evolution of site characterization research in India. Collectively, these studies emphasize the need for an integrated, scale-appropriate, and regionally validated framework for assessing local site effects, liquefaction and other induced hazards, thereby contributing to more reliable seismic design and the resilience of India's rapidly expanding urban and critical infrastructure.

Theme: Seismology, Earthquake Geotechnical Engineering and Microzonation

From Bhuj to Beyond: Prof. T. G. Sitharam's Legacy in Soil Liquefaction Research

Anbazhagan P, Abhishek Kumar, Dhanaji Chavan, Ramakrishna, Sreevalsa Kolathayar, Monalisha, Balreddy Muthanna

ABSTRACT

Soil liquefaction has been one of the most significant geotechnical hazards associated with earthquakes, causing severe damage to foundations, lifelines, and infrastructure worldwide. In India, systematic research on earthquake-induced soil liquefaction gained momentum following the 2001 Bhuj earthquake under the leadership of Prof. T. G. Sitharam at the Indian Institute of Science (IISc), Bengaluru. This presentation reviews more than two decades of pioneering research in earthquake geotechnical engineering, highlighting the progression from fundamental laboratory investigations on liquefiable Indian sands to advanced numerical modeling and mitigation techniques. Early studies focused on understanding the cyclic behavior, pore-pressure generation, dynamic properties, and liquefaction resistance of Indian sandy soils through cyclic triaxial testing, thereby establishing a strong experimental foundation for liquefaction assessment in the Indian context.

Subsequent research expanded the scope to investigate cyclic and post-liquefaction behavior, discrete element modeling (DEM) of granular soils, and the influence of fines on liquefaction susceptibility. Significant contributions were made toward understanding the role of non-plastic silt and low-plasticity clay fines in modifying the cyclic response, liquefaction resistance, and post-liquefaction strength recovery of sand–fine mixtures. These investigations resolved several inconsistencies reported in earlier studies and provided valuable insights into the behavior of natural and reclaimed soil deposits. The integration of experimental observations with numerical simulations enabled a deeper understanding of the micro-mechanical processes governing liquefaction and post-liquefaction soil behavior.

The presentation further highlights recent advances in liquefaction mitigation through induced desaturation, particularly research on air-injected desaturated sandy soils. Experimental and numerical studies demonstrated that controlled desaturation can significantly increase liquefaction resistance and reduce pore-pressure buildup during earthquake loading. The findings establish air-induced desaturation as a promising, economical, and environmentally sustainable ground-improvement technique for liquefaction mitigation. Finally, the presentation discusses emerging challenges and future research directions, including the reassessment of liquefaction triggering relationships for silt-rich soils, evaluation of re-liquefaction potential, and development of reliable methodologies for assessing liquefaction under moderate earthquakes, thereby contributing to safer and more resilient geosystems.

List of PhD students whose work is considered in the presentation

1. **Govindaraju, J.L (2005)**, "Liquefaction and Dynamic Properties of Sandy Soils".
2. **Ravishankar, B.,V., (2006)**, "Cyclic and monotonic undrained behaviour of Sandy soils".
3. **Vinod. J. S. (2006)**, "Liquefaction and dynamic properties of granular materials: A Discrete element approach".
4. **Dash, Hemanta Kumar (2008)**, "Undrained Cyclic and Monotonic Response of Sand-silt Mixtures".
5. **Bala Reddy Muthanna (2014)**, "Liquefaction and Post liquefaction behavior of sand fines mixtures. "
6. **Chavan, Dhanaji (2021)**, Liquefaction resistance and cyclic response of air–injected desaturated clean sandy soil: experimental and numerical investigations

Research Advances of AI in Geotechnical Engineering

Pijush Samui

ABSTRACT

The concept of working procedures of human brain is used to develop AI. In AI, dataset is required to develop the model. The performance of AI depends on the quality & quantity of dataset. AI acquire knowledge from data for any physical phenomena. Hence, no assumption is required for the development of AI. AI can be used for classification and regression problems. In this lecture, 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), Support Vector Machine(SVM), Relevance Vector Machine (RVM), Artificial Neural Network(ANN), Histogram-based Gradient Boosting(HGB) and Naive Bayes(NB)} are used in the various fields of geotechnical engineering such as site characterization, liquefaction, shallow foundation, etc. Participants will know the use of MATLAB for development of different AI techniques. The future application of various AI will be also discussed in the field of geotechnical engineering such as Digital Twin(DT), Structural Health Monitoring(SHM), etc. This article also gives the advantages of various AI techniques. The concept of hybrid AI will also be discussed.

Theme: Computational Methods and Geomechanics

From Learning to Leading: Advances in DEM Research

Dr Vinod J S

ABSTRACT

The Discrete Element Method (DEM) has become an key tool for understanding the behaviour of granular materials through particle-scale modelling. This presentation, From Learning to Leading: Advances in DEM Research, highlights the DEM research carried out at the Indian Institute of Science to cutting-edge applications in geotechnical engineering. The first part discusses investigations into monotonic, dynamic, particle shape and wave propagation behaviour of granular materials. The second part presents recent advances in ballast breakage modelling, methane hydrate-bearing sediments, cone penetration testing, instability phenomena, and partially saturated soils. Together, these studies demonstrate the growing role of DEM in addressing complex geotechnical engineering challenges.

Theme: Sustainability, Social Impact and Education

Coastal Reservoir for Solving the World's Water Crisis

CR Parthasarathy

ABSTRACT

This presentation is the part of feasibility study conducted by Indian Institute of Science, Bangalore with **Prof TG Sitharam** as the principal investigator along with about other 40 scientists to explore the feasibility for constructing coastal reservoir in Arabian Sea off Mangaluru coast. This envisages storing fresh water in a reservoir along the coast by building a sea dike to impound the flood waters of Netravati River. On one side, the dike will ensure the required quantity of freshwater flow from Netravati River to the reservoir without being drained to the sea. On the other side, the sea dike will prevent seawater from entering the reservoir, avoiding the salt contamination of the freshwater supply. Present study presents detailed investigation of the soil profiles of surrounding region of Mangaluru to explore the site condition at off Ullal beach. Lithological data on the Netravati estuary were also presented with key observation on the soil profiles in the area proposed for location of coastal reservoirs. The key finding of the study is that the region offshore of Ullal is devoid of sand and is comprised mainly of soft Silty clays. Lithological data of nine foundations at Netravati Bridge near Ullal are also presented in this paper. Based on the findings of geotechnical investigations, the paper concludes that construction of sea dike in Arabian Sea off Mangaluru coast is feasible. This one pilot project is a concept to be adopted across the Indian peninsula connected with pipe line at mean sea level, which can permanently resolve the water scarcity issue. This aspect has been patented as Sarovar Mala.

Theme: Sustainability, Social Impact and Education

Sustainability aspects of Large Scale Mega Infrastructure projects

Prof Deepankar Choudhary

ABSTRACT

For various mega infrastructure projects, the foundation solutions that consider **sustainability aspects** including safety and economy will be discussed in the presentation. In this connection, new BIS code IS 19117 (2025) and its applications for possible mega projects will also be highlighted.

Public transportation towards sustainable mobility

Prof Raviraj H Mulangi

ABSTRACT

In 2012, Prof.T.G. Sitharam was Chairman of CiSTUP, during that period he was guiding me for my Ph.D. My research topic was, “Performance Evaluation of Public Bus Transport Operations in Karnataka by Using Non-Parametric and Multivariate Analysis”. We have given many suggestions to Public Bus Transport Operators in Karnataka to improve their efficiency and one of the suggestions was to minimize dead kilometer of BMTC premier buses. I have continued working on this topic after joining NITK Surathkal. We explored the use Electronic Ticketing Machine (ETM) for public bus transport demand, worked on traveltime analysis and Impact of Side Friction on Travel Time Reliability, visualization and Assessment of Roadworks using Automatic Vehicle Location (AVL) Data of Mysore ITS. Also worked on BRTS of Hubli Dharwad city to explore Automatic Passenger Counter (APC) data for Forecasting Passenger Demand with Neural Networks. Now we are working on Deep Learning (D.L) - based Passenger Flow Prediction using Weather and Temporal Attributes. These research work focus on achieving SUSTAINABLE DEVELOPMENT GOALS 3, 7, 9, 11 and 13. Together, these contributions build smart, efficient, reliable, low- carbon public transport systems, the backbone of sustainable urban mobility.

A Distributional PPO Framework for Sustainable and Energy-Aware Cloud Task Scheduling

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ABSTRACT

By executing massive numbers of interdependent activities across virtualized resources, cloud computing platforms enable many data-intensive and latency-sensitive applications. Task scheduling is challenging due to dynamic task arrivals, changing execution times, fluctuating resource availability, and rising energy consumption. Long execution periods, resource underutilization, and energy consumption are the consequences of the failure of traditional heuristic and rule-based scheduling algorithms to address variability and schedule tasks based on static resource availability. In this research article, we propose Distributional Proximal Policy Optimization (D-PPO), which is an enhanced version of the Proximal Policy Optimization algorithm, which is a Reinforcement Learning (RL) algorithm. Unlike the traditional PPO algorithm that aims to predict the expected return from the environment, the proposed method models the entire return distribution using quantile regression. The critic network is trained using the Quantile Huber loss. The reward function penalizes the marginal power cost of each placement decision and encourages consolidation onto fewer active hosts, directly targeting energy efficiency. The algorithm is tested on the GOCJ (Google Cloud Jobs) dataset sampled from real job-length traces from Google data cluster traces. Experimental results show that the proposed D-PPO algorithm achieves the lowest energy consumption among all evaluated schedulers. Compared with the best-performing heuristic baseline i.e., Priority Scheduling, D-PPO reduces energy use by about 27%. Compared with the best-performing RL baseline by EM ratio i.e., Standard PPO, D-PPO reduces energy use by about 39%. D-PPO also achieves the best EM Ratio among all evaluated methods. These findings establish Distributional PPO as a scalable solution for cloud resource management that supports greener and more resilient cloud infrastructures.

Keywords: *Cloud scheduling, Cloud Computing, Deep Reinforcement Learning, Proximal Policy Optimization, Quantile Huber loss.*

Stabilization of Expansive Soil Subgrade through Lime-Sand Admixture for Flexible Pavement

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Abstract

Expansive soils owing to low bearing capacity pose severe challenges for pavement stability and integrity. This study investigates the effectiveness of sand (S) and lime in enhancing the performance of a highly expansive soil (ES) subgrade. The ES was first mixed with varied proportions of S; thereafter, lime was added to the ES-S mixtures. A series of California Bearing Ratio (CBR) tests were conducted to study the load-bearing capacity behaviour of the soil mixes. Resilient moduli (M_r) were obtained through cyclic CBR tests. Subsequently, mechanistic-empirical designs were performed to evaluate the pavement thickness. The results show that both CBR and M_r increase with sand addition in untreated soils, while in lime-treated soils, the increase continues up to about 70% sand content, indicating improved load-bearing capacity and elastic behaviour of the mixtures. It was observed that with the sand-lime treatment of the expansive subgrade the pavement thickness can be reduced significantly, with a maximum reduction of about 63% observed in the bituminous layer. The findings of the present study highlight the effectiveness of the sand-lime stabilization for pavement construction on expansive soils.

Keywords: Lime-sand stabilization; Expansive soil; Subgrade; California Bearing Ratio; Resilient modulus; Pavement design.

Synergistic Stabilization of Contaminated Dump-yard Soil via Gradation-Optimized C&D Waste and GGBS-based Geopolymer Binders for Pavement Infrastructure

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ABSTRACT

The proliferation of uncontrolled municipal solid waste disposal has necessitated the development of advanced remediation strategies for dump-yard soils, which typically exhibit deleterious geomechanical properties and heavy metal contamination. This research investigates the synergic valorization of Construction and Demolition (C&D) waste dust and Ground Granulated Blast Furnace Slag (GGBS)-based geopolymer binders to stabilize such marginal matrices for pavement subgrade applications. Building upon a gradation-optimized framework - utilizing 30% C&D waste dust to transform the soil from a poorly graded to a acceptably well-graded ($C_u = 6.50$) state this study introduces a geopolymerization phase to enhance structural integrity through chemical synthesis. A binder system comprising GGBS was integrated at varied dosages, utilizing an alkaline activator solution developed as per the literature. Experimental results from Unconfined Compressive Strength (UCS) testing at 7 days of curing indicate a significant non-linear enhancement in mechanical performance. A peak UCS of over 2.3 MPa was achieved at an optimal binder dosage of 9%, representing a 358% improvement over the cured control and effectively exceeding the threshold requirements for stabilized subgrades. The performance evolution suggests a dual-mechanism gain: the initial mechanical interlocking provided by the angular C&D micro-aggregates followed by the development of a rigid aluminosilicate framework C-A-S-H /N-A-S-H gel-phases). Notably, dosages exceeding the 9% threshold resulted in a systematic reduction in strength, attributed to the disruption of the optimized mineral skeleton and the dilution of the binder-to-activator stoichiometric balance. These findings provide a high-performance, sustainable methodology for subgrade stabilization, promoting a circular economy through the dual sequestration of industrial and municipal waste streams.

Keywords: *Contaminated Soil; Geopolymerization; C&D Waste Valorization; Unconfined Compressive Strength; Pavement Subgrade.*

Experimental Investigation on Geogrid Reinforced retaining structures under sequential seismic loading: A Shaking- table study

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ABSTRACT

In general, geosynthetic-reinforced soil structures have shown better performance in seismically active areas, due to their enhanced deformability and ability to transfer loads more efficiently within the reinforcing elements with minimal deformation. However, investigations into the performance of these systems in response to a series of repetitive seismic events, specifically the combination of a main shock followed by aftershocks, and their impact on the strain development mechanism within the reinforcing elements-backfill soil are limited. The current study examines the dynamic behavior of a scaled-down geogrid-reinforced retaining structure subjected to repetitive dynamic events. For experimental testing, the scaled-down model structure with 900 mm height was selected with 80% backfill in-situ density. For the repetitive sequential scaled-down input earthquake motions, the acceleration and strain distribution characterization within the components of the structure were evaluated experimentally using 1-g uniaxial shaking table testing. For simulating sequential repeated shaking, scaled Chi-Chi earthquake simulations representing the main shock and the El-Centro earthquake representing the aftershock have been provided as input motions. Through contact-based instrumentation, such as accelerometers, displacement sensors, and strain gauges embedded in reinforcing members and non-contact 2D DIC-based monitoring, the interaction of different components in geo-structures was evaluated. Based on experimental observations, the various parameters affecting the stability of the geo-structure under repeated events were evaluated and presented. The strain development was higher at mid portion of the reinforcing element as compared to the other portion. Higher strain development was observed at mid-depth within the structure for the given input motions. About 54% to 247% increment was observed in the case of Chi Chi earthquake and 22% to 232% increment was observed in the case of Imperial valley earthquake. The induced densification results in strain development within the geo-structure affecting stability during subsequent shaking. The observations evidenced the need for Continuous monitoring to enable the real-time measurement of strain change, settlement, and displacement, enabling continuous early detection of critical strain localization, timely intervention through targeted repairs, and consequently, improved resilience and extended service life of reinforced soil structures in the geotechnical systems.

Keywords: *Geosynthetic reinforced structure, seismic loading, Digital Image Correlation, Geogrid Reinforcement, Geo- Structures.*

Strength and hydraulic stability enhancement of sandy soil using biochar-assisted MICP

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ABSTRACT

Microbially Induce Calcium Carbonate precipitation (MICP) technique has been observed to produce eco-friendly cementation material that has been effectively utilized in improvement of the soil. Incorporation of biochar in this technique to assess its impact on the soil stability has been assessed in this study.

Addition of 2% biochar by weight to the sandy soil and treating it with *Sporosarcina ureae* with 7 rounds of treatment lasting for 7 days revealed significant alteration in the strength of the sand specimen when compared with sandy soil treated without biochar. The UCS strength of bio-cemented sandy specimen and biochar assisted bio-cemented sandy soil were found to be 92 kPa and 308 kPa, respectively. The treated specimens were also checked for their stability against running water, with the velocity of water high enough to erode the soil particles.

It was found that the specimens treated without the assistance of biochar lost almost 30% of the particles whereas the specimens assisted with biochar during the treatment were able to retain 10% of more soil particles. This enhancement in strength could be attributed to increased calcium carbonate precipitation due to assistance of biochar which was verified through acid-washing method and SEM-EDS analysis further affirmed this observation.

This strategy, as a potential environmental and sustainable technique could be utilised for the preservation of soil at the banks of river often inundated by running water, especially during the floods. Supplementing the MICP technique with biochar not only enhances the efficiency of the approach but also serves as a tool for long term carbon sequestration.

Keywords: *MICP, biochar, bio-cementation*

Deflection behaviour of piles on sloping terrain

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ABSTRACT

The increasing demand for infrastructure development on marginal and sloping terrains has heightened the use of pile foundations, yet understanding their behaviour under inclined loading remains a complex geotechnical challenge. Current design practices often neglect the behaviour of individual piles in sloping terrains with differing sand layer densities. This study investigates the deflection behaviour of single piles embedded in sloping ground through experimental model testing and three-dimensional finite element analysis using PLAXIS 3D, with the objective of evaluating the influence of pile diameter, sand density, and slope angle on lateral pile response.

Laboratory experiments were performed on hollow aluminium model piles of three diameters (6 mm, 8 mm, and 10 mm), each 300 mm long with 1 mm wall thickness, installed in a 600 mm × 600 mm × 600 mm wooden test tank. Sand beds at two relative densities ($R_d = 25\%$ and 50% , dry unit weights of 15.7 kN/m^3 and 16.3 kN/m^3) were prepared using the sand raining technique, with fall heights of 4 cm and 50 cm respectively, calibrated through prior trials. The upper sand layer was sloped at 10° , 15° , and 20° . Inclined loading at 15° to the horizontal was applied via a pulley-wire system until 25 mm top-head displacement was achieved. Pile deflection with depth was measured using flex sensors attached at 25 mm intervals, and top-head displacement was monitored using LVDTs. Numerical simulations were conducted in PLAXIS 3D using 10-node tetrahedral elements, Mohr-Coulomb soil model, pile-soil interface reduction factor $R_{inter} = 0.67$, and a three-phase loading sequence (K0 initial stress, pile activation, incremental load application).

The results demonstrated that the 6 mm diameter pile exhibited the greatest lateral deflection at all tested slope angles and density conditions due to its lowest flexural rigidity ($EI = 3.52 \times 10^6 \text{ N-mm}^2$), while the 10 mm pile showed the highest load-carrying capacity. Across all pile diameters, load-carrying capacity decreased as slope angle increased from 10° to 20° , attributed to the progressive reduction in passive soil resistance on the downslope side and reduced confining stress near the free slope surface. The experimental and PLAXIS 3D numerical results showed good agreement, with deviations of 2%–11%, validating the numerical modelling approach. These trends are consistent with findings reported by Muthukkumaran et al. (2004), Chae et al. (2004), and Dhattrak and Bhagat (2016), confirming that slope geometry and pile stiffness are critical parameters governing pile performance in sloping ground.

The study concludes that increasing pile diameter significantly enhances stiffness and load-carrying capacity under inclined loading on sloping ground, and that steeper slopes progressively reduce lateral resistance. The validated PLAXIS 3D model provides a reliable tool for extending parametric investigations beyond laboratory constraints. The findings underscore the importance of accounting for slope geometry, pile stiffness, and sand density in the design of pile foundations on sloping terrain to ensure adequate performance and safety.

Keywords: *Sloping ground, Pile deflection behaviour, Inclined loading, PLAXIS 3D, Finite element analysis*

Comparative Evaluation of Empirical Rock Slope Stability Methods Along Dedicated Freight Railway Corridor in Aravalli Hills, India **[TH02-23]**

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ABSTRACT

Rock cut slopes developed for a high-speed transportation corridors in rocky terrains frequently exhibit structurally controlled failures, posing long-term safety and maintenance challenges. This study presents a systematic comparative assessment of two established empirical classification approaches i.e. Landslide Hazard Evaluation Factor (LHEF) and Slope Mass Rating (SMR) applied to newly excavated rock slopes along a segment of the Western Dedicated Freight Corridor (WDFC) near Raipur, Sohna, Gurgaon, within the Proterozoic Aravalli Hill range of India. The investigated slopes were formed through controlled blasting and mechanized excavation, producing steep to near-vertical cut faces in predominantly quartzite interbedded with schist and phyllite rocks. Detailed field investigations were conducted at four representative locations, involving systematic measurement of discontinuity orientation, spacing, persistence, aperture, infilling condition, groundwater state, and slope geometry in accordance with IS:11315-2023 guidelines. Laboratory testing, including Uniaxial Compressive Strength (UCS) and petrographic analysis, was performed to characterize intact rock behavior.

LHEF-based Total Estimated Hazard (TEHD) values indicate hazard classes ranging from Moderate to Very High, reflecting the combined influence of lithology, slope morphology, land cover, and structural disposition. In contrast, SMR results reveal variability in stability classes primarily governed by discontinuity–slope interaction and excavation method, identifying potential planar and wedge-controlled failure mechanisms.

The comparative analysis demonstrates that LHEF is effective for macro-level hazard zonation, whereas SMR provides enhanced sensitivity to structurally controlled instability in engineered rock cuts. The LHEF is more sensitive in evaluating the susceptibility as compared to the SMR system. The study highlights that the Location 2 has the highest vulnerability, followed by Location 3, 1 and 4. The SMR may be used to employ the mitigation measures which is not available with any other method, including LHEF. The necessity of reliable stability appraisal and mitigation for such critical railway infrastructure in rocky terrains, thereby contributing to resilient corridor design and risk-informed slope management.

Keywords: Rock Slope Stability; Landslide Hazard Evaluation Factor (LHEF); Slope Mass Rating (SMR); Railway Corridor Infrastructure.

Strength behavior of soil stabilized with red mud-based geopolymer

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ABSTRACT

The high potential for swelling and shrinkage, low strength, and high compressibility due to seasonal moisture changes pose significant challenges for soft soils in subgrade applications. The use of conventional stabilizers such as cement and lime has been shown to enhance the engineering properties of expansive soils, but their production consumes significant energy and emits considerable amounts of carbon dioxide. A large amount of red mud, an industrial byproduct from alumina production, is produced and poses a major environmental disposal problem. The use of red mud as a geopolymer precursor material offers a sustainable solution to enhance the properties of soft soil and promote the use of industrial wastes. Hence, this study aims to examine the performance of alkali-activated red mud in improving the strength and microstructural properties of soft soil for subgrade applications.

Red mud was added at different percentages (10, 20, and 30%), and sodium hydroxide and sodium silicate solutions were used at molar concentrations of 6, 8, and 10 M, with a sodium silicate to sodium hydroxide ratio of 1.5. The specimens were prepared and kept for curing periods of 0, 7, 14, and 28-days. Unconfined compressive strength (UCS) and California Bearing Ratio (CBR) tests were used to assess the engineering performance, scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), and X-ray diffraction (XRD) were used to assess the geopolymerization mechanism and microstructural evolution.

The engineering performance of the stabilized soil was significantly improved, as exhibited in the experimental results. After 28-days of curing, the UCS of the untreated soil was increased from 0.12 to 2.94 MPa, and CBR was increased from 1.8 to 46%, which is within the acceptable limit for subgrade as provided in the IRC: 37-2018. The optimum performance was obtained when 20% red mud was activated at a molarity of 10 M, and a sodium silicate-to-sodium hydroxide ratio of 1.5. The microstructural analysis substantiates the formation of N-A-S-H gel of geopolymer, which led to significant improvement in the strength gain by enhancement of particle bonding and reduction in pore spaces, and also to the formation of a dense matrix. The results have confirmed that alkali-activated red mud can be used as an effective and sustainable stabilizer for soft soils, thereby improving strength & bearing capacity, and promoting the beneficial use of industrial waste. This geopolymer stabilization method offers an environmentally friendly and sustainable alternative to traditional chemical stabilizers for subgrade construction.

Keywords: *Red mud, geopolymerization, stabilization, compressive strength.*

Utilization of industrial waste materials for enhancing subgrade soil properties: a comprehensive review

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ABSTRACT

The sustainable management of weak subgrade soils, coupled with the rapidly increasing generation of industrial by-products, presents significant technical and environmental challenges to modern geotechnical engineering and infrastructure development. Conventional stabilization techniques relying on cement and lime, although effective, are associated with high energy consumption, carbon emissions, and depletion of natural resources. In this context, the utilization of industrial waste materials offers a promising and sustainable alternative aligned with circular economy principles.

This paper presents a comprehensive and critical review of the application of industrial waste materials—including fly ash, pond ash, ground granulated blast furnace slag (GGBS), steel slag, red mud, construction and demolition waste, and other industrial residues—for enhancing the engineering performance of subgrade soils. The review synthesizes recent experimental, analytical, and numerical studies with a focus on stabilization mechanisms, performance enhancement, and long-term geosystem reliability. Particular emphasis is placed on chemical and pozzolanic reactions, microstructural evolution, and particle-level interactions that govern strength development and stiffness improvement.

Key mechanistic and performance-based indicators, such as unconfined compressive strength, California bearing ratio, resilient modulus, durability under wet-dry and cyclic loading conditions, and deformation resistance, are systematically evaluated. Furthermore, the environmental and economic benefits of industrial waste-based stabilization—including waste valorization, reduction in greenhouse gas emissions, conservation of natural aggregates, and improved lifecycle performance—are critically discussed within the framework of sustainable geosystem design.

The paper also identifies important research gaps related to field-scale validation, long-term durability under aggressive environmental conditions, material variability, and the need for standardized mix design methodologies and performance-based specifications. Overall, the review demonstrates that industrial waste-based stabilization techniques provide a technically reliable, environmentally sustainable, and resilient solution for improving subgrade performance, thereby contributing effectively to long-term geosystem surety.

Keywords: *Industrial waste utilization, Subgrade stabilization, Sustainable geosystems, Pozzolanic materials, Resilient modulus, Environmental sustainability.*

Comparison of LEM 3D and FEM 2D for slope stability analysis in a part of Western Ghats

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ABSTRACT

Accurate evaluation of slope stability is essential for mitigating rainfall-induced landslides in mountainous regions such as the Western Ghats, India, where steep terrain, highly weathered soils, and extreme monsoonal precipitation frequently trigger slope failures. Although both the Limit Equilibrium Method (LEM) and Finite Element Method (FEM) are widely employed for stability assessment, their applicability differs considerably in terms of computational efficiency, physical representation, and scalability.

This study presents a comparative assessment of three-dimensional (3D) LEM and two-dimensional (2D) FEM for evaluating slope stability in the Madikeri and Somwarpet regions of Kodagu district, Karnataka. Regional-scale analysis was performed using the United States Geological Survey's Scoops3D model, which systematically searches multiple three-dimensional spherical slip surfaces to identify the minimum Factor of Safety (FOS) throughout the study area. The analysis was conducted under dry conditions using a homogeneous soil profile to establish a common baseline for comparison. Subsequently, twenty-eight historical landslide locations from the 2018 Kodagu rainfall event were selected for detailed numerical modelling using PLAXIS 2D. The finite element analyses employed the Mohr-Coulomb constitutive model together with the strength reduction technique for FOS determination. Rainfall infiltration was simulated through transient seepage analysis using observed rainfall records for 1, 3, 6, and 10-day durations, while groundwater flow and unsaturated soil behaviour were incorporated to evaluate rainfall-induced degradation in slope stability.

The Scoops3D analysis identified distinct spatial variations in regional stability, with most slopes exhibiting FOS values greater than 1.5 under dry conditions, while localized steep terrain displayed FOS values below unity. Statistical evaluation of the regional results showed a positively skewed log-normal distribution of FOS values, indicating that a considerable proportion of the terrain exists in a marginally stable state. Comparative analyses demonstrate that Scoops3D generally predicts higher FOS values than PLAXIS 2D because of its assumptions of homogeneous material properties, predefined spherical failure surfaces, and the absence of transient hydro-mechanical coupling. In contrast, the FEM simulations captured stress redistribution, pore pressure evolution, seepage-induced reduction in effective stress, and progressive failure mechanisms, resulting in consistently more critical stability estimates, particularly under prolonged rainfall.

The comparison highlights the complementary strengths of both approaches. Scoops3D provides rapid and computationally efficient regional screening, whereas PLAXIS 2D offers a more physically representative assessment of individual critical slopes. The study demonstrates that integrating regional three-dimensional screening with detailed finite element analysis provides a practical framework for slope hazard assessment, prioritization of vulnerable slopes, and development of more reliable landslide risk mitigation strategies in complex mountainous terrains.

Keywords: *Slope stability, Factor of Safety (FOS), Scoops3D, Plaxis 2D*

Dynamic Split Tensile Behaviour and High Strain Rate Anisotropy of 3D Printed Concrete under SHPB

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ABSTRACT

3D printed concrete (3DPC) has emerged as a promising construction material; however, its mechanical performance is strongly influenced by printing-induced anisotropy, particularly under dynamic loading conditions. This study investigates the static and dynamic splitting tensile behavior of 3DPC, with emphasis on strain-rate effects and directional dependency. Quasi-static and high strain-rate tests were conducted using Brazilian disc specimens extracted along different directions (X, Y, and Z). Dynamic tests were performed using a Split Hopkinson Pressure Bar (SHPB) setup, ensuring stress equilibrium conditions. The results indicate that under static loading, the tensile strength varies marginally (3.0-3.2 MPa), suggesting nearly isotropic behavior. In contrast, dynamic loading significantly enhances tensile strength, with peak values reaching up to 8.8 MPa, and the Z-direction exhibiting superior performance. The anisotropy coefficient increased from 0.0569 (static) to 0.3069 (dynamic), highlighting pronounced directional dependency at high strain rates. Furthermore, the dynamic increase factor (DIF) confirms strong strain-rate sensitivity, with higher values observed in the Z-direction.

Keywords: *3D printed concrete (3DPC), dynamic split tensile strength, split hopkinson pressure bar (SHPB), high strain rate loading, and anisotropy.*

Probabilistic Seismic Hazard Assessment for Salem District, Tamil Nadu, India

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ABSTRACT

Earthquake hazard assessment plays a vital role in ensuring the safety and resilience of infrastructure, particularly in rapidly developing urban regions. Although Salem District is classified under Seismic Zone III according to IS 1893 (Part 1): 2016, increasing evidence of seismic activity associated with ancient fault systems necessitates a comprehensive site-specific seismic hazard evaluation. This study presents a Probabilistic Seismic Hazard Analysis (PSHA) for Salem District by integrating historical earthquake records, seismotectonic information, and region-specific ground motion prediction equations to estimate engineering design parameters.

A comprehensive earthquake catalogue covering the period from 1807 to 2021 was compiled using data obtained from the International Seismological Centre (ISC), National Earthquake Information Center (NEIC), Geological Survey of India (GSI), and India Meteorological Department (IMD). The collected earthquake magnitudes were standardized to moment magnitude (M_w) using empirical conversion relationships, followed by declustering to eliminate dependent events such as foreshocks and aftershocks. The final database comprised 277 independent earthquake events, while a detailed seismotectonic map identifying 52 active faults was prepared for seismic source characterization. Completeness analysis was performed using the Stepp method to ensure the statistical reliability of the earthquake catalogue before estimating seismic recurrence parameters.

Ground Motion Prediction Equations (GMPEs) developed specifically for Peninsular India were employed to estimate bedrock Peak Ground Acceleration (PGA) and Spectral Acceleration (S_a). Probabilistic seismic hazard calculations were implemented using MATLAB to generate seismic hazard curves, Uniform Hazard Response Spectra (UHRS), and spatial hazard maps for multiple return periods. The analysis indicates that the estimated bedrock PGA increases from approximately 0.027g for a 72-year return period to about 0.172g for a 2475-year return period, reflecting increasing seismic demand with longer exposure periods. Comparison with IS 1893 (Part 1): 2016 reveals that the estimated PGA for longer return periods slightly exceeds the codal value of 0.16g specified for Seismic Zone III, highlighting the importance of site-specific seismic hazard assessment over generalized seismic zonation. The generated hazard maps and response spectra provide valuable seismic design parameters for engineers, planners, and policymakers involved in infrastructure development within the Salem region. The study establishes a reliable framework for synthetic ground motion generation, seismic microzonation, site response analysis, and performance-based earthquake engineering. The outcomes contribute to improved earthquake-resistant design practices and support disaster risk reduction strategies, thereby enhancing the resilience and sustainability of future infrastructure in Salem District and similar stable continental regions of India.

Keywords: *Probabilistic Seismic Hazard Analysis (PSHA), Ground Motion Prediction Equations (GMPEs), Peak Ground Acceleration (PGA)*

Numerical Investigation of Impedance Characteristics of Adjacent Strip Footings on Dense Sand under Cyclic Loading Using the HSsmall Model

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ABSTRACT

Dynamic loading generated by machine foundations, transportation systems, and seismic excitation governs the serviceability and performance of shallow foundation systems. Although the dynamic impedance of isolated foundations is well established, practical foundations are frequently constructed in close proximity, resulting in structure–soil–structure interaction that modifies both stiffness and energy dissipation. A better understanding of these interaction mechanisms is therefore essential for the reliable dynamic design of closely spaced shallow foundations.

The present study numerically investigates the vertical dynamic interaction between two adjacent rigid strip footings resting on dry dense sand. Two-dimensional finite element analyses are performed in PLAXIS 2D under plane strain conditions using the Hardening Soil model with small-strain stiffness (HSsmall) to represent stress-dependent stiffness, stiffness degradation, and hysteretic damping. Harmonic vertical displacement is prescribed at the footing level, while Rayleigh damping together with viscous boundaries is adopted to simulate realistic wave propagation and energy dissipation. Steady-state displacement and reaction-force histories are evaluated in the frequency domain to determine the complex vertical impedance. Interference factors corresponding to the real component, imaginary component, and magnitude of the complex impedance are subsequently determined to quantify the influence of footing proximity.

The results shows a distinct non-monotonic interaction behaviour, with all interference factors reaching their maximum values at a spacing ratio of $S/B = 1$. At this spacing, the real impedance interference factor attains values of approximately 1.55–1.60 for 1 Hz excitation and about 1.70 for 10 Hz, whereas the damping interference factor increases to 1.85–1.90, indicating a stronger amplification of damping than stiffness. The magnitude of the complex impedance reaches nearly 1.70, confirming that the greatest dynamic interaction occurs when the footing spacing is approximately equal to one footing width. Although the interaction decreases as the spacing increases, the interference factors remain greater than unity even at $S/B = 3$, demonstrating that dynamic coupling persists over relatively large separation distances. Variations in excitation frequency produce a more pronounced influence on the interaction than the prescribed displacement amplitude considered in this study.

The study demonstrates that footing spacing is the governing parameter controlling the dynamic interaction between adjacent strip footings. The findings show that neglecting structure–soil–structure interaction may underestimate both the dynamic stiffness and the damping characteristics of closely spaced foundation systems. The proposed numerical framework therefore provides useful guidance for the analysis and design of shallow foundations subjected to cyclic and vibratory loading.

Keywords: *Dynamic Impedance, Adjacent footings, HSsmall Model, Cyclic loading*

Effect of sawdust ash on the geotechnical properties of marine clay

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Marine clay deposits are widely encountered in coastal regions and often exhibit poor engineering properties such as high compressibility, low shear strength, and excessive settlement, which affect the stability and performance of civil engineering structures. Conventional soil stabilization methods using cement and lime are effective but associated with high cost and environmental concerns due to carbon emissions. The present study investigates the feasibility of using sawdust ash (SDA), an agricultural/industrial waste material, as an eco-friendly stabilizing agent for improving the geotechnical properties of marine clay.

Marine clay collected from Marina One, Kochi, Kerala, was used in the study. The soil was sundried, pulverized, passed through a 425 μm sieve, and prepared for laboratory investigations. Sawdust ash was produced by controlled burning of sawdust obtained from a local wood mill and sieved through a 300 μm sieve. X-ray diffraction analysis of SDA revealed the presence of amorphous silica along with quartz and calcite phases, indicating its potential for pozzolanic activity. The soil was blended with SDA in proportions of 0%, 2%, 4%, 6%, and 8% by dry weight. Atterberg limits, Standard Proctor compaction, and Unconfined Compressive Strength (UCS) tests were conducted to evaluate the effect of SDA addition.

The initial marine clay exhibited high plasticity, with liquid limit and plasticity index values of 128% and 87%, respectively. Sundrying reduced these values to 82% and 43% due to aggregation of fine clay particles. SDA was found to have a specific gravity of 2.1 and pH of 10.4, indicating its reactive nature. The addition of SDA resulted in a reduction of plasticity index from 43% to 40%, showing improved soil behaviour. The maximum dry density decreased from 14 kN/m^3 to 11 kN/m^3 , while the optimum moisture content increased from 13% to 16% with increasing SDA content due to the porous and low-density nature of ash particles.

The UCS results showed a continuous increase in strength with SDA addition up to an optimum content of 6%. The maximum UCS value of 127 kPa was achieved after 28 days of curing with 6% SDA. Further increase in SDA content resulted in reduced strength due to the presence of excess unreacted ash particles. The improvement in strength is attributed to pozzolanic reactions between silica and alumina present in SDA and calcium compounds in the soil, resulting in the formation of cementitious products such as calcium silicate hydrate (C–S–H).

The study concludes that sawdust ash can be effectively utilized as a sustainable soil stabilizer for improving the strength and engineering behaviour of marine clay. The utilization of SDA not only enhances soil performance but also provides an environmentally beneficial solution by converting waste material into a valuable construction resource for ground improvement applications.

Keywords: Marine clay, Sawdust ash, Soil stabilization, Geotechnical properties, UCS, Sustainable construction

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Seismic Response of Offshore Wind Turbine Monopile Foundation in c - ϕ Soils

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ABSTRACT

The rapid growth of offshore wind energy has increased the use of monopile foundations due to their simplicity and cost-effectiveness. However, there are ongoing concerns about how well these foundations perform under different environmental and seismic conditions. This study explores the behaviour of a monopile foundation for a 5-MW offshore wind turbine using advanced 3D modelling in PLAXIS 3D. The monopile is treated as a linear elastic structure, while the surrounding soil is modelled with the Mohr–Coulomb framework. The analysis assesses the impact of both wind and seismic forces on the monopile, ensuring a sufficiently large soil domain is included to reduce boundary effects. The numerical model was validated against published results for combined wind and seismic loading, with a maximum difference of 8.74%.

Various parameters were considered, including soil cohesion, internal friction angle, monopile length and diameter. The results show that increasing soil cohesion from 10 to 60 kPa lowers lateral displacement by about 60% at the top of the tower and 65% at the pile head. Extending the monopile length from 30 m to 40 m decreases pile-head displacement from 0.055 m to 0.01 m, while increasing the diameter further reduces lateral flexibility. The influence of the internal friction angle ϕ is most pronounced at low cohesion, where an increase from 30° to 40° reduces displacement by 10–13%, compared to only 5–9% at higher cohesion levels. These findings demonstrate that seismic forces significantly increase lateral movement and emphasise that both soil strength parameters and design factors (length, diameter) are essential to ensuring the stability of offshore monopile foundations in c - ϕ soils.

Keywords: *Offshore Wind Turbine (OWT), Monopile Foundation, Seismic Response, Lateral Displacement, PLAXIS 3D.*

Unified Properties of the Stone Masonry Dam for Stability Analysis

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1 Introduction

Stone masonry (SM) structures, particularly gravity dams, represent a significant portion of the civil infrastructure worldwide. These structures are complex composite systems consisting of irregularly shaped natural stones and lime-based (surki) mortar. Over decades of service, these materials undergo significant deterioration due to environmental factors, leading to increased porosity and a reduction in structural stiffness. For modern seismic safety evaluations, accurate material parameters—specifically Density, Young's modulus (E), and Poisson's ratio (ν) are critical. However, conventional rock core sample testing standards may not capture the heterogeneous nature of composite SM core samples. This research addresses the shortfall by developing a specialized framework for determining the Unified properties of stone masonry through integrated Experimental and Numerical Homogenization Techniques.

2 Research Aim and Objectives

- Experimentally characterize **pure rock and pure mortar** and use them as inputs to numerical modeling. Develop an **RVE model** of stone–mortar composite. Obtain **homogenized Young's modulus, Poisson's ratio, shear modulus, and density**. **Validate** RVE results with laboratory measurements.
- Address the **gap in existing codes**(IS 13030:2025, ASTM D2845, ASTM D2845 etc..) which cover only rock or mortar, not composite masonry. Provide reliable material inputs for **Dynamic analysis, seismic safety, and risk assessment** of Masonry Gravity dams.

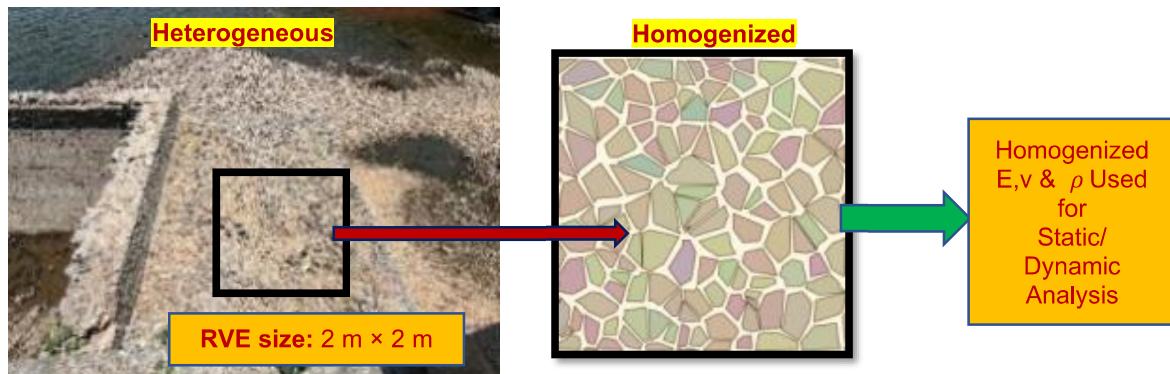


Figure1: KRS Dam Modelling in Abaqus software

3 Results and discussion

The results indicate that the homogenized stiffness of the masonry is highly sensitive to the stone volume fraction. Increasing the stone content from 66% to 90% results in a **91% increase** in the effective Young's Modulus, highlighting the critical role of the stone-to-mortar ratio in the overall stability and unified properties of the dam structure.

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Table 1. Variation of modulus with stone content.

Engineering Properties	Input Value given to RVE Model		Homogenized Youngs Modulus: E (Gpa)		
	Stone (Gpa)	Mortar (Gpa)	66% Stone	76% Stone	90% Stone
E (Gpa)	60	1.2	6.16	7.15	11.77
ν	0.2	0.3	0.28	0.24	0.28

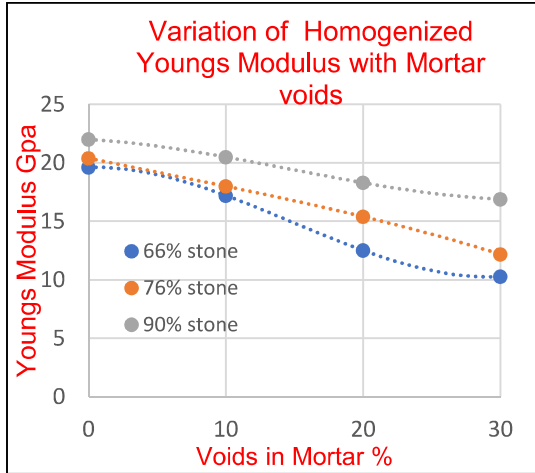


Figure 3 : Plot of E vs % of Mortar

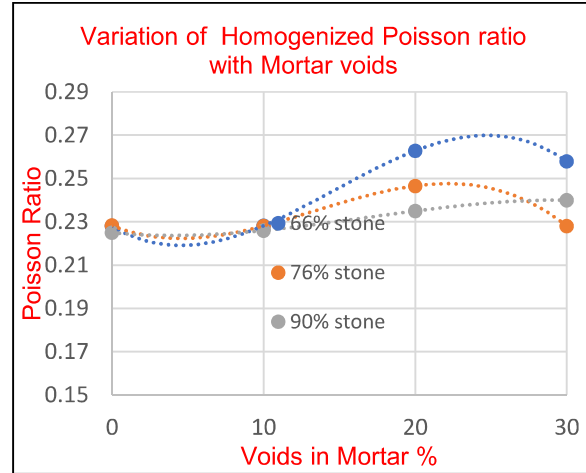


Figure 4 : Plot of Poisson ratio vs % of Mortar

4 Conclusion

The numerical homogenization study using the RVE approach demonstrates that the effective mechanical properties of Stone Masonry are strongly influenced by Mortar voids and Stone content. The homogenized Young's modulus (E_{eff}) shows a clear decreasing trend with increasing void percentage, indicating significant stiffness degradation due to mortar damage and porosity. Conversely, higher stone content (90%) consistently results in greater stiffness and improved mechanical stability compared to 66% and 76% cases. The effective Poisson's ratio (ν_{eff}) exhibits a slight increase with voids, reflecting enhanced deformability of the composite material. The variation observed across different random geometrical realizations (RNG) is minimal, confirming the reliability and robustness of the RVE-based modeling approach.

Furthermore, the developed RVE model enables the direct estimation of homogenized properties by assigning individual material properties—Young's modulus (E), Poisson's ratio (ν), and density (ρ) to stone and mortar phases separately. Based on these inputs, the model effectively computes the equivalent (homogenized) Young's modulus, Poisson's ratio, and density of the composite masonry system. These homogenized parameters (E_{eff} , ν_{eff} , ρ_{eff}) can be directly utilized for dynamic analysis of masonry dams, such as seismic response and vibration studies, ensuring a realistic representation of the heterogeneous material behavior at the macro-scale.

Overall, the results highlight that mortar voids play a dominant role in governing the mechanical behavior of masonry systems, having a more pronounced impact than random stone distribution.

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Planning and Design of Reinforced Earth Wall for Approaches of Major Bridge on Complex Hilly Terrain: Sustainable Perspective

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1 Abstract

The Construction of bridge approaches in complex hilly terrain poses significant geotechnical and construction challenges due to large elevation differences, restricted right-of-way, heterogeneous subsurface conditions, and the need for cost-effective and sustainable solutions. This paper presents a detailed case study on the planning and design of reinforced earth (RE) walls for the approach roads of a high-level cable-stayed bridge across the Manair River at Sadhashivpally, connecting Hyderabad-Karimnagar-Ramagundam Road and Rayapatnam-Kodad Road (NH-563), Karimnagar District, Telangana. The site is characterized by steep embankment heights, limited space, and the presence of massive in-situ boulders, which disrupted soil continuity and hindered proper compaction and placement of geosynthetic reinforcements. The primary challenge was to achieve a stable and near-vertical embankment face while maintaining permissible gradients for vehicular movement and minimizing excessive earthwork. Conventional retaining structures were found to be uneconomical and impractical under the given constraints. Accordingly, a reinforced earth wall system using geogrids and self-sustainable soils was adopted. Special emphasis was placed on the strategic placement and length of reinforcements to counteract mobilized shear stresses at the embankment edges, enabling the use of locally available soils in the remaining fill and thereby reducing overall project cost. The study discusses site investigation, soil characterization, selection of suitable fill materials, determination of design parameters, and the methodology adopted for excavation and controlled removal of boulders. A sustainable construction approach was implemented by reusing excavated boulders for the production of fine and coarse aggregates, significantly reducing material transportation and environmental impacts. The results demonstrate that RE walls offer a safe, economical, and sustainable alternative to conventional retaining walls in hilly terrains. The findings of this case study provide practical insights into the design and execution of reinforced earth structures on constrained sites and may serve as a valuable reference for researchers and practicing engineers involved in bridge approach construction in complex geomorphological conditions.

2 Introduction

Rapid urbanization and the development of transportation infrastructure in India have increased the demand for sustainable and cost-effective solutions for bridge approach systems in challenging terrains. The construction of approach embankments for high-level bridges in hilly and constrained locations often encounters significant geotechnical difficulties, including steep elevation differences, limited working space, instability of filled soil, and the presence of rock outcrops or boulders. The literature review highlights that the performance and stability of reinforced earth wall systems for bridge approaches in complex hilly terrains are primarily governed by the characteristics of standard backfill material IRC: SP:102–2014 (2014), the interface frictional resistance between the reinforcement and backfill soil, and sustainable construction practices, in addition to the availability of suitable backfill material within the project terrain. Ho, S. K., & Rowe, R. K. (1996) reported that the friction angle of granular backfill significantly affects wall deformation and reinforcement strain, with weaker backfills causing higher lateral displacement and reinforcement stresses. Hatami, K., & Bathurst, R. J. (2005) demonstrated that a small cohesive component in granular backfill can reduce wall deformation when proper soil–reinforcement interaction and reinforcement stiffness are maintained. Cardoso et al. highlighted the potential use of recycled aggregates and construction and demolition waste (CDW) as sustainable engineered fill materials, while Vibha, S., & Divya, P. V. (2021). confirmed that processed CDW performs comparably to conventional sand backfill in reinforced earth wall applications. Overall, these studies emphasize the importance of suitable backfill selection, reinforcement interaction, and sustainable materials for the safe and economical design of reinforced earth walls in challenging terrains. However, the present site consists of large rock boulders located within the carriageway length of the elevated reinforced embankment portion (Fig 1 & 2), which disturbed the conventional practice of placing reinforced geogrid layers continuously within the required embedment length from the wall face into the soil at certain locations. Therefore, an attempt was made to provide GEOSTRAP reinforcements with adequate tensile strength to safely resist the active earth pressure acting on the reinforced earth wall. Accordingly, the GEOSTRAP layers were installed near the edge portions and anchored to both the face panels and the nearby rock boulders to effectively resist the pull-out forces.

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3 Methodology

The preliminary soil investigation was carried out by drilling five boreholes to the required depth to assess the subgrade strength as per the project requirements. In addition, various laboratory tests were conducted on the soil samples collected from the borrow area to evaluate their suitability as fill material for the construction of the reinforced earth (RE) wall. The properties of the borrow area materials, such as grain size distribution, angle of internal friction, Atterberg limits, percentage finer content, maximum grain size, maximum dry density (MDD), optimum moisture content (OMC) obtained from the compaction test, and pH values, were found to be within the permissible limits specified in IRC: SP:102-2014 and MoRTH guidelines. Hence, the borrow area materials were considered suitable for use as fill material in the construction of the reinforced earth wall. Unweathered rock samples collected from the proposed RE wall location were identified as granite. Preliminary laboratory investigations were conducted to assess their suitability for use as construction materials, including sand, aggregates, and 150 mm boulders. After confirming compliance with relevant standards, the materials were utilized accordingly in PCC for the foundation base, and 150 mm boulders in random rubble (RR) masonry. The combination of these materials was also used as a graded filter in front of the stone masonry retaining wall. The test results are presented in Table 1.

Table 1. Basic physical and engineering properties of Backfill soil.

Properties	Average Value of	MoRTH permissible
Maximum dry density, g/cc	1.98	-
Optimum Moisture Content, %	11	-
Cohesion (c) kg/cm ²	0.14	-
angle of shearing resistance, ϕ	38	≥ 30
Uniformity Coefficient(Cu)	23.1	≥ 4
Max grain Size (mm)	12.5	75
% Fines < 75 microns	< 15	10
Coefficient of Permeability 'k' cm/s	2.64×10^{-4}	Good drainage
Gravel (14%), sand (74%) and Fines (10%) and Classification of soil : SW-SM		
Plasticity index (Ip)	NP	≤ 6



(a)



(b)

Figure 1. Pictures of (a) Boulders prevailing at the site, and (b) horizontal layer of RE Wall with geogrid.

4 Conclusions

At the proposed reinforced soil wall, passing through soil/ rocky/boulder terrain, for which the following conclusions are made. 1. Whenever possible, the boulders could be removed so that the required length of the reinforcement can be provided. 2. When the boulders could not be removed, the 'GEOSTRAP' reinforcement that is anchored to the boulders can be adopted in place of full-length reinforcement. 3. The cut rock could be used to make the aggregate for construction, following the sustainable practices. 4. By adopting suitable modifications/adjustments, the construction difficulties of RE walls across unfavourable terrains could be overcome, as in the present case. Design and sustainable perspective construction concept of the present case study may be helpful to the researchers and practising engineers in the Planning and Execution of a bridge on a hillock.

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Cost-effective Geophysical Approaches for Resilient Infrastructure. An Integrated Framework for Geotechnical Hazard Assessment and Risk-Based Design Decisions.

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1 Introduction

The characterisation of subsurface structures and their influence on geotechnical behaviour remains a challenge in hazard-prone regions. Established geotechnical investigations may fail to capture the subsurface fault severity and its impact on soil-structure interaction. In active tectonic regions like the Himalaya or regions having deep-seated faults and other geological structures, the constraints can significantly influence both the characterization of subsurface material properties and dynamic site response and therefore the silent, but critical vulnerability for infrastructure safety. In the recent past, the geophysical methods have demonstrated their capability in subsurface characterisation, however, many of these methods are expensive, labour-intensive, and require significant financial investments. In this context, the present study highlights the capability of cost effective, less labor-intensive geophysical approaches, including the analysis of earth's field nuclear magnetic resonance (EFNMR Magnetometers), Ambient Vibration Testing (AVT Microtremors) and Satellite based Hyperspectral remote sensing dataset (EO-1 Hyperion) for feasible investigation strategies. The integration of these data sets may provide a more comprehensive understanding of soil characterization and soil-structure interaction, thereby supporting sustainable infrastructure development that aligns with the United Nations Sustainable Development Goals, particularly SDG 9 and SDG 11. Geomagnetic surveys have emerged as a robust and efficient tool to delineate the subsurface faults, particularly in complex regions where direct geological observations are limited (Ayaz and Bukhari, 2020; Ayaz et al., 2025). These studies not only highlight the presence of major fault traces but also features like fault branching, segmentation and overall shear zone characterization based on the facts including magnetic characterization, magnetization, alteration and hydration. On the other hand, Hyperspectral remote sensing offers a complementary approach by detecting the surface mineralogical alterations associated with fault zones via detecting the variations in soil spectral signatures, particularly related to Fe^{2+} and Fe^{3+} absorption features, oxidation-reduction environments, and is effective for surface characterisation (Ayaz et al., 2023). Further, our ongoing ambient vibration testing (AVT) provides critical insights about the dynamic behavior of soil and structures through Horizontal-to-Vertical Spectral Ratio (HVSr) and Power Spectral Density (PSD) methods, enabling the stability estimation of foundational modes of structure and validating energy distribution across modal frequencies (SESAME, 2004). Also, to prevent catastrophic failures due to resonance, it is essential that the dynamic response of a structure remains distinct from the natural frequency of the site (Anbazhagan et al., 2019). This study therefore proposes the integrated multi-scale framework to address the gap in a comprehensive understanding of subsurface, surface and structure interactions in geotechnical hazard assessment and risk based design decisions for sustainable infrastructure.

2 Methodology

The methodology utilised the linear and gridded profile datasets of magnetic data for the NW Himalaya and Peninsular India, Hyperspectral dataset for the NW Himalaya and the AVT data for the VV Sagar Dam, Karnataka. These datasets acquired from geologically distinct regions were used to evaluate the robustness and broader applicability of the proposed framework, establishing its significance for hazard assessment across diverse tectonic and geotechnical settings (Fig. 1).

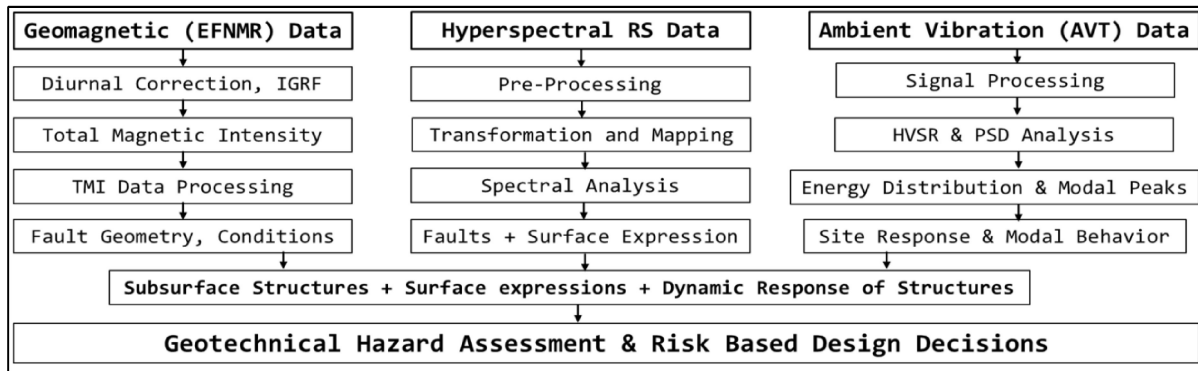


Figure 1. Flow chart showing complete methodology

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3 Results and discussion

The study shows a good correlation between the geomagnetic, hyperspectral analysis and delineation of subsurface faults. The faults are found associated with the magnetic minima due to the influence of hydraulic activities, martitization and alteration in oxidation and reduction environment at the faults. The clear and continuing lineage of magnetic low was found in a gridded data acquired in one of the region at NW Himalaya (Fig.2a). The fault anomaly is clearly identified in a single linear profile in another part of the region (Fig.2b) where as linear dataset at peninsular India also clearly trace the fault anomaly (Fig.2c), thereby showing the method works irrespective of the crustal thickness and lithological changes. Further, the hyperspectral studies are proving efficient in identifying the faults due to the absorption features at the strike of the fault which are typical of Fe³⁺ and Fe²⁺ and the soil spectrum across the fault is different and can be separated by clustering and discrete wavelet transform (Fig.2d). Also, the Ambient Vibration Testing prove significant in assessing the stability of foundational modes at low frequency and local energy distribution at high frequency (Fig. 2e).

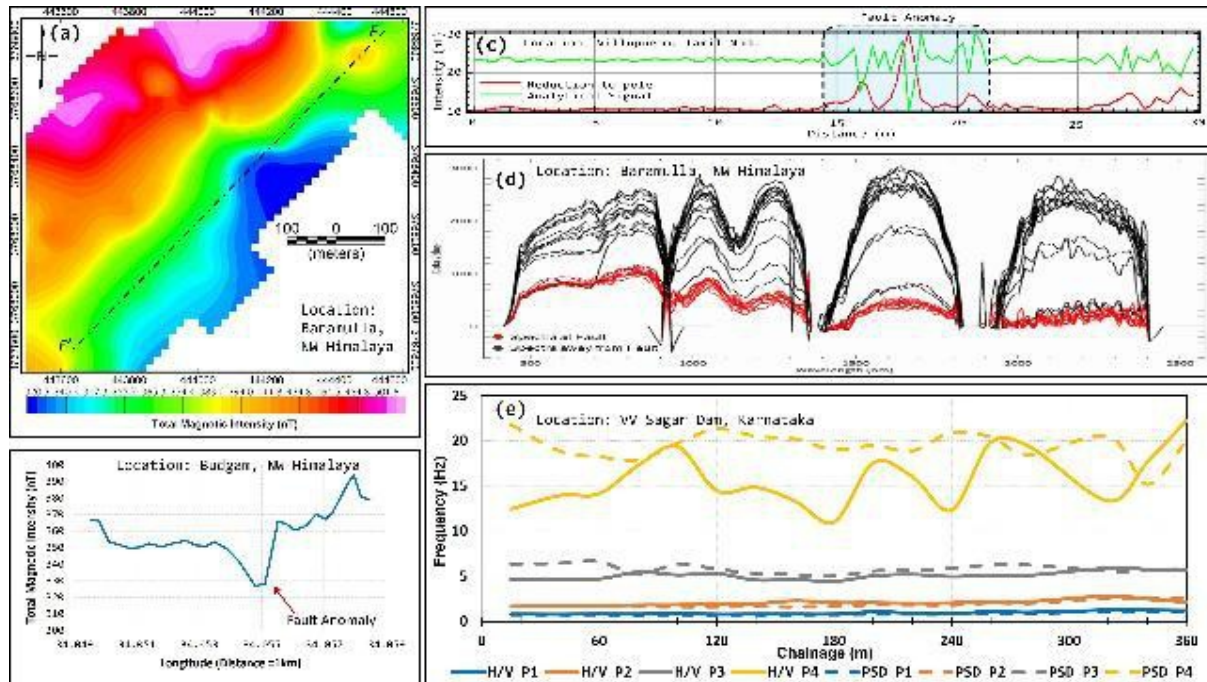


Figure 2. (a) Gridded Total Magnetic Intensity (TMI) (b) TMI of single linear profile (c) RTP and Analytical signal of TMI (d) Spectral analysis of HS Dataset (e) Modal behaviour of VV Sagar Dam.

4 Conclusion

The proposed methodology is cost-effective and meaningful for a comprehensive understanding of geotechnical hazard assessment and outlining mitigation strategies for risk based design for sustainable infrastructure.

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Critical Evaluation of IS 8009 Settlement Correlations for Foundations on Compressible Soils

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1 Introduction

The prediction of foundation settlement is a fundamental requirement for ensuring structural serviceability and long-term performance in geotechnical engineering (Peck et al., 1974). In Indian engineering practice, settlement of shallow foundations is commonly evaluated using the empirical procedure provided in IS 8009 (Part 1):1976 (IS 8009 (Part 1), 2006), which outlines simplified methods for foundations subjected to symmetrical static vertical loading. The standard relates settlement behaviour primarily to Standard Penetration Test (SPT) N value and footing width, with additional correction factors introduced to account for groundwater conditions, foundation depth and footing rigidity. While the code recognizes that settlement may consist of immediate deformation, primary consolidation, secondary compression and creep, the practical design procedure largely relies on empirical relationships between penetration resistance and deformation response.

Although several aspects of the settlement formulation in the code require further clarification, the present study focuses specifically on the SPT N-value settlement correlation charts and their limitations. These charts relate settlement per unit pressure to penetration resistance and footing width, yet their experimental basis and the dataset used for their plotting are not clearly documented. In addition, the charts are limited to footing widths of approximately 6 m, beyond which no guidance is provided for larger foundations. This work investigated the applicability of IS 8009 for a soft soil site with a mat foundation in the residual terrain of Bengaluru, India. The investigation report indicates that the site historically formed part of a lake or tank area that was later filled with debris and municipal waste before being developed into a residential complex consisting of three eight-storey buildings. Typical borehole data and soil properties from the site are used to estimate settlement as per IS 8009 and other methods based on site data through analytical calculations and numerical modelling.

2 Settlement Estimation and Numerical Validation

The settlement estimation was initially performed following the empirical procedure described in IS 8009. For the representative borehole analysed, the penetration resistance near the foundation level was approximately $N = 16$. However, the provided SPT N-value plot reveals an extremely erratic profile: values fluctuate between $N=14$ and 16 at the surface, peak sharply at $N = 64$ at a depth of 4 m, and then collapse to a critical range of $N = 3$ to 8 between 5 m and 8 m before hitting rebound at 12 m. For the 20 m footing width, the code's primary settlement correlation charts were extrapolated beyond their maximum limit of 6 m by assuming a linear trend. Then, incorporating correction factors for the load intensity q , water table C_w , depth C_d , and rigidity C_r , the final empirical settlement adding immediate and consolidation settlement was determined to be 224.7 mm. The detailed empirical calculation and the correction factors used in accordance with the code provisions are summarized in Table 1 and Table 2.

Table 1: Empirical Immediate Settlement Calculation using IS 8009

Layer	H (m)	N_{avg}	S (m per unit pressure(kg/cm ²)) from Fig.9	C_w	C_d	C_r	Pressure(kg/cm ²))	S(mm)
1	2	15.44	0.0220	0.50	0.98	0.8	1.8	15.55
2	1	64.11	0.0045	0.50	0.98	0.8	1.8	3.18
3	4	6.84	0.1151	0.50	0.98	0.8	1.8	81.21
4	3	22.59	0.0134	0.50	0.98	0.8	1.8	9.46
5	20	60	0.0045	0.50	0.98	0.8	1.8	3.18
Immediate Settlement =								112.6

Table 2: Empirical Consolidation Settlement Calculation using IS 8009

Layer	H(m)	I	q	σ_0	$\sigma_0 + \Delta\sigma$	C_c	C_r	σ_c (kPa)	Sc (m)	Sc (mm)
1	0.5	0.2496	144.4	29.6	1838.37	0.145	0.009	167	0.04606800	46.06
2	0.5	0.2496	144.4	122.055	1329.7	0.272	0.012	65	0.06605543	66.05

To evaluate settlement behaviour considering the governing deformation mechanisms within the soil profile, a parameter-based analytical approach was adopted using soil properties obtained from site investigation and laboratory testing. Total settlement was divided into components representing immediate deformation (S_i) within the soil skeleton, compression

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of weak soil layers (S_p) under applied stress, settlement associated with degradation of organic material (S_b) within the fill deposits, and long-term creep (S_{creep}) deformation (Terzaghi, 1943; Das, 2007; Hettiarachchi, 2009).

$$S_b = m_j' = m_{j0} e^{-k_j' t}$$

where m_j' represents the remaining mass at time t , m_{j0} is the initial mass of the biodegradable component, and k_j' is the decay rate constant.

IS 8009 provides calculating consolidation settlement of strata, which requires additional consolidation tests and parameters. In this apart from using SPT N based calculation, soil properties of E , C_c , C_r and C_α are estimated and settlement are estimated through analytical approach. The analytical method with soil properties is the results of 0.102 m for immediate settlement, of 0.220 m for biodegradable settlement, of 0.103 m for primary compression, and of 0.004 m for creep, resulting in a total settlement of about 429.24 mm. This approach explicitly accounts for mechanisms that cannot be represented through penetration resistance correlations alone.

The analytical evaluation was subsequently examined using PLAXIS 2D numerical modelling under an applied foundation pressure of 180 kPa. The soil profile was simulated using the Hardening Soil model, which captures stress-dependent stiffness behaviour and allows stiffness to be defined through compression indices (C_c , C_r) or Young's modulus. To represent time-dependent deformation within compressible layers, the Soft Soil Creep model was incorporated. Soil parameters used in the numerical model were derived from laboratory testing and calibrated to represent the heterogeneous strata observed at the site, with analysis showing a 456.2 mm of total settlement.

Table 2: Parameter-Based Analytical Settlement Estimation

BoreHole	S_i (m) - (Immediate)	S_b (m) - (Biodegradable)	S_p (m) - (Primary Settlement)	S_{creep} (m) - (Creep)	S_t (m)	Total Settlement (mm)
BH1	0.10231	0.22003	0.10304	0.00386	0.42924	429.24

3 Results and discussion

The comparison between the empirical and parameter-based evaluations shows a significant difference in predicted settlement magnitude. The IS 8009 procedure predicted approximately 224.7 mm, whereas the analytical evaluation predicted approximately 429.24 mm under the same loading condition. The PLAXIS 2D numerical simulation predicted a maximum settlement of approximately 456.2 mm after 50 years of consolidation, including differential settlement, representing the long-term deformation of the soil-foundation system under sustained loading. The empirical estimate is therefore approximately half of the settlement predicted through the analytical evaluation, indicating that the SPT chart bases estimation as per the code significantly underestimates the deformation potential of the soil profile.

The discrepancy is primarily associated with the limitations of the empirical correlation used in IS 8009, where settlement is correlated with SPT N-values as indicators of soil stiffness. In the present soil profile, zones with very low penetration resistance ($N \approx 3-8$) occur within heterogeneous layers containing debris and biodegradable material associated with the former dump filled layers, which is also reflected in the numerical modelling results. These materials undergo progressive compression and degradation-related settlement under sustained loading. Such mechanisms are not fully represented in penetration-resistance-based approach, resulting in lower predicted settlements using the empirical procedure compared with the analytical and numerical evaluations.

4 Conclusion

In this study, the settlement of a mat foundation of 20 m width was estimated using SPT N values as per the IS8009 chart, an analytical formula based on site-specific subsurface layer data, and PLAXIS 2D modelling with the same loading and soil data. SPT N-based chart value range from **4.5 to 115.1 mm**, which is very low compared to the other two methods. Further N-based charts do not account for filling and biodegradable layers commonly found in urban developments. The current IS 8009 framework proved fundamentally inadequate for predicting settlement in a heterogeneous fill with a municipal waste environment because it lacks the analytical depth to isolate plastic compression and creep from simple field resistance data. Relying on unverified empirical extrapolations and vague constants for soils is an engineering risk that standardized national codes should no longer permit without explicit warnings about its limitations.

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Theme: Geosynthetics and Ground Improvement

The Role of Geosynthetics in Indian Infrastructure Development: Current Practices and Beyond...A journey with Prof. TGS

Sireesh Saride, Amarnath Hegde & Deendayal Rathod

ABSTRACT

India's rapidly expanding infrastructure sector, driven by urbanization, industrialization, and increasing investments in transportation and urban development, demands innovative and sustainable engineering solutions. Geosynthetics, including geogrids, geocells, and geocomposites, have emerged as indispensable materials for enhancing the performance, durability, and cost-effectiveness of civil engineering infrastructure. Their versatile applications in foundations, roadways, railways, embankments, and retaining structures have significantly improved infrastructure performance while reducing construction time, maintenance requirements, and environmental impacts.

This presentation provides a comprehensive overview of the research contributions made by Prof. T.G. Sitharam and his research students in the field of geosynthetics over the past 25 years. It highlights the evolution of their research through systematic laboratory investigations, analytical and numerical studies, design developments, and successful field implementations. The early phase of the research focused on evaluating the performance of geogrids and laboratory-fabricated geocells through medium to large-scale plate load tests. These investigations were subsequently extended to commercially available geocells, followed by comprehensive three-dimensional numerical analyses to better understand stress distribution, confinement effects, and load-transfer mechanisms in reinforced foundation systems. Based on these studies, analytical design methodologies were developed to predict failure strain and bearing capacity of geosynthetic-reinforced foundation beds.

Building on these foundational studies, the research expanded to several innovative applications of geosynthetics in civil engineering. These include reinforced pavements, buried pipelines, vibration isolation systems, geosynthetic-encased stone columns, and other ground improvement techniques. Recognizing the importance of sustainable infrastructure, the group also explored the use of natural geosynthetic materials such as bamboo, jute, and coir as environmentally friendly alternatives to conventional polymeric products. In addition, the presentation showcases several field case studies that demonstrate the successful translation of research findings into engineering practice, validating the effectiveness of the proposed methodologies under real-world conditions and finally development of code of practices.

Overall, the research contributions of Prof. T.G. Sitharam and his group have significantly advanced both the scientific understanding and practical application of geosynthetics in India. Their work has contributed to the development of rational design methodologies for reinforced foundations and ground improvement systems, expanded the range of geosynthetic applications in infrastructure engineering, and promoted sustainable construction practices. These contributions continue to serve as valuable references for researchers, practicing engineers, and policymakers working toward the development of resilient, durable, and sustainable infrastructure.

Theme: Geotechnical Investigation and Site Characterization

Importance Of Site Characterization Based On In-Situ Investigation And The Lesson Learnt

Abhishek Kumar Sharma, Naveen James, Govindaraju, B V Ravihankar

ABSTRACT

Seismic site characterization in India has evolved significantly over the last two decades, from conventional geotechnical investigations to integrated, multi-scale assessment of subsurface conditions and local site effects. A major impetus to systematic research in this area was provided by ****Prof. T. G. Sitharam at the Indian Institute of Science (IISc), Bangalore****, who initiated pioneering research on seismic microzonation and site characterization by integrating geology, geotechnical investigations, geophysical measurements, site response analysis, and spatial hazard mapping. The comprehensive seismic microzonation studies of Bangalore provided one of the early frameworks for understanding how local soil and rock conditions modify earthquake ground motions in Indian geological settings. This research subsequently expanded through investigations led by his students, extending site characterization studies to urban regions, the Indo-Gangetic Basin, shallow bedrock terrains of Peninsular India, and the Kalpakam Nuclear Power Plant site. Extensive use of Standard Penetration Test (SPT) data, Multichannel Analysis of Surface Waves (MASW), seismic borehole testing, and other geophysical techniques enabled the development of regional correlations, engineering bedrock maps, and improved subsurface models. These investigations also raised fundamental questions regarding the universal applicability of conventional site classification parameters, particularly V_{s30} , to Indian shallow bedrock conditions and demonstrated the importance of soil thickness, engineering bedrock depth, impedance contrast, and spatial variability in realistic assessment of local site effects.

The lessons learnt from this continuing research journey demonstrate that reliable site characterization cannot depend on a single parameter, empirical correlation, or investigation technique. The initial research framework established at IISc has progressively evolved into integrated investigations combining SPT, MASW, downhole and crosshole seismic testing, electrical resistivity, Ground Penetrating Radar, and advanced laboratory characterization using resonant column and cyclic triaxial testing. Field and laboratory studies have further highlighted the importance of measurement quality, particularly the influence of SPT hammer energy on N-values and their correlations with shear-wave velocity and maximum shear modulus. Recent innovations involving automated P- and S-wave arrival-time identification, improved seismic downhole interpretation and ray-path analysis, resolution of high impedance contrasts, non-contact visual measurement of SPT hammer energy, and region-specific shear modulus and damping models represent important advances towards reducing uncertainties in subsurface characterization. The progression from the pioneering microzonation initiatives of ****Prof. T. G. Sitharam at IISc Bangalore**** to the present generation of advanced field, laboratory, and computational investigations illustrates the evolution of site characterization research in India. Collectively, these studies emphasize the need for an integrated, scale-appropriate, and regionally validated framework for assessing local site effects, liquefaction

and other induced hazards, thereby contributing to more reliable seismic design and the resilience of India's rapidly expanding urban and critical infrastructure.

Theme: Seismology, Earthquake Geotechnical Engineering and Microzonation

From Bhuj to Beyond: Prof. T. G. Sitharam's Legacy in Soil Liquefaction Research

Anbazhagan P, Abhishek Kumar, Dhanaji Chavan, Ramakrishna, Sreevalsa Kolathayar, Monalisha, Balreddy Mutthana

ABSTRACT

Soil liquefaction has been one of the most significant geotechnical hazards associated with earthquakes, causing severe damage to foundations, lifelines, and infrastructure worldwide. In India, systematic research on earthquake-induced soil liquefaction gained momentum following the 2001 Bhuj earthquake under the leadership of Prof. T. G. Sitharam at the Indian Institute of Science (IISc), Bengaluru. This presentation reviews more than two decades of pioneering research in earthquake geotechnical engineering, highlighting the progression from fundamental laboratory investigations on liquefiable Indian sands to advanced numerical modeling and mitigation techniques. Early studies focused on understanding the cyclic behavior, pore-pressure generation, dynamic properties, and liquefaction resistance of Indian sandy soils through cyclic triaxial testing, thereby establishing a strong experimental foundation for liquefaction assessment in the Indian context.

Subsequent research expanded the scope to investigate cyclic and post-liquefaction behavior, discrete element modeling (DEM) of granular soils, and the influence of fines on liquefaction susceptibility. Significant contributions were made toward understanding the role of non-plastic silt and lowplasticity clay fines in modifying the cyclic response, liquefaction resistance, and post-liquefaction strength recovery of sand–fine mixtures. These investigations resolved several inconsistencies reported in earlier studies and provided valuable insights into the behavior of natural and reclaimed soil deposits. The integration of experimental observations with numerical simulations enabled a deeper understanding of the micro-mechanical processes governing liquefaction and post-liquefaction soil behavior.

The presentation further highlights recent advances in liquefaction mitigation through induced desaturation, particularly research on air-injected desaturated sandy soils. Experimental and numerical studies demonstrated that controlled desaturation can significantly increase liquefaction resistance and reduce pore-pressure buildup during earthquake loading. The findings establish air-induced desaturation as a promising, economical, and environmentally sustainable groundimprovement technique for liquefaction mitigation. Finally, the presentation discusses emerging challenges and future research directions, including the reassessment of liquefaction triggering relationships for silt-rich soils, evaluation of re-liquefaction potential, and development of reliable methodologies for assessing liquefaction under moderate earthquakes, thereby contributing to safer and more resilient geosystems.

List of PhD students whose work is considered in the presentation

1. **Govindaraju, .L (2005)**, "Liquefaction and Dynamic Properties of Sandy Soils".
2. **Ravishankar, B.,V., (2006)**, "Cyclic and monotonic undrained behaviour of Sandy soils".

3. **Vinod. J. S. (2006)**, "Liquefaction and dynamic properties of granular materials: A Discrete element approach".
 4. **Dash, Hemanta Kumar (2008)**, "Undrained Cyclic and Monotonic Response of Sand-silt Mixtures".
 5. **Bala Reddy Muthanna (2014)**, "Liquefaction and Post liquefaction behavior of sand fines mixtures. "
 6. **Chavan, Dhanaji (2021)**, Liquefaction resistance and cyclic response of air-injected desaturated clean sandy soil: experimental and numerical investigations
- Theme:** Seismology, Earthquake Geotechnical Engineering and Microzonation

Research Advances of AI in Geotechnical Engineering

Pijush Samui

ABSTRACT

The concept of working procedures of human brain is used to develop AI. In AI, dataset is required to develop the model. The performance of AI depends on the quality & quantity of dataset. AI acquire knowledge from data for any physical phenomena. Hence, no assumption is required for the development of AI. AI can be used for classification and regression problems. In this lecture, 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), Support Vector Machine(SVM), Relevance Vector Machine (RVM), Artificial Neural Network(ANN), Histogram-based Gradient Boosting(HGB) and Naive Bayes(NB)} are used in the various fields of geotechnical engineering such as site characterization, liquefaction, shallow foundation, etc. Participants will know the use of MATLAB for development of different AI techniques. The future application of various AI will be also discussed in the field of geotechnical engineering such as Digital Twin(DT), Structural Health Monitoring(SHM), etc. This article also gives the advantages of various AI techniques. The concept of hybrid AI will also be discussed.

Theme: Computational Methods and Geomechanics

From Learning to Leading: Advances in DEM Research

Dr Vinod J S

ABSTRACT

The Discrete Element Method (DEM) has become an key tool for understanding the behaviour of granular materials through particle-scale modelling. This presentation, From Learning to Leading: Advances in DEM Research, highlights the DEM research carried out at the Indian Institute of Science to cutting-edge applications in geotechnical engineering. The first part discusses investigations into monotonic, dynamic, particle shape and wave propagation behaviour of granular materials. The second part presents recent advances in ballast breakage modelling, methane hydratebearing sediments, cone penetration testing, instability phenomena, and partially saturated soils. Together, these studies demonstrate the growing role of DEM in addressing complex geotechnical engineering challenges.

Theme: Rock Mechanics, Tailing Dams and Mining

Beyond the Mines: TGS Contributions to Rock Mechanics

Panel Discussion:

Prof. Mahendra Singh

Dr. H. S. Venkatesh

Dr. M Ramulu

Theme Presenters:

Prof. V. B. Maji

Dr. Resmi Sebastian

Dr. Vivek Padmanabha

Abstract:

Tailings dams represent some of the most critical engineering structures in the mining industry, carrying significant environmental and safety risks in the event of structural failure. This presentation reviews the extensive contributions of Prof. T.G. Sitharam to the field of geotechnical and earthquake engineering, focusing specifically on his research and consultancy work regarding the stability, design, and management of tailings impoundments. Utilizing advanced finite element modeling, conventional limit equilibrium methods, and transient seepage analyses, Prof. Sitharam's work addresses the complex challenges of managing high-volume industrial waste, including zinc tailings, red mud, and fly ash. A hallmark of his methodology is the evaluation of dam-raising techniques—such as upstream and downstream methods—under extreme environmental stressors, including high seismic activity and intense monsoon-induced rainfall. His practical applications at prominent Indian mining sites, such as the Rampura Agucha Mine and South Kalipani, demonstrate how the strategic inclusion of waste rock can accelerate consolidation, mitigate pore water pressure, and substantially enhance both static and dynamic factor of safety profiles. Ultimately, Prof. Sitharam's framework bridges the gap between theoretical soil mechanics and sustainable, resilient mining infrastructure, offering a blueprint for modern tailings dam design in seismically active and meteorologically sensitive regions.

The research on seismic wave propagation in jointed rocks is rooted in the research led by Prof. T. G. Sitharam in geotechnical earthquake engineering and rock mechanics. The presentation highlights the seismic wave propagation in jointed rock masses under long- and intermediate-wavelength conditions through an integrated programme of laboratory experimentation and numerical simulation. The study examines the influence of joint spacing, orientation, roughness, infill characteristics, wave frequency, and strain level on the transmission, reflection, attenuation, and nonlinear behaviour of seismic waves. Resonant column experiments demonstrate that joint geometry and infill materials significantly influence damping and stiffness degradation, with filled joints exhibiting substantially higher energy dissipation than frictional joints. Numerical simulations, validated against laboratory observations,

successfully reproduce wave propagation across single and multiple joints under intermediate-wavelength conditions. The study quantifies energy partitioning using transmission, reflection, and absorption coefficients, and also reveals that multiple reflections within jointed rock masses can alter transmitted wave amplitudes and that wave-mode conversion is primarily controlled by the characteristics of the incident wave. Overall, this research advances the understanding of seismic wave–joint interaction and provides experimentally validated insights for improving the seismic analysis, design, and stability assessment of rock engineering structures and underground excavations.

This presentation highlights TGS's pioneering contributions to rock mechanics, beginning with groundbreaking research on hydraulic fracturing conducted during his Ph.D. at the University of Waterloo and extending to the development of innovative shock wave-assisted rock fracturing techniques. Recognizing the limitations of conventional water-based hydraulic fracturing in clay-rich shale formations, particularly those containing swelling smectite minerals, his research introduced shock wave fracturing as a promising alternative. By utilizing high-intensity compressible gas shock waves generated in a specially designed shock tube facility, the technique delivers rapid, high-energy loading that induces dynamic tensile and shear failure without the need for water injection. The work encompasses the design and development of dedicated experimental facilities, including a vertical shock tube integrated with a triaxial confining chamber, enabling controlled investigation of fracture initiation and propagation under in-situ stress conditions. This research has laid the foundation for a safer, environmentally sustainable, and energy-efficient approach to reservoir stimulation and has opened new avenues for shock wave applications in rock engineering and unconventional resource extraction.

Professor T.G. Sitharam's pioneering contributions to blasting engineering lie at the intersection of fundamental rock mechanics, geological joint characterisation, and advanced field instrumentation. Moving beyond traditional empirical blasting formulas, his collaborative research established the "repeated vibration paradigm." This work proved that cumulative, sub-critical cyclic dynamic loading from successive production blasts progressively degrades the structural integrity of surrounding rock masses. By integrating his expertise in the equivalent continuum characterisation of jointed rock with field data from triaxial geophones, borehole extensometers, and borehole cameras, Prof. Sitharam successfully mapped how preexisting geological joint orientations dictate blast damage intensity. This research led to the development of site-specific damage-controlled attenuation models, providing critical frameworks for safely executing cyclic underground excavations and optimizing blast designs near sensitive infrastructure.

Theme: Sustainability, Social Impact and Education

Coastal Reservoir for Solving the World's Water Crisis

CR Parthasarathy

ABSTRACT

This presentation is the part of feasibility study conducted by Indian Institute of Science, Bangalore with **Prof TG Sitharam** as the principal investigator along with about other 40 scientists to explore the feasibility for constructing coastal reservoir in Arabian Sea off Mangaluru coast. This envisages storing fresh water in a reservoir along the coast by building a sea dike to impound the flood waters of Netravati River. On one side, the dike will ensure the required quantity of freshwater flow from Netravati River to the reservoir without being drained to the sea. On the other side, the sea dike will prevent seawater from entering the reservoir, avoiding the salt contamination of the freshwater supply. Present study presents detailed investigation of the soil profiles of surrounding region of Mangaluru to explore the site condition at off Ullal beach. Lithological data on the Netravati estuary were also presented with key observation on the soil profiles in the area proposed for location of coastal reservoirs. The key finding of the study is that the region offshore of Ullal is devoid of sand and is comprised mainly of soft Silty clays. Lithological data of nine foundations at Netravati Bridge near Ullal are also presented in this paper. Based on the findings of geotechnical investigations, the paper concludes that construction of sea dike in Arabian Sea off Mangaluru coast is feasible. This one pilot project is a concept to be adopted across the Indian peninsula connected with pipe line at mean sea level, which can permanently resolve the water scarcity issue. This aspect has been patented as Sarovar Mala.

Subsurface Profiling Using Multi-Parameter Ensemble and Fuzzy Clustering from GPR Data

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1 Introduction

Accurate characterization of subsurface conditions is essential for geotechnical engineering, infrastructure planning, and hazard mitigation, particularly in complex geological environments. Conventional investigation methods, such as borehole drilling and in-situ testing, provide reliable but spatially limited data and are often costly and time-intensive (Anbazhagan and Panjami, 2024). Consequently, non-invasive geophysical techniques, particularly Ground Penetrating Radar (GPR), have gained prominence for acquiring continuous and high-resolution subsurface information. In this study, subsurface profiling is carried out using GPR survey data by considering key parameters of dielectric permittivity and volumetric water content, which are critical for characterizing subsurface material properties and moisture distribution (Daniels, 2004). GPR enables detailed imaging of shallow subsurface features and is highly effective in detecting stratigraphic variations, voids, and water-bearing zones (Anbazhagan et al.2020). However, the interpretation of GPR-derived datasets remains challenging due to signal attenuation, noise, and inherent uncertainty. To address these limitations, machine learning approaches, particularly clustering techniques, are employed for objective and data-driven analysis (Delforge et al. 2021; Doyoro et al.2025). In this framework, multiple GPR-derived parameters are integrated and processed using an ensemble clustering strategy that combines K-means, Fuzzy C-means, and Gaussian mixture models. This hybrid approach leverages hard, soft, and probabilistic clustering to better capture subsurface heterogeneity. The integrated clustering results are used to generate a representative subsurface profile and compute a Subsurface Risk Index (SRI), enabling the identification of weak zones and moisture-rich regions. This methodology provides an efficient and reliable tool for improved subsurface characterization and informed geotechnical decision-making.

2 Methodology

The methodology integrates GPR-derived data, standardized using Z-score normalization and reduced for feature optimization. Cluster validation techniques guide the selection of optimal clusters. An ensemble approach combining K-means, Fuzzy C-means, and Gaussian mixture models generates a unified subsurface profile, followed by SRI computation for identifying critical zones. A detailed flow chart of the methodology is depicted in Figure 1.

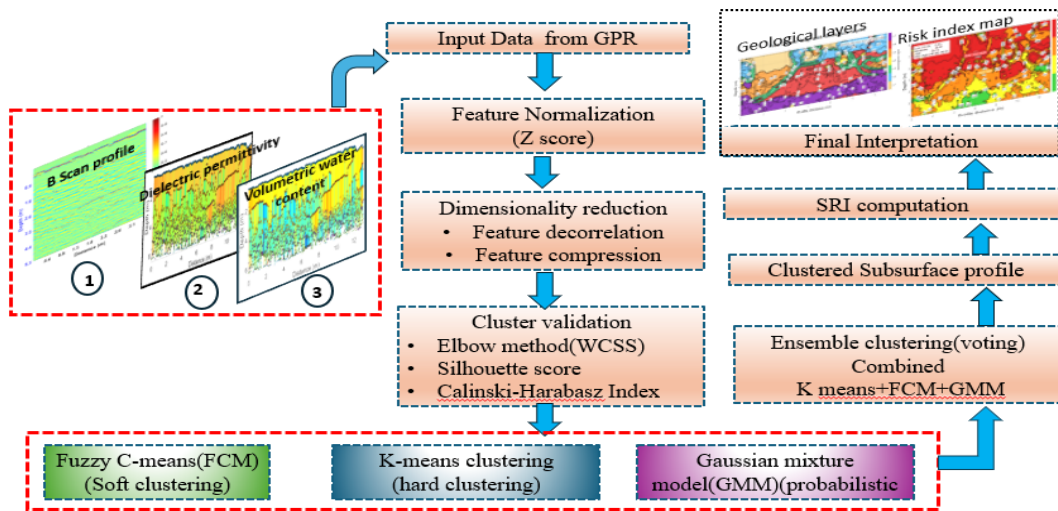


Figure 1. Flow chart showing complete methodology.

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3 Results and discussion

The study was conducted at the Central Power Research Institute (CPRI), Bangalore, over a two-layer subsurface profile consisting of a silty clay top layer underlain by bedrock, using an 80 MHz MALA GX GPR system as shown in Figure 2. GPR data were acquired in RD3 format and further processed by continuous wavelet transform based time–energy density analysis of individual traces to extract parameters such as decay characteristics and dielectric permittivity for subsequent layer identification and property estimation. Variations of dielectric permittivity and volumetric water content are plotted in Figure 3. Figure 4 presents the geological layer delineation obtained through ensemble clustering of the derived GPR parameters, clearly distinguishing subsurface strata. Figure 5 illustrates the SRI map generated using fuzzy logic, highlighting zones of varying risk based on the integrated clustering results.

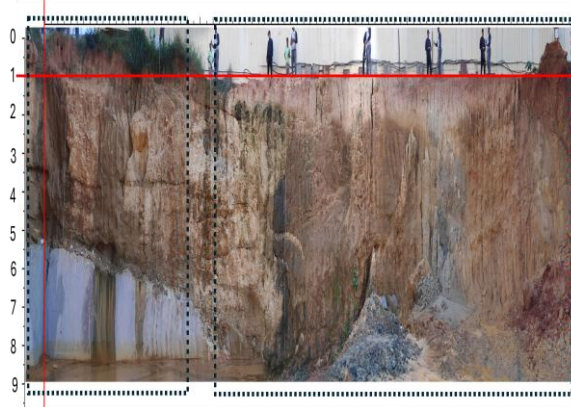


Figure 2. Survey location CPRI, Bangalore.

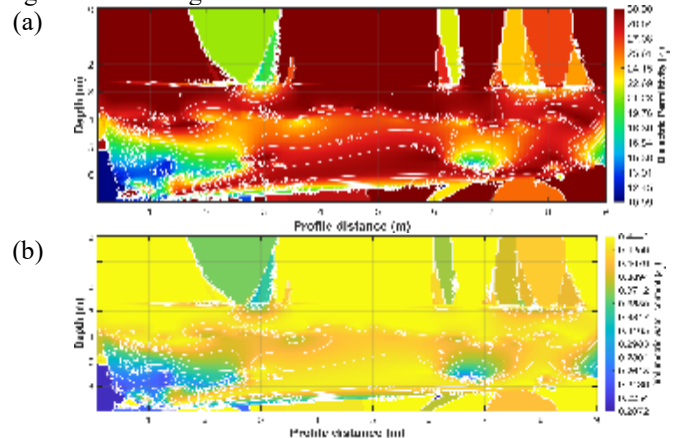


Figure 3. (a) Dielectric permittivity (b) Volumetric water content.

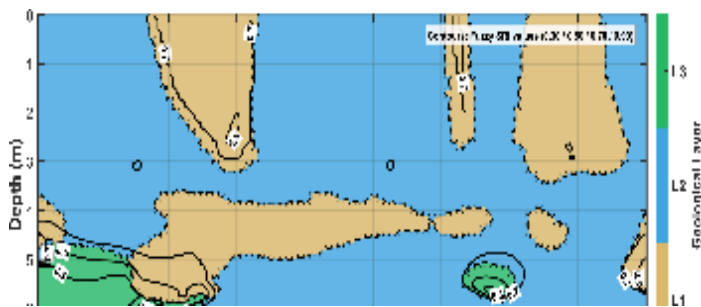


Figure 4. Geologic layers by clustering.

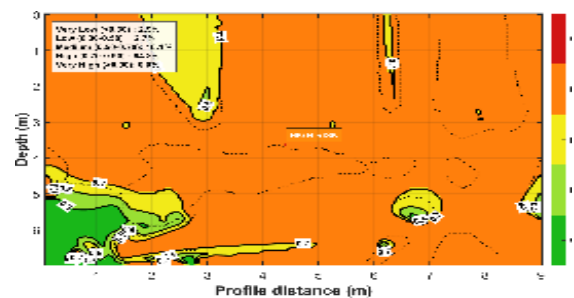


Figure 5. SRI Map of the area by fuzzy logic.

4 Conclusion

The proposed methodology effectively integrates GPR-derived parameters, of dielectric permittivity and volumetric water content, with ensemble and fuzzy clustering techniques to accurately delineate the two-layer soil profile of silty clay over bedrock. The resulting geological layer model and SRI map demonstrate the capability of the approach to identify subsurface variability and potential risk zones, providing a reliable basis for geotechnical assessment.

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Application of Nonlinear Iterative Inversion in Downhole Seismic Tomography

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1 Introduction

Traditional downhole tests (DHT) provide localized velocity profiles which do not consider any lateral changes in the subsurface. Moreover, the seismic raypath is mostly assumed to be horizontal from source to the receiver [1][2] (Figure 1a). DHT has undergone extensive development over time, with many studies focussing on improving raypath tracing under the influence of refraction, and identification of interfaces between different strata with utilization of arrival time history [1][2][3]. However, detection of changes in stiffness along the horizontal direction remains a challenge. In such cases, seismic tomography can offer a more robust framework for isolating shallow subsurface anomalies by utilizing multiple source offsets [4][5]. This abstract discusses application of an iterative inversion scheme based on two-dimensional ray tracing that accounts for raypath curvature in heterogenous subsurface media. From the waveform data collected in the field experiments, the first arrival times can be used to image the P-wave or S-wave velocity.

2 Methodology

The subsurface region is divided into a regular grid of cells. Within each cell, the velocity is interpolated between grid points using a constant gradient scheme, resulting in raypaths composed of circular segments rather than straight lines [4][5][6]. Triangular elements are utilized as they allow for the interpolation of velocity using a constant gradient scheme, enabling the analytical calculation of raypaths as circular segments. Within each triangle, the velocity is interpolated using a constant gradient scheme. This specific interpolation results in raypaths composed of circular segments that can be calculated analytically. This is far superior to rectangular cells, which often require computationally expensive numerical integration of ray equations [4]. Travel time T along a raypath Γ is calculated as the integral of slowness $u(r)$:

$$T = \int_{\Gamma} u(r) dl \quad (1)$$

The initial velocity model used to start the iterative sequence is selected by calculating the average of all straight-line apparent velocities determined from the straight distances and observed travel times of every source-receiver pair (Figure 1b). The inversion then iteratively updates the model by solving for perturbations δv using damped least-squares:

$$\delta \mathbf{T} = \mathbf{A} \delta v \quad (2)$$

where $\mathbf{A}$ is the matrix containing source-receiver and raypath geometry information, with elements $a_{ij} = \frac{\partial T_i}{\partial v_j}$. Within each iteration, first the nonlinear forward problem and then the linearized inverse problem are solved.

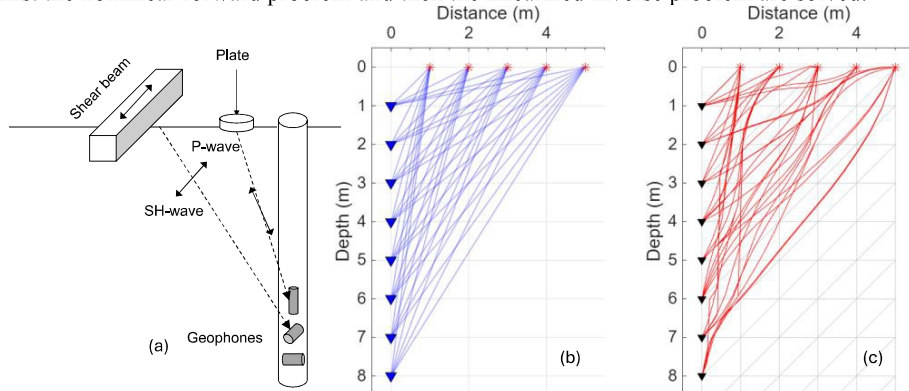


Figure 1. (a) A typical schematic of DHT (b) Initial assumption of straight raypath between source and receiver (c) Final raypaths traced after iterative inversion, showing significant refractions.

A field study was conducted at the Department of Civil Engineering, IISc, involving a downhole test up to a depth of 8m. Data was collected using five source offsets positioned at 1m, 2m, 3m, 4m, and 5m from the borehole (Figure 1b). Once the arrival times of S-waves at all the receiver depths were estimated, S-wave velocity (V_s) was estimated using single source offsets as well as tomography, as discussed further.

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3 Results and Discussion

Figure 2a shows V_s profiles for fixed source offsets when determined individually, showing the variation in V_s values as different profiles are obtained from five DHT. Seismic tomography proved superior to fixed-offset DHT by providing a wider range of raypaths (Figure 1c), and velocity anomalies. Fixed-offset tests suffered from limited raypath coverage, making it difficult to uniquely identify the lateral extent of anomalies. The V_s tomogram effectively isolated a low-velocity zone in the top 3 m corresponding to clayey and silty sand, followed by a sharp transition into weathered rock at approximately 3.5 m (Figure 2b). The resolution matrix diagonal confirmed the reliability of these results (Figure 2c), showing high-confidence values (0.6–0.7) in well-sampled regions where rays from multiple offsets intersected, while highlighting the "Ray coverage boundary" (Figure 2b) beyond which the model relied on damping and the initial guess. In this region, the model resolution is zero. Ultimately, the selection of a fine grid minimized the loss of resolution and ensured that existing features were refined, proving that tomographic inversion is superior to traditional DHT for delineating lateral heterogeneity of complex shallow subsurface profiles.

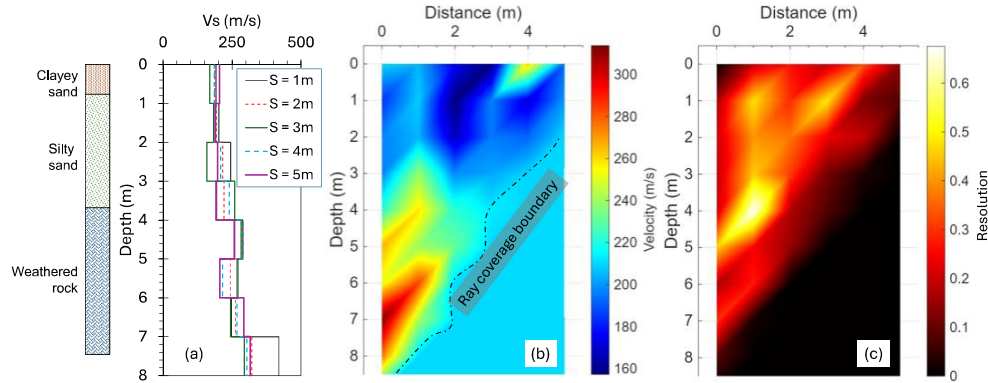


Figure 2. (a). Subsurface strata and V_s profiles from single-offset DHT (b) V_s tomogram obtained from inversion (c) Diagonal of Resolution Matrix (0 to 1) showing high resolution at maximum ray coverage

4 Conclusion

The implementation of a nonlinear iterative inversion scheme for downhole seismic tomography demonstrates significant advantages fixed-offset downhole tests (DHT) for shallow subsurface characterization. By utilizing a multi-offset DHT configuration, the method successfully isolated transition from silty sand to weathered rock. The selection of a triangular mesh enabled the use of analytical circular raypath segments to model wave propagation. Furthermore, the resolution matrix confirmed high-fidelity results in regions with dense ray intersections. This study confirms that incorporating raypath curvature and iterative updates into the downhole tomography process is highly advantageous for refining geological features. Ultimately, the downhole tomography provides a reliable and detailed velocity model, providing high-resolution geotechnical and geophysical investigations of the shallow subsurface.

5 Acknowledgements

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Machine learning–based Vs30 and f_0 mapping for seismic site characterization of the Himalayan region

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1 Introduction

Seismic site classification underpins earthquake hazard assessment, building-code implementation, and urban risk mitigation. The shear-wave velocity of the top 30 m (V_{s30}) and the site predominant frequency (f_0) jointly characterize the amplification behaviour of near-surface materials. The Himalayan region, which has hosted destructive events such as the 1905 Kangra (Mw 7.5), 1934 Bihar (Mw 8.1), 2005 Kashmir (Mw 7.6), and 2015 Nepal (Mw 7.8) earthquakes. It combines high seismicity, geological complexity, and rapidly expanding urban centres, yet existing site-classification products rely on single-parameter proxies or spatial interpolation and cannot capture the combined influence of terrain, geology, and bedrock geometry [1, 2]. This study presents an integrated framework that couples satellite-derived morphometry with geological and bedrock-depth information through stacked-ensemble machine learning to predict V_{s30} and f_0 at the regional scale.

2 Data and methodology

For V_{s30} , a database of 3,077 measurements was compiled from 39 published studies across the Himalayan region [3], spanning cross-hole, MASW, HVSr, and SPT-N correlation methods. Twelve predictors were extracted from the 30 m SRTM DEM and the regional geological map: elevation, slope, terrain ruggedness index, topographic position index, roughness, vector ruggedness measure, topographic wetness index, curvature, distance to the nearest river, morphometric class, and geological unit. For f_0 , approximately 4,400 HVSr observations from 26 studies were combined with the GLO-30 DEM, bedrock-depth [4], and geology maps, yielding 20 predictors that cover topography, terrain indices, landform class, hydrology, and subsurface information. For both tasks we adopted a stacked-ensemble architecture. For V_{s30} , bagged trees, boosted trees, and exponential Gaussian process regression base learners are combined through a meta-learner. For f_0 , a two-stage regression-kriging scheme is adopted: a tree-ensemble stack captures the nonlinear terrain–frequency relationship, and ordinary kriging of the residuals recovers residual spatial structure. Bayesian optimization was used to tune hyperparameters in both cases, and 5-fold cross-validation with a held-out test partition was used to ensure unbiased evaluation.

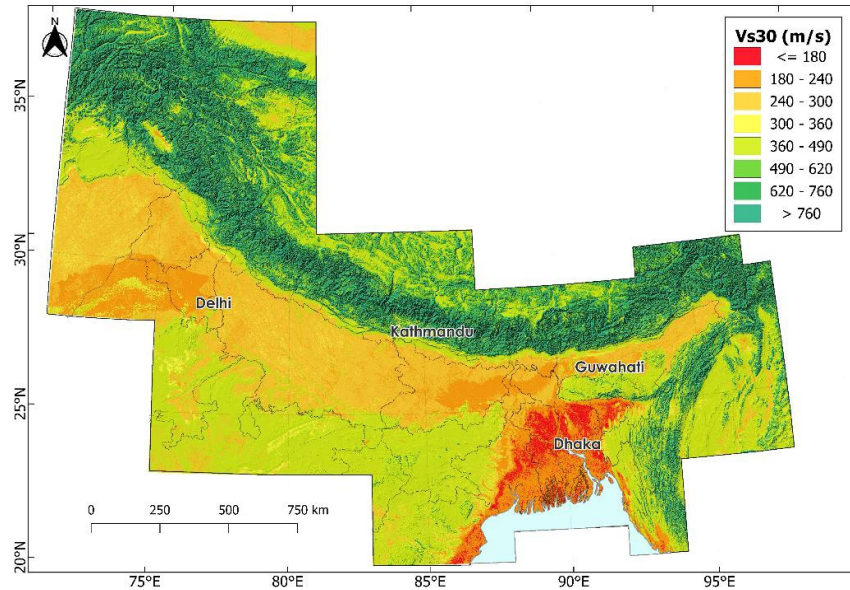


Figure 1. Predicted V_{s30} (m/s) map of the Himalayan region at 1 km resolution

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3 Results

The Vs30 stacked ensemble achieves RMSE = 78.3 m/s, $R^2 = 0.38$, and MAE = 53 m/s on the independent test set; a 64.6% MAE reduction and 52.6% RMSE reduction relative to the Allen and Wald slope proxy [1], with the largest gain (80.5%) in the 180–259 m/s range that dominates urban soil sites. SHAP analysis identifies elevation, geology (Quaternary sediments and Precambrian rocks), roughness, and VRM as the dominant predictors. Regional maps at 1 km (Fig. 1) and urban-scale maps at 50 m were produced for Delhi, Dhaka, Kathmandu, and Guwahati. The f_0 model attains R^2 values of 0.509–0.553 and RMSE values of 0.587–0.633 across folds. Variogram analysis of residuals reveals structured variance (52% of total) over a 7.3 km range, validating the regression-kriging step. Multiresolution valley-bottom flatness, Precambrian-rock presence, elevation, and bedrock depth emerge as the leading predictors. High-resolution f_0 maps (Fig. 2) differentiate deep sedimentary basins ($f_0 < 1.0$ Hz) from bedrock-controlled zones ($f_0 > 3.0$ Hz).

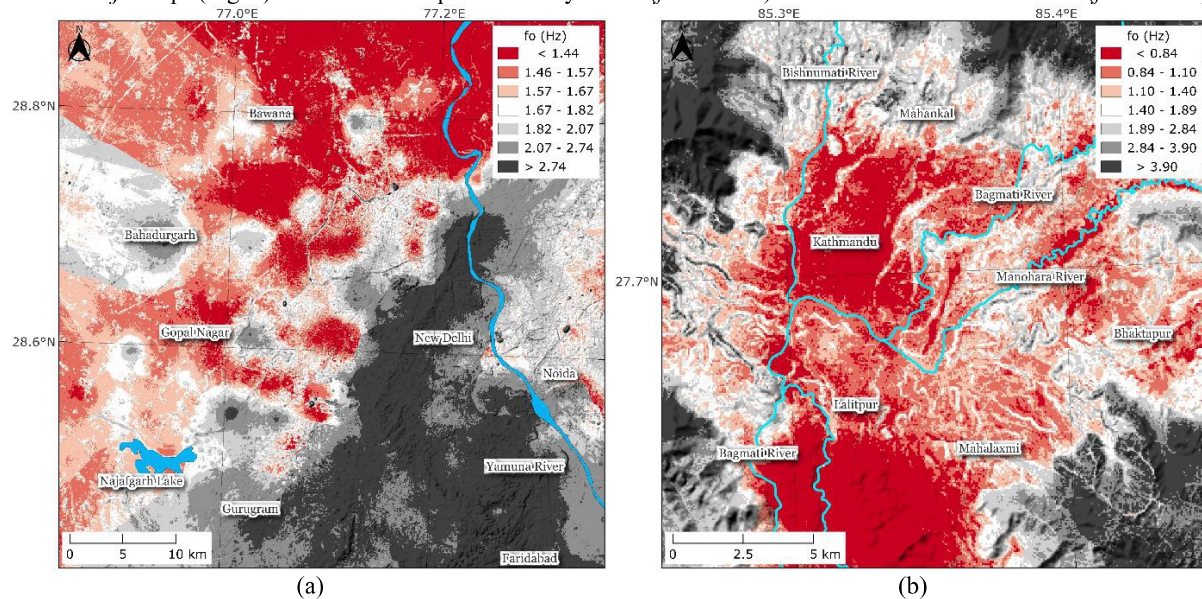


Figure 2. f_0 (Hz) maps at 50 m resolution for (a) Delhi and (b) Kathmandu

For site characterization, Vs30 quantifies mean subsurface velocity, whereas f_0 captures the resonant response of sedimentary deposits over bedrock. Their shared dependence on geology and morphometry justifies using satellite-derived inputs in data-sparse terrain.

4 Conclusion

Integrating DEM-derived terrain morphometry with geological and bedrock-depth information via stacked-ensemble learning delivers a robust, cost-effective framework for regional seismic site characterization. The Vs30 and f_0 models outperform single-parameter proxies across diverse terrain types and yield high-resolution maps directly usable for hazard zonation and building-code implementation. Future work will integrate higher-resolution geology, transfer learning for data-sparse sub-regions, and a unified Vs30– f_0 classification scheme.

5 Acknowledgements

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Energy-Dependent Behaviour of SPT N-Values: Insights from Simultaneous Measurement of Hammer Efficiency and Shear Wave Velocity

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1 Introduction

The Standard Penetration Test (SPT) is widely used in geotechnical investigations, where the measured N-value is commonly adopted to estimate soil properties and develop empirical correlations [1–3]. However, the reliability of SPT results is strongly influenced by hammer energy transfer, which varies significantly due to differences in equipment configuration and field practices [4, 5]. Despite this, most existing correlations, including those relating N-value to shear wave velocity (V_s), do not explicitly consider energy transfer efficiency [6]. This can lead to an inconsistent interpretation of soil properties. The present study investigates the influence of measured hammer energy on SPT N-values and examines its implications on N- V_s correlations using simultaneous field measurements.

2 Field Investigation and Methodology

A comprehensive field investigation program was conducted in which Standard Penetration Test (SPT) measurements with direct hammer energy recording were performed alongside shear wave velocity (V_s) profiling using Multichannel Analysis of Surface Waves (MASW). The study was carried out across multiple sites in the peninsular region of India, covering a range of subsurface conditions.

Hammer energy was measured using the SPT-Hammer Energy Measurement Apparatus (SPT-HEMA), in accordance with ASTM D4633 (2016) [7]. The system consists of instrumented rods equipped with force and acceleration sensors, enabling acquisition of high-frequency time-history data during each hammer blow. The recorded signals were processed to obtain force, velocity, and corresponding energy transfer characteristics.

Energy transfer efficiency was quantified as Energy Transfer Ratio (ETR). The energy was evaluated using two approaches: (i) the conventional force-velocity (FV) method based on a fixed integration time window, and (ii) the force-velocity change-in-direction (FVCD) method, in which energy is computed up to the first reversal of force or velocity, representing the effective energy transfer [8–10].

Shear wave velocity profiles were obtained using MASW, with multiple geophones arranged linearly along the ground surface and an impulsive source used to generate surface waves. The acquired data were processed to obtain dispersion curves and corresponding V_s profiles at locations coinciding with SPT boreholes.

A substantial dataset comprising multiple boreholes and a wide range of N-values and ETR conditions was analysed to ensure a representative evaluation of energy effects on SPT- V_s correlations.

3 Results and Discussion

The measured N-values exhibit significant variation with changes in energy transfer efficiency (ETR), confirming the strong dependence of penetration resistance on hammer energy. The dataset was categorised into different ETR ranges, and a consistent trend was observed wherein lower energy levels correspond to higher measured N-values and vice versa. This behaviour highlights the inherent variability introduced by field energy conditions.

In contrast, the corresponding shear wave velocity (V_s) profiles remain relatively stable for similar soil strata, indicating that soil stiffness is largely independent of variations in hammer energy. This fundamental difference leads to inconsistencies in conventional N- V_s correlations when energy effects are neglected.

The FVCD method was adopted in this study as it captures the effective energy transfer over the actual penetration duration and has been shown to provide more reliable estimates compared to the conventional FV approach [8]. A comparative analysis of N- V_s and energy-corrected N_{60} - V_s relationships, based on FVCD-derived energy, shows that uncorrected N-values exhibit significant scatter with poor correlation trends, whereas energy-corrected N_{60} values demonstrate improved and more consistent relationships with V_s , as shown in Figure 1. This is reflected in the improved coefficient of determination (R^2) for N_{60} - V_s correlations across different ETR ranges. In each ETR range, the energy-corrected N_{60} shows a more consistent correlation with V_s than the measured N-value. These results clearly indicate that incorporating energy correction enhances the reliability of SPT-based correlations.

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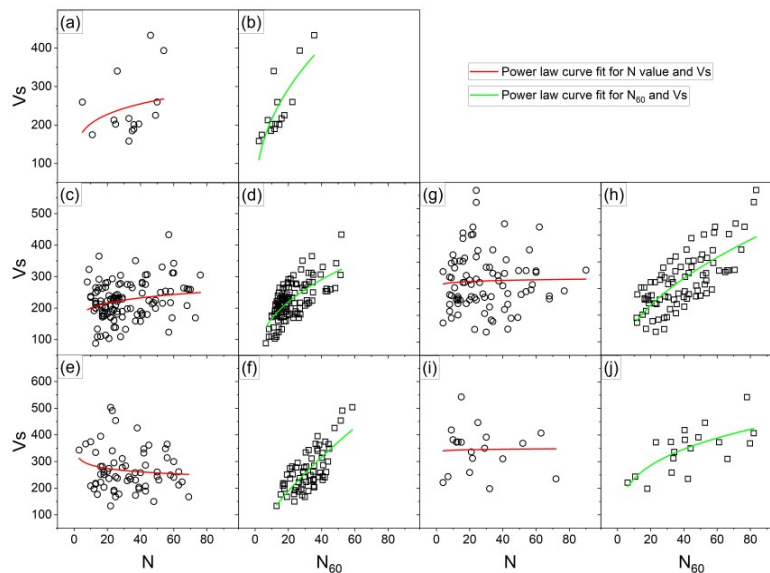


Figure 1. Comparison of N-Vs and N_{60} -Vs relationships within different ETR ranges: (a, b) 15-30%, (c, d) 30-50%, (e, f) 50-70%, (g, h) 70-90%, and (i, j) >90%.

4 Conclusions

Based on the analysis, the key conclusions of this study are as follows:

- Measured SPT N-values show significant dependence on hammer energy transfer efficiency (ETR).
- Shear wave velocity (V_s) remains relatively consistent for similar soil conditions, indicating that soil stiffness is largely unaffected by variations in hammer energy.
- Uncorrected N-Vs relationships exhibit considerable scatter, whereas energy-corrected N_{60} -Vs correlations show improved consistency and stronger correlation trends across different ETR ranges.
- Incorporating measured energy and FVCD method into SPT analysis is essential for reliable interpretation and for developing more robust N-Vs correlations in geotechnical practice.

5 Acknowledgements/Funding sources

The authors thank the Dam Safety (Rehabilitation) Directorate, Central Water Commission for funding the project entitled “Capacity Buildings in Dam Safety” under Dam Rehabilitation and Improvement Project” M/s Secon for funding Project “Effect of shear wave velocity calibration on Amplification of shallow and deep soil sites” Ref: SECON/IISc/MoES/VO/07-18/0079 date.14/8/2018. The authors also thank Mr Suhas, Mr Sirivanth and Mr Vishwas, Project Interns and Mr Ravinesh Kumar, Research Associate, Department of Civil Engineering, Indian Institute of Science, for their assistance in field tests and processing of acquired field data.

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Evolution of Seismic Zonation and Design Response Spectra in IS 1893: A Critical Review

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1 Introduction

Seismic design practices in India have evolved significantly through successive revisions of IS 1893 following the 1934 Bihar–Nepal earthquake [1]. While several historical structures in India have withstood major earthquakes, there exists limited documented evidence of systematic seismic design prior to codification. The first formal seismic code, IS 1893:1962, was developed based on global practices and limited regional data, with provisions intentionally kept flexible for future revisions [2]. The code emphasises that structures designed as per its provisions should withstand moderate earthquakes without damage and severe earthquakes without collapse, although these intensity levels were not explicitly quantified in early versions. Over time, revisions have incorporated improved understanding of seismic hazard, soil behavior, and structural dynamics, particularly after significant earthquakes such as Latur (1993), Jabalpur (1997), and Bhuj (2001). This study aims to systematically compare the evolution of seismic zonation, soil classification, and design response spectra in IS 1893 (1962–2016), and to evaluate their implications on seismic demand and design consistency in India.

2 Evolution of Seismic Zonation

The seismic zonation of India has undergone substantial transformation over the past six decades, reflecting advances in understanding seismic hazard. Early zonation maps (1962, 1966) were based on historical earthquake intensities, tectonic considerations, and macroseismic observations, with certain regions classified under Zone 0, indicating negligible seismic risk [2,3]. However, subsequent earthquakes in these regions demonstrated the inadequacy of such classifications, leading to the removal of Zone 0 in the 1970 revision. Revisions in 1975 and 1984 introduced incremental improvements but continued to rely primarily on historical seismicity. A major advancement occurred in the 2002 revision, in which zonation was simplified to four seismic zones (II–V) and associated with defined zone factors (Z) corresponding to the Maximum Considered Earthquake (MCE). This framework was retained in the 2016 revision with improved clarity and consistency. Despite these developments, seismic zonation in IS 1893 remains largely based on past earthquake records and observed intensities, with limited incorporation of potential fault rupture characteristics, strain accumulation within probable rupture zones, and probabilistic seismic hazard assessment [4,6] to meet future requirements.

3 Evolution of Soil Classification and Site Effects

The representation of site conditions in IS 1893 has evolved from simplistic empirical approaches to more refined geotechnical classifications. Early versions (1962, 1966) classified soils based on bearing capacity, assuming negligible settlement under seismic loading, which limited their applicability for soils prone to deformation or liquefaction. The 1970 revision introduced classification based on Standard Penetration Test (SPT) N-values, providing a better representation of soil stiffness and strength. Soils were categorized into three types: rock/hard soil, medium soil, and soft soil, with subsequent revisions (1975, 1984) retaining similar classifications with minor refinements. Significant improvements were introduced in the 2002 and 2016 versions, where soil classification was standardized (Type A, B, C) and directly linked to spectral amplification, enabling better incorporation of site effects. However, current provisions remain simplified and do not explicitly consider layered soil profiles, nonlinear soil behaviour, liquefaction potential, or basin effects [4]. Additionally, regional variability in subsurface conditions across India is not fully addressed. Therefore, while code-based classification provides a practical framework, site-specific investigations and ground response analyses are essential for reliable seismic design [5,6].

4 Evolution of Design Response Spectra

Design response spectra in IS 1893 have evolved from empirical representations to standardized formats suitable for engineering design. Early versions (1962–1970) provided average acceleration spectra with multiple damping levels (0–20%), leading to inconsistencies in application. The 1975 and 1984 revisions introduced the response spectrum method and normalized spectral acceleration (S_a/g), marking a transition toward dynamic analysis. A major advancement occurred in 2002, when a standardized design response spectrum for 5% damping was introduced, with clearly defined

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spectral shapes for different soil types. This included a plateau of constant acceleration (~ 2.5 Sa/g), which significantly influenced seismic force estimation. The 2016 revision retained the same spectral framework but improved clarity by introducing separate spectra for different analysis methods (2A and 2B). While these developments have enhanced consistency and usability, the spectra remain generalised and do not fully capture regional ground motion characteristics, attenuation behaviour, or site-specific amplification effects [7,8]. Incorporating strong-motion records and region-specific attenuation models can further improve spectral accuracy and reliability. A comparative summary of the evolution of code-based design provisions is presented in Table 1; however, recent studies indicate that region-specific spectral models are necessary for improved seismic design[8].

Table 1. Comparative Evolution of Seismic Zonation and Design Spectra in IS 1893

Aspect	1962 / 1966	1970 / 1975 / 1984	2002	2016
Seismic Zonation Basis	Intensity-based using historical and macroseismic data (Zone 0 included)	Modified intensity-based; Zone 0 removed with improved regional understanding	Hazard-based zonation with defined zone factors (Z) based on MCE	Same as 2002 with improved clarity and consistency
Number of Zones	Included Zone 0	Zone 0 removed; ~ 5 zones	4 zones (II–V)	4 zones (II–V)
Design Approach	Static force-based design	Static + early dynamic considerations	Response spectrum-based design	Refined response spectrum methods
Response Spectrum Representation	Absolute acceleration with multiple damping curves	Introduction of response spectrum concept	Standardized normalized spectrum (Sa/g)	Same spectral form with improved application (2A & 2B)
Spectral Characteristics	Irregular, non-uniform spectra	Improved but still complex	Smooth spectrum with constant acceleration plateau (~ 2.5 Sa/g)	Similar shape with an extended period range
Soil Classification Basis	Bearing capacity-based classification	SPT N-value-based classification	Standardized soil classes (Type I, II, III)	Refined classification (Type A, B, C)
Soil Effect Representation	Minimal consideration	Limited inclusion	Explicit spectral amplification based on soil type	Same as 2002 with improved clarity
Consideration of Future Seismicity	Not included	Limited	Semi-rational; based on past seismicity	Similar limitations persist
Major Limitation	Lack of data and unclear definitions	Still largely empirical	Generalized spectra	Lack of site-specific and regional spectra

5 Conclusion

The IS 1893 reflects significant progress in seismic design philosophy in India, transitioning from empirical approaches to more rational and standardized methods. The introduction of improved hazard estimation, soil classification, and normalized response spectra has enhanced design consistency and safety. However, limitations remain in terms of site-specific hazard characterization, regional seismic variability, and region-specific design spectra. Future revisions should focus on integrating probabilistic seismic hazard analysis, region-specific spectra, and advanced site response modeling to improve the accuracy and reliability of seismic design in India.

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Settlement Analysis of Transformer Yard Foundation in Thin Layer Soil

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1 Introduction

The structural stability of electrical transformer foundations is a critical requirement for the operational continuity of high-voltage power distribution networks. Unlike conventional residential or commercial structures, where settlement tolerances are relatively flexible, transformer units are exceptionally sensitive to even minor geometric instabilities. The presence of rigid busbars, high-tension cabling, and sensitive cooling systems requires a stringent permissible settlement threshold, typically set at 25 mm for total settlement and 15 mm for differential settlement. Any deviation from these limits risks of the rupturing electrical connections, oil leaks, and subsequent catastrophic system failure (IS 10028: Part 1). This study focuses on the PB Transformer Yard, where significant post-construction settlement was reported. The investigation seeks to determine the root cause of this deformation by integrating comprehensive field geotechnical data with high-fidelity three-dimensional finite element modeling to simulate the long-term behavior of the foundation system under operational loads.

2 Site Characterization and Material Properties

The subsurface investigation at the Transformer Yard involved a systematic field program comprising six auger boreholes and three trial pits as shown in Fig. 1(i). The stratigraphic profile consistently identified a surficial layer of reddish-brown silty sand with gravel extending to a depth of approximately 1.8 m. This layer is characterized as poorly compacted fill material, exhibiting Standard Penetration Test (SPT) N-values as low as 4, indicating a very loose to medium-dense state. Underlying this compressible stratum is a competent layer of soft disintegrated weathered rock. Laboratory testing confirmed that the fill material possesses high compressibility and a low coefficient of consolidation, rendering it highly susceptible to both immediate and time-dependent settlement. The primary geotechnical parameters derived for the numerical analysis are summarized in Table 1.

Table 1. Geotechnical Parameters for Numerical Analysis

Stratum	Model	$\gamma_{sat}(\text{kN/m}^3)$	E (MPa)	c' (kPa)	ϕ'	e_0	C _c	C _r	C _{α}
Layer 1	SSC	19.8	3.6	0.27	9	0.63	0.095	0.019	0.029
Layer 2	HS	20.0	16.8	0.00	34	0.60	-	-	-

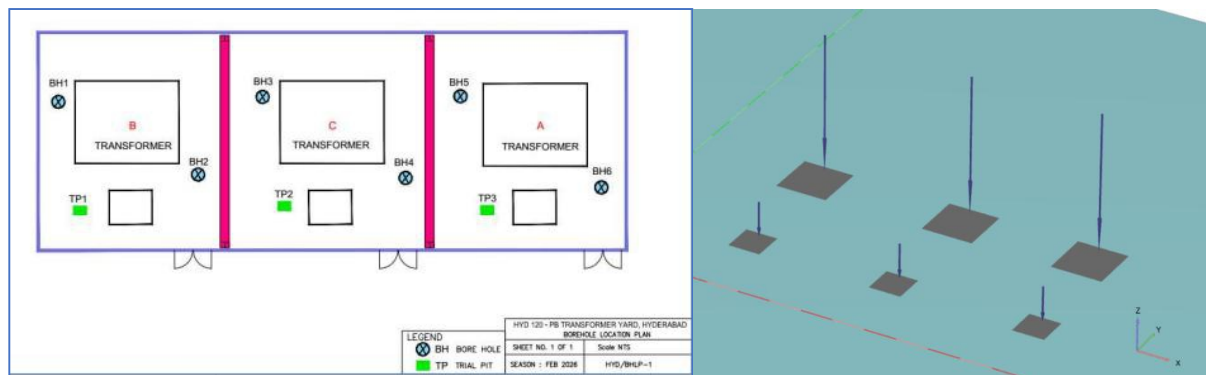


Fig. 1: (i) Transformer and Concrete Deck drawing from the site (ii) PLAXIS 3D model as per site dimensions

3 Numerical Modelling

The complexity of the compressible soil layer and overlapping stress zones necessitated the use of PLAXIS for a comprehensive soil-structure interaction analysis. The foundations were modeled as 1.6 m x 1.6 m isolated square footings at an embedment depth of 1.0 m 3D as shown in Fig. 1(ii). The constitutive behavior of the weathered rock was captured using the Hardening Soil (HS) model, which accounts for stress-dependent stiffness and plastic yielding. For the upper compressible silty sand, the Soft Soil Creep (SSC) model was implemented to specifically analyze the time-dependent

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secondary compression (PLAXIS Manual 2024a), which is often a dominant factor in uncompacted fill materials. The loading phase simulated the operational load by applying a distributed load of 60 kN/m² for the main transformer unit and an adjacent load of 10 kN/m² representing the concrete deck area. A fine volumetric mesh was generated to ensure convergence in high-stress gradient regions, and the simulation was conducted over a ten-year temporal zone, considering the almost straight line after that to observe the progression of settlement and the development of the pressure bulb.

4 Results and Discussion

The numerical results revealed a maximum total settlement of approximately 160 mm (Fig. 2(i)) for a time period of 10 years, which closely aligns with the analytical estimate of 153 mm derived from IS 8009 Part 1 methodology, considering the immediate and secondary consolidation settlement. This value exceeds the permissible limit of 25 mm by more than six times, indicating a significant design inadequacy. The SSC model indicates that settlement develops gradually, with the settlement-time response showing that most deformation occurs within the first decade of operation, followed by a reduced, minimal rate of settlement. The displacement contours (Fig. 2(ii)) show settlement beneath each footing, including the contribution from creep deformation. The effective stress distribution (Fig. 2(iii)) shows that the 60 kN/m² applied load generates a pressure bulb that fully penetrates the 1.8 m thick weak fill layer. Due to the low stiffness and limited confinement of the silty sand, stresses also spread laterally while dissipating vertically. The stress influence zones of adjacent transformer foundations also overlap, similar to the pressure bulb pattern, indicating interaction between neighbouring units within the transformer yard and increasing stresses within the compressible layer, which may lead to differential settlement. No influence of the concrete deck on the transformer foundations was observed in either the stress distribution or the pressure bulb, suggesting that it does not contribute to additional settlement. Since the footing is located only 0.8 m above the weathered rock interface, loads are transferred through the most compressible portion of the soil profile, confirming that the loose fill layer governs the observed settlement behaviour.

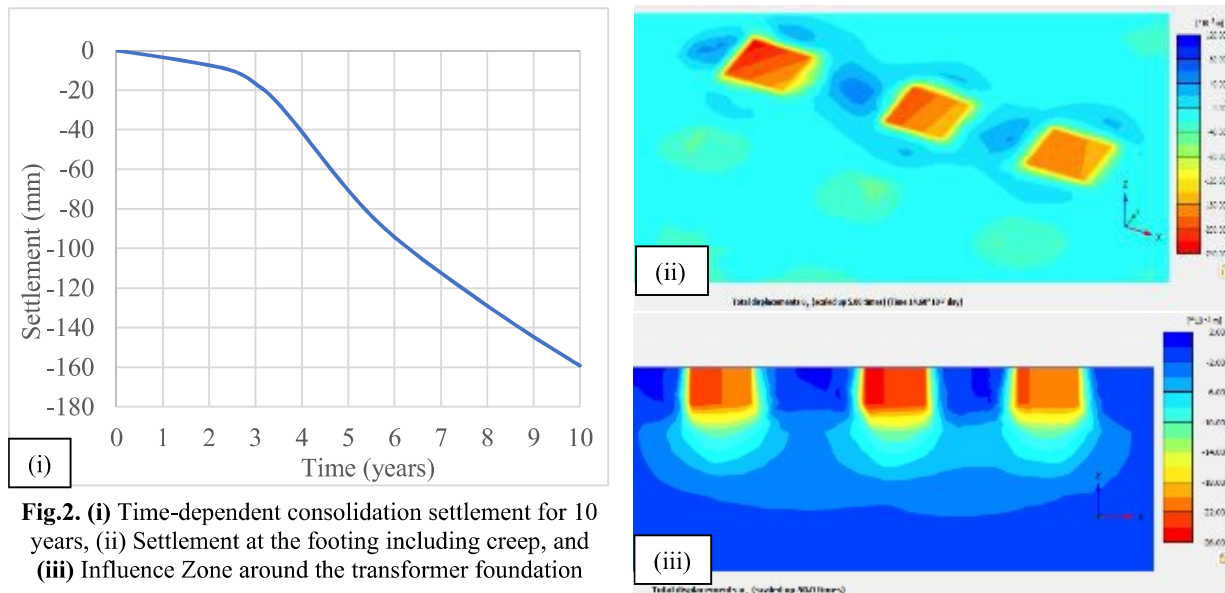


Fig.2. (i) Time-dependent consolidation settlement for 10 years, (ii) Settlement at the footing including creep, and (iii) Influence Zone around the transformer foundation

5 Conclusion

The forensic numerical analysis of the Transformer Yard confirms that the existing foundation design is inadequate for the high-sensitivity equipment due to its placement on uncompacted fill. To mitigate the risk of electrical field disasters, future designs must ensure that foundations penetrate the entire thickness of the fill material to rest directly on the weathered rock at a minimum depth of 2.0 m with an embedment of 0.5 m. For the existing Transformer Yard, ground improvement via cementitious pressure grouting or equivalent methods is recommended to enhance the stiffness of the silty sand layer. Furthermore, the installation of high-precision settlement markers at the corners of each footing is mandatory to monitor for differential tilting. These measures are essential to achieve a near-zero settlement condition required for the long-term operational safety of the transformer infrastructure.

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Nearshore Karst Hazards in Coastal Sediments: Geophysical Delineation from the Coromandel Coast, India

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1 Introduction

Nearshore coastal zones are highly susceptible to subsurface instability due to karstification within unconsolidated sediments (Ford and Williams, 2007). Along the Coromandel Coast, buried karst effects such as dolines pose significant risks to coastal infrastructure and groundwater systems. This study integrates two-dimensional Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW) to delineate subsurface karst hazards (McGrath et al., 2002; Anbazhagan and Panjani, 2024). ERT identifies resistivity contrasts associated with dissolution features and voids (Arandjelovic, 1966), while MASW detects buried dolines via low shear-wave velocity (V_s) anomalies, thereby improving characterisation of nearshore subsurface conditions.

2 Methodology

The site was selected based on surface elevation variations indicative of doline formation identified from field observations from the nearshore. 2D ERT delineated subsurface heterogeneity and aquifer geometry, while MASW detected low V_s anomalies associated with buried dolines. Figure 1 represents a detailed flowchart of the methodology.

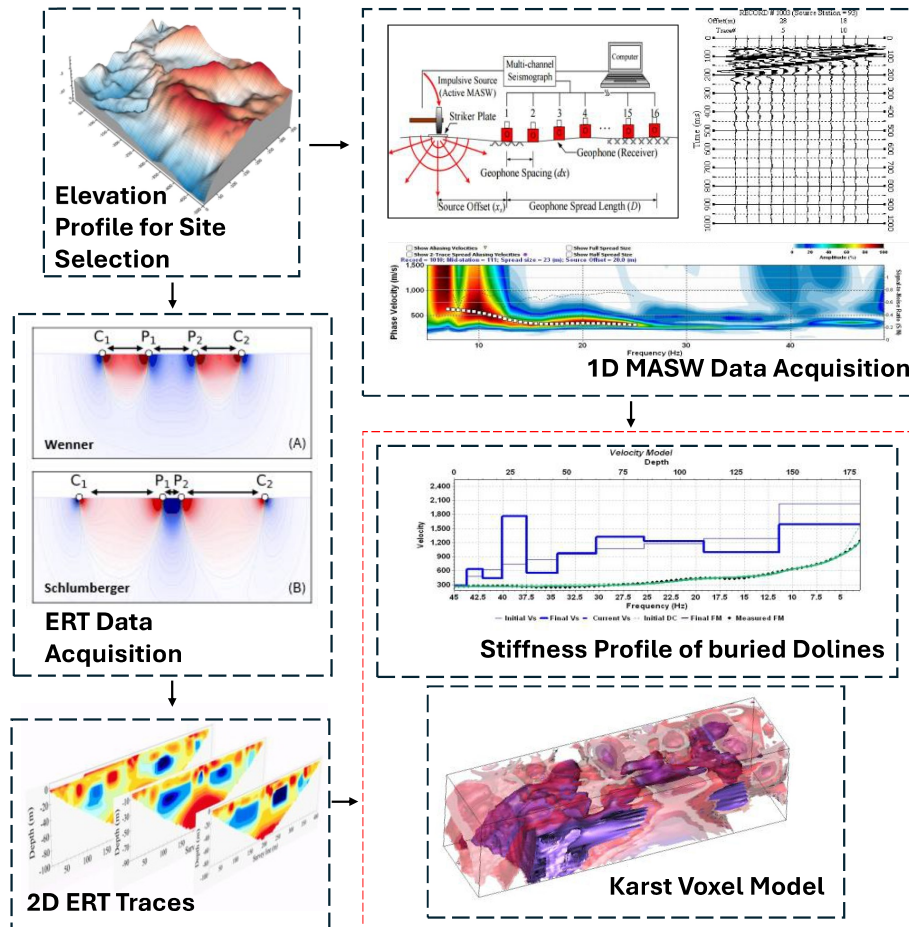


Figure 1. Flow chart showing complete methodology.

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3 Results and discussion

The study was conducted in the nearshore region of the Coromandel Coast, India, over red silty sand underlain by fossiliferous limestone followed by a marlstone bed. 2D ERT data were acquired using Wenner and Schlumberger arrays along multiple parallel lines, revealing deep karst aquifer anomalies (Figure 2). Multiple profiles were integrated to generate a resistivity-based Voxler model that shows the phreatic aquifer pathway (Figure 3). Figure 4 shows Vs variation with depth for buried doline (S1-S3) and non-doline regions (NS1-NS3), indicating differences in subsurface soil stiffness above the underlying karst. The results suggest that nearshore subsurface karst, developed within the underlying fossiliferous shell limestone, forms cavities and conduits that host irregular phreatic flow paths, reducing overlying soil stiffness in areas of subsidence. Coastal influences such as tidal fluctuations, saline intrusion, and freshwater mixing further enhance dissolution, contributing to subsidence and instability in these zones.

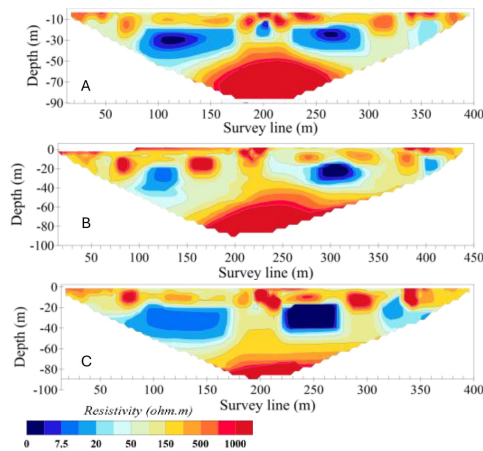


Figure 2. (A-B) Multiple 2D Resistivity Tomograms

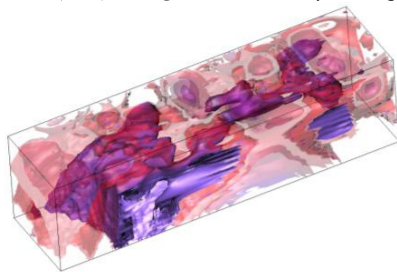


Figure 2. Resistivity based Voxel model of underlying Karst showing the phreatic aquifer.

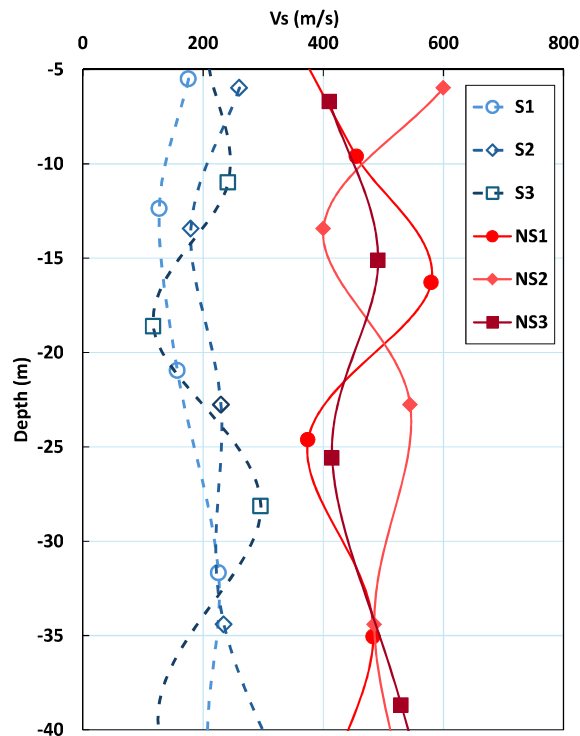


Figure 4. Plot showing the Vs profiles of Doline (S) and Non-Doline regions (NS).

4 Conclusion

The Integrated geophysical investigation using 2D ERT and MASW effectively delineated subsurface karst hazards in the nearshore environment of the Coromandel Coast, India. ERT-derived resistivity models revealed aquifer geometry and dissolution features, while MASW identified buried dolines through low shear-wave velocity zones. The results highlight significant subsurface instability, emphasizing the need for careful geotechnical evaluation and hazard mitigation in coastal infrastructure planning.

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Evaluation of Seepage-Induced Softening in Earthen Dams Using ERT and MASW

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1 Introduction

Earthen dams are among the most often utilized hydraulic structures globally, and their safety is heavily influenced by the hydraulic and mechanical properties of embankment materials. Seepage through such dams is frequent; nevertheless, uncontrolled or concentrated seepage can increase saturation, reduce effective stress, and cause materials to soften over time, potentially leading to internal erosion and structural instability. As a result, identifying seepage paths and determining their impact on material stiffness is critical for assessing dam safety. Previous studies have mostly used geotechnical and geophysical methodologies to explore seepage after its surface manifestation (Panthulu et al. 2001; Rozycki et al. 2006; Bolève et al. 2011; Ikard et al. 2015; Guo et al. 2022). In this study, an integrated geophysical investigation was conducted at the Kabini Dam in Karnataka, India, to delineate seepage-affected zones and quantify seepage-induced softening using non-invasive techniques such as Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW). Two-dimensional ERT surveys were carried out along the crest and slope using the Wenner-Schlumberger array, which provides the most effective balance of lateral and vertical resolution for detecting moisture fluctuations caused by seepage. The generated resistivity sections represent the embankment's internal hydraulic conditions. MASW surveys were conducted along the crest at chainage 1200 m to assess shear wave velocity (V_s), which is a measure of material stiffness. The data was collected using 24 geophones (4.5 Hz) spaced 1 m apart with a source offset of 15 m. The integrated interpretation of ERT and MASW results reveals a clear correlation between low resistivity and reduced V_s , indicating seepage-induced softening and demonstrating the effectiveness of combined geophysical methods for assessing dam integrity.

2 Methodology

An integrated geophysical approach combining ERT and MASW was used to assess the dam's internal condition. ERT surveys were conducted using a multi-electrode system to obtain 2D resistivity profiles, identifying moisture-rich and potential seepage zones. MASW surveys were performed along the same alignment to derive shear wave velocity (V_s) profiles from dispersion analysis, representing material stiffness. The integration of ERT and MASW data enabled a correlation between hydraulic anomalies and mechanical properties, with low resistivity and reduced V_s zones indicating seepage-affected and weakened dam areas. The detailed ERT and MASW survey procedure is illustrated in Figure 1.

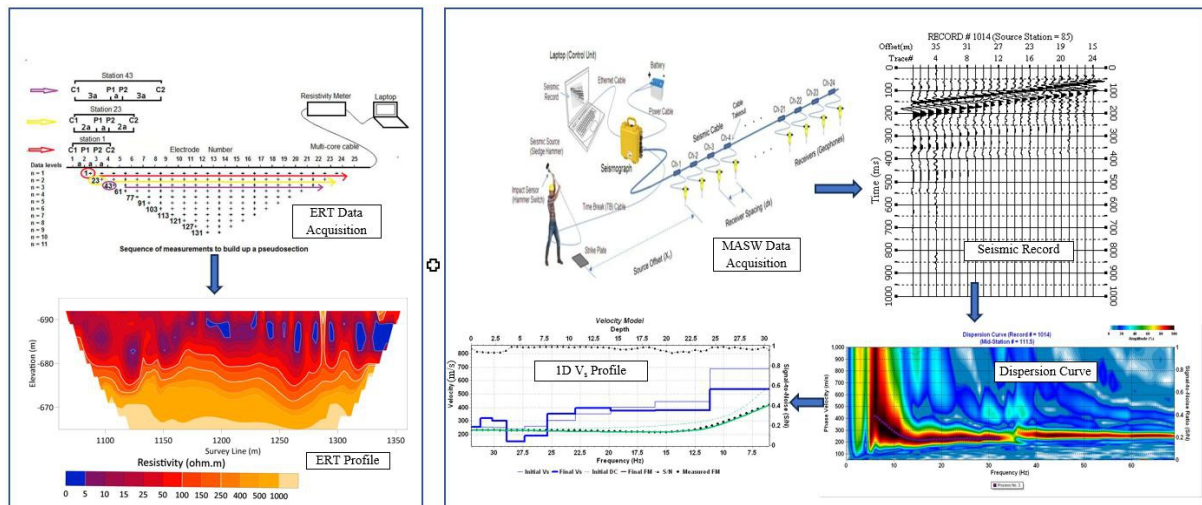


Figure 1. An illustration of the ERT and MASW survey procedure.

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3 Results and discussion

ERT and MASW were conducted to evaluate the hydraulic and mechanical conditions of the earthen dam (Figure 2). The inverted ERT results (Figure 3) identified distinct low-resistivity zones ($0\text{--}20\ \Omega\cdot\text{m}$) within the embankment, which are interpreted as moisture-rich seepage pathways, while higher resistivity values ($>80\ \Omega\cdot\text{m}$) represent relatively dry and intact regions. Based on the continuity and intensity of these anomalies, a representative location at chainage 1200 m was selected for detailed MASW investigation. The dispersion characteristics obtained from MASW data (Figure 1) were inverted to derive shear wave velocity (V_s) profiles (Figure 4), which show a significant reduction (120–180 m/s) in seepage-affected zones compared to higher V_s values (250–350 m/s) in non-seepage areas. The combined V_s –resistivity correlation (Figure 5) clearly indicates seepage-induced softening of the embankment material.

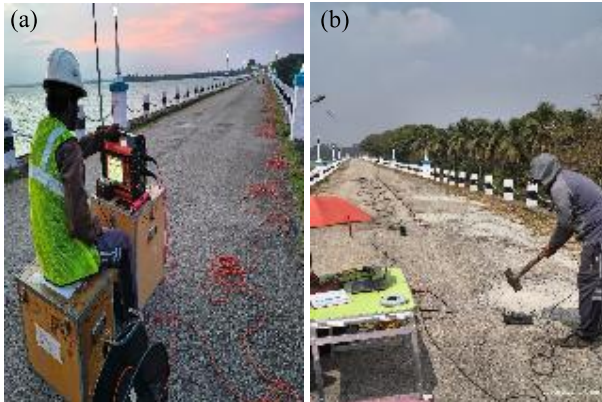


Figure 2. (a) ERT and (b) MASW survey at the Kabini Dam site.

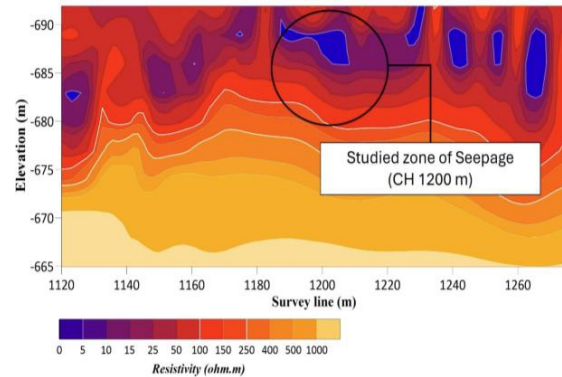


Figure 3. Inverted 2D ERT section showing seepage zones.

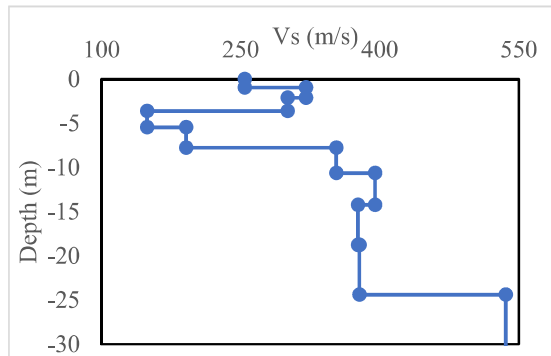


Figure 4. 1D MASW V_s Profile at Ch. 1200m.

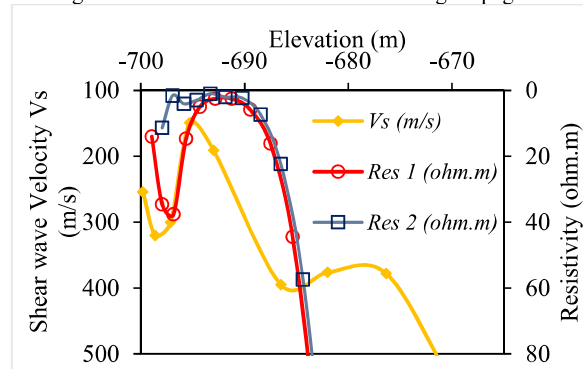


Figure 5. Correlation of low resistivity and reduced V_s .

4 Conclusion

The integration of ERT and MASW provides a reliable, non-invasive method for detecting seepage zones and resulting material stiffness losses in earthen dams. Regions with low electrical resistivity have a substantial correlation with zones with lower shear wave velocity, indicating a clear link between seepage and stiffness deterioration. These findings demonstrate that geophysical approaches are highly effective for assessing the internal condition and integrity of dam structures.

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Development of Sustainable Self-Healing Concrete Using Carbon-Negative Material and Watermelon Seed Based Bio-cementation

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ABSTRACT

This study investigates the self-healing performance of concrete incorporating a carbon-negative material (CNM) formulated from an industrial powder blend consisting of 60% iron powder, 20% glass powder, 8% limestone powder, 10% metakaolin, and 2% oxalic acid. CNM was used as a partial replacement of cement at substitution levels of 10%, 20%, and 30%, both with and without bio-cementation treatment, to reduce the environmental impact associated with conventional cement production. A watermelon seed powder solution, in combination with yeast, urea, and calcium lactate, was employed as a natural bio-cementation agent to enhance mechanical properties, durability, and crack-healing efficiency through biologically induced mineral precipitation. Eight concrete mixtures were prepared, comprising two control mixes and six CNM-based mixes with and without the incorporation of the bio-cementation agent. The performance of these mixtures was evaluated using compressive strength, water absorption, ultrasonic pulse velocity (UPV), crack-healing efficiency, and sorptivity tests after 28 days of water curing. To assess the self-healing capability of the developed concrete composites, all experimental investigations were conducted on both cracked and uncracked specimens under controlled curing conditions. Microstructural characterization was carried out using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) to identify healing products and elucidate mechanisms responsible for crack closure and matrix densification. The MB20 mix incorporating bio-enzyme demonstrated the best overall performance, with compressive strength reaching 48.60 MPa and significant improvements in durability. Water absorption decreased markedly from 4.44% to 1.42%, while the ultrasonic pulse velocity (UPV) increased from 3586 m/s to 5245 m/s, indicating a denser and more homogeneous matrix. Sorptivity decreased from 1.10 mm to 0.75 mm, reflecting reduced capillary water absorption and enhanced impermeability. Furthermore, the mix achieved 91% crack-healing efficiency, reducing crack width to 0.07 mm via urease-mediated microbial-induced calcium carbonate precipitation (MICP), thereby promoting calcite deposition, pore refinement, and effective crack sealing. CNM addition enhanced cement use efficiency and reduced resource consumption, as indicated by cement use efficiency (CUE) and economic index (EI) evaluations. Overall, the best combination of strength, durability, and self-healing performance was achieved by combining 20% CNM with bio-enzyme treatment. The results demonstrate that the combined use of CNM and plant-based bio-cementation agents offers a promising, sustainable approach to developing durable, self-healing concrete with a reduced carbon footprint. This approach contributes to environmentally responsible construction practices while improving the service life of cementitious structures.

Keywords: Carbon negative material, Self-healing concrete, Bio-cementation, Crack healing, Sustainability

Parametric Assessment of Soil Quality and Geochemical Variations Induced by Effluent Irrigation: Implications for Agro-Environmental Sustainability

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ABSTRACT

The increasing scarcity of freshwater resources and rapid urbanisation have accelerated the adoption of treated municipal wastewater as an alternative irrigation source in agricultural systems. While treated effluent provides a reliable water supply and contributes essential nutrients, its long-term application may alter soil physicochemical characteristics and promote the accumulation of trace elements. This study evaluates soil quality and geochemical variations in agricultural lands irrigated with treated wastewater within a 1 km radius of the municipal sewage treatment plant (STP) in Davanagere, Karnataka, India, with the objective of assessing the sustainability of effluent irrigation practices.

A total of thirty composite soil samples were collected from agricultural fields regularly irrigated with treated wastewater. Samples were analysed for soil pH, electrical conductivity (EC), organic carbon (OC), macronutrients (nitrogen, phosphorus, and potassium), micronutrients such as Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Calcium (Ca), Magnesium (Mg), and Boron (B), and trace metals such as lead (Pb), Chromium (Cr), Cadmium (Cd), and Nickel (Ni) using standard laboratory procedures. Statistical analyses were performed to evaluate spatial variability and relationships among soil quality parameters.

The results indicated slightly alkaline soil conditions with a mean pH of 7.87 ± 0.16 and low salinity levels ($EC = 0.38 \pm 0.13$ dS/m), suggesting no immediate salinity hazard. Organic carbon content was relatively high ($1.23 \pm 0.18\%$), reflecting enrichment from continuous wastewater application. Significant nutrient enhancement was observed, with mean total nitrogen, phosphorus, and potassium concentrations of 1607.9 ± 242.35 kg/ha, 249.50 ± 74.45 kg/ha, and 342.70 ± 93.71 kg/ha, respectively. Micronutrient concentrations remained within adequate ranges for plant growth. Trace metals were detected at low concentrations, with mean Pb, Cr, Cd, and Ni values of 1.99, 0.18, 0.52, and 1.86 ppm, respectively, remaining within permissible limits. Correlation analysis revealed strong positive associations between organic carbon and nutrient concentrations, highlighting the role of wastewater-derived organic matter in improving soil fertility.

The study demonstrates that treated wastewater irrigation can significantly enhance soil fertility and nutrient availability while maintaining acceptable soil quality conditions. However, the gradual accumulation of trace metals indicates the need for periodic monitoring and site-specific management strategies to ensure long-term agro-environmental sustainability. The findings support the safe and sustainable reuse of treated wastewater as a supplementary irrigation resource in water-scarce regions.

Keywords: Treated wastewater irrigation, Soil quality, Macronutrients, Trace metals, Agro-environmental sustainability

Numerical analysis of coir geocell-reinforced pavements for enhanced structural performance

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ABSTRACT

Flexible pavements constructed over weak subgrade soils are highly susceptible to excessive rutting and deformation, posing significant challenges for low-volume road infrastructure in tropical and developing regions. Conventional synthetic geocell reinforcement, although effective, raises concerns regarding environmental impact, non-biodegradability and dependence on petroleum-derived materials. This study investigates the structural performance of coir-based cellular confinement systems as a sustainable alternative for reinforcing flexible pavements, with the primary objective of evaluating the influence of reinforcement placement depth and infill material characteristics on load-settlement behaviour under static loading conditions.

A three-dimensional finite element model was developed using PLAXIS 3D to simulate the response of coir geocell-reinforced flexible pavements. The pavement layers were modelled using the Mohr-Coulomb constitutive framework, while the coir geocell was represented by geogrid structural elements with an axial stiffness of 86 kN/m. The model geometry comprised a 1400 mm deep domain with subgrade, subbase, and base layers and a 300 mm diameter circular loading plate was applied at the surface. Interface elements were used to simulate soil-reinforcement interaction. The numerical framework was validated against published experimental load-settlement data, yielding a deviation of less than 8% at the maximum applied load.

Parametric analyses were subsequently performed to examine three reinforcement placement depths and three infill materials: sand, fly ash, and Wet Mix Macadam (WMM). The results demonstrate that reinforcement placement depth significantly governs pavement performance. Settlement reduction ratios (SRR) of 20.7%, 37.7%, and 55.2% were obtained for geocell placement at the bottom of the subbase layer, bottom of the base layer, and 0.1D within the base layer, respectively, identifying 0.1D as the optimum location. Stress contour analysis confirmed that the geocell effectively redistributed applied stresses over a wider area, reducing stress concentration in the underlying subgrade. With respect to infill material, WMM yielded the lowest settlement of 13.24 mm, followed by fly ash at 14.50 mm and sand at 16.58 mm. The relative improvement factor (RIF) of fly ash over sand was approximately 12.6%, compared with 20.1% for WMM, confirming that infill stiffness exerts a substantial influence on confinement efficiency and deformation control.

The study concludes that coir geocell reinforcement is an effective and environmentally compatible solution for improving the structural performance of flexible pavements. Placement at 0.1D within the base layer provides the highest confinement benefit, while fly ash offers a sustainable and high-performing infill alternative with only marginal increase in settlement relative to WMM. These findings support the adoption of natural fibre-based geocells in low-volume road construction as a viable pathway toward sustainable pavement engineering.

Keywords: *Pavement reinforcement, PLAXIS 3D, Sustainable materials, Placement depth.*

Biopolymer-Based Sustainable Subgrade for Pavement Applications

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ABSTRACT

Bio-geotechnology offers sustainable alternatives to traditional soil stabilization methods, which are typically based on cement and lime and are associated with high carbon emissions. This study evaluates the effectiveness of xanthan gum (XG) used as a bio-based stabilizer for non-plastic soil. XG was added at dosages of 0.5%, 1%, 1.5%, 2%, and 2.5% by dry weight of soil. California Bearing Ratio (CBR) tests, both unsoaked and soaked, were used to assess the mechanical performance of stabilized soil. The results indicate that incorporating XG enhances inter-particle bonding and increases soil stiffness. This leads to significant improvements in load-bearing capacity with increasing dosage and curing time, due to the formation of a hydrogel and the stiffening of the soil matrix. The unsoaked CBR of untreated soil was 6.08%, and for treated soil, it rose to 26.7% at 2.5% dosage, corresponding to an improvement of approximately 332%. Pavement design was carried out according to IRC:37-2018 guidelines, and IIT PAVE software was used to simulate pavement response to repeated traffic loading and to calculate critical subgrade tensile and compressive strains. The improved subgrade strength enabled a reduction in the required granular layer thickness from 340 mm for untreated soil to 300 mm for XG-treated soil. Furthermore, the critical horizontal tensile strain at the bottom of the bituminous layer (ϵ_t) and the critical vertical compressive strain at the top of the subgrade (ϵ_v) were reduced by approximately 30.7% and 42.5%, respectively, indicating improved resistance to fatigue cracking and rutting, which are the primary modes of pavement distress. The computed strain values remained within the permissible limits specified by IRC:37–2018, confirming the structural adequacy and long-term performance of the stabilized pavement system. In addition to enhancing pavement performance, the reduction in pavement thickness offers potential savings in construction materials and overall project costs. The findings demonstrate that xanthan gum is an effective, sustainable, and environmentally friendly stabilizer for non-plastic soils and presents a viable low-carbon alternative to conventional chemical stabilizers for transportation infrastructure. The adoption of XG-based soil stabilization can contribute to the development of resilient and sustainable pavement systems while supporting Sustainable Development Goals (SDGs) 9, 12, 13, and 15.

Keywords: *Biopolymer, Non-plastic soil, CBR, Pavement, IIT PAVE.*

Analytical Evaluation of Subgrade-Controlled Rutting in Flexible Pavements: A Case Study of Soft Clay Strata in Jhalawar, Rajasthan

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ABSTRACT

Rutting is a critical distress mechanism in flexible pavements constructed over soft subgrades, particularly under repeated loading and adverse moisture conditions. Conventional design often relies on empirical methods that may not fully capture site-specific soil behavior. This study presents a subgrade-controlled analytical evaluation using field-derived data from a geotechnical investigation at Dug, District Jhalawar.

Subsurface exploration through three boreholes revealed a stratigraphy comprising Medium Plastic Clay mixed with sand. Laboratory testing indicated a high clay fraction and a Liquid Limit of approximately 38%, signifying moderate plasticity and potential moisture sensitivity. The research integrates these field parameters into a three-layer mechanistic pavement model under a standard 80 kN axle load to evaluate vertical compressive strains at the top of the subgrade under both unsoaked and soaked conditions. Using a calibrated power-law rutting model specific to Indian cohesive soils, permanent surface deformation was predicted for traffic repetitions ranging from 104 to 106.

The analytical results demonstrate that moisture-induced stiffness degradation accelerates rutting progression, causing the pavement structure in the soaked state to exceed the critical 20 mm serviceability limit specified in IRC:37 at approximately 5.5×10^5 repetitions, nearly 50% earlier than the unsoaked baseline. This quantitative evaluation highlights the limitations of empirical design charts for moisture-sensitive foundations and establishes a baseline for climate-resilient regional road pavement design.

Keywords:

Keywords: Flexible Pavements 1, Geotechnical Investigation 2, Layered Elastic Analysis 3, Rutting 4, Subgrade Behavior 5.

Sustainable approach for infrastructure development: A State-of-the-Art Review

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ABSTRACT

This paper present extensive review on contemporary trend and various applications of smart and sustainable materials in civil engineering field like building, road, bridges and other transportation and infrastructure construction industry. Smart and sustainable materials enhanced structural performance, energy efficiency, and also reduced environmental impact which attained sustainable development goals. Smart materials, are have capacity to sense and respond to environmental changes, offer solutions for more robust and efficient structures. Alternative Raw Materials (ARMs) can be recycled construction materials and used for developing new constructions, which ultimately reduce CO2 emission, increase circular economy and environment friendly solutions also. The future scope of this study will be practical policies and its implementing method in the construction field.

Keywords: *Sustainable materials, smart materials, civil engineering field, environment friendly, energy efficiency.*

The study on the significance of sugarcane bagasse Ash as a supplementary cementitious material in concrete

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ABSTRACT

With advances in a country's infrastructure, the demand for cement and cementitious materials has predominantly increased in the construction sector over the past decades. The scale of research activities on sustainable construction materials, especially waste materials, has drawn sharp attention to waste recycling and the utilization of potential waste materials in the construction sector. One such waste is sugarcane bagasse ash, predominantly available in different parts of India. Many studies on its abundance and availability have motivated researchers towards the study of this material, which is rich in Silica content. The significance of physical, chemical, and morphological features of Sugarcane Bagasse ash (SCBA) in contributing to strength and durability parameters has been investigated in this section of the study. The percentage replacement of SCBA with cement, as per the previous studies, is marginal, which needs to be enhanced through the preprocessing of the SCBA. This void is explored to attain the full potential of the material and to analyze the influence on its strength and durability properties by increasing the material's fineness through milling. The study infers that the finer SCBA in concrete has significantly contributed to the enhancement of structural properties in comparison with Coarse ACBA. This is evident from the study's microstructural characterization using Scanning Electron Microscopy studies and X-Ray Diffraction analysis. The overall summary highlights the impact of SCBA in concrete as a binding material.

Keywords: *Sugarcane bagasse ash, Pozzolan material, fineness.*

Structural Performance of Recycled Polypropylene Mattress-Reinforced Base Layers

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ABSTRACT

The global movement towards sustainable transportation infrastructure has prioritized the integration of circular economy principles into pavement engineering. This research investigates the structural performance of a three-dimensional honeycomb mattress made of 100% recycled plastic, when used as a reinforcement in the granular layers of a pavement structure. The structural performance was evaluated through a series of large-scale laboratory tests on a model pavement. The pavement structure has a total height of 900 mm, with a 500 mm thick subgrade and a 400 mm thick granular layer. The granular layers compacted over a prepared subgrade of different California Bearing Ratio (CBR) conditions of 5% and 10%. A total of six pavement sections were considered with and without recycled PP mattresses at the interface of base and subbase layers. The structural performance was evaluated in terms of modulus improvement factors (MIF) derived from monotonic loading test load-settlement data. The MIF values are evaluated as 2.00 and 1.63 for subgrade CBR conditions of 5% and 10%, respectively. A design example is presented to demonstrate the use of recycled PP mattresses in pavements. An overall 14% thickness reduction is observed for both the subgrade CBR conditions. These findings demonstrate that the 3D confinement and interlocking mechanisms of the recycled PP mattress significantly optimize the load distribution and increase the overall stiffness of the pavement system.

Keywords: *Recycled plastic, Three-dimensional mattress, Base reinforcement, Modulus improvement factor, Sustainable infrastructure.*

Sustainable Stabilization of Expansive Soils Using Microbially Induced Calcite Precipitation (MICP) and Biopolymers: A Critical Review

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ABSTRACT

Expansive soils, characterized by high swelling and shrinkage potential due to minerals like montmorillonite, pose significant risks to civil infrastructure. Traditional stabilizers like lime and cement, though effective, contribute approximately 8% of global human-caused CO₂ emissions and adversely alter soil pH. This review critically evaluates Microbially Induced Calcite Precipitation and biopolymer stabilization as sustainable, low-carbon alternatives. MICP utilizes ureolytic bacteria, primarily *Sporosarcina pasteurii*, to precipitate calcium carbonate which bonds soil particles and fills pores to enhance mechanical strength and reduce swelling. However, its efficacy in dense clays is technically limited by restricted bacterial transport through narrow pore throats (< 0.5 μm), suggesting that bio-stimulation of indigenous strains is more viable than bio-augmentation for uniform stabilization. In contrast, biopolymer stabilization (e.g., xanthan or guar gum) employs natural polymers to form a cohesive hydrogel matrix via hydrogen and ionic bonding with clay minerals. This mechanism is particularly superior in sulfate-rich expansive soils, as it avoids the deleterious formation of ettringite, a common failure mode in lime-treated soils that leads to secondary heave. Microstructural analyses confirm the development of rigid mineral bridges in MICP and adhesive "bio-bridges" in biopolymer treatments. While these methods offer critical benefits in volumetric stability and shear strength, their large-scale implementation is currently hindered by high material costs and a lack of standardized engineering codes. Future research must prioritize long-term durability assessments under cyclic environmental stressors and the mitigation of biochemical byproducts like ammonia. This paper presents a focused state-of-the-art review of MICP for expansive soil stabilization, synthesizing recent experimental findings, treatment mechanisms, microstructural insights, and performance limitations. Comparisons with biopolymer-based stabilization are included from a sustainability perspective, and key research gaps and future directions are identified to support the effective implementation of bio-mediated soil improvement techniques in geotechnical practice.

Keywords: MICP, Biopolymer, Soil stabilization

Removal of Chromium from Paint Industry Effluent Using Marigold Flower Waste as a Biosorbent – Batch and Column Studies

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ABSTRACT

Industrialization and rapid growth of urban area led to a discharge of large quantity of untreated wastewater into the environment. The discharge of industrial wastewater, particularly from paint manufacturing units, poses a significant environmental concern due to the presence of toxic heavy metals. Chromium (Cr) is one of the most hazardous heavy metals commonly found in effluents generated from paint, pigment, electroplating, tanning, textile and metal finishing industries. Paint industry effluent contains significant amount of chromium due to the use of chromium-based pigments, corrosion inhibitors and additives. When it released in to the environment without treatment, chromium can accumulate in soil and water, posing a serious risk to the human health and aquatic life. Conventional wastewater treatment techniques are often costly and may generate secondary waste, limiting their sustainability. Although these methods reduce the metal concentrations, they are associated with high operational cost, sludge generation, complex operation. In this study, marigold flower waste is investigated as an economical and eco-friendly biosorbent for the removal of Cr from paint industry effluent. The physical and chemical characteristics of paint industry effluent and marigold flower waste were investigated to evaluate their properties and potential for effective waste management and resource utilization. Metal concentrations in wastewater samples before and after treatment were quantified using inductively coupled plasma mass spectrometry (ICP-MS). The treatment performance was evaluated through batch adsorption experiments and column leaching studies employing marigold-based filter media. In addition, scanning electron microscopy (SEM) was used to examine the surface morphology of the adsorbent, while Energy Dispersive X-ray (EDX) analysis was performed to determine the changes in elemental composition of marigold flower waste before and after metal adsorption. The efficiency of metal removal and the influence of adsorbent dosage on adsorption performance were assessed. Results showed that the effluent contained Cr concentrations declined substantially by 90% in column treatment method and 68% in batch experiment.

The study successfully demonstrated the potential of marigold flower waste powder as a low-cost, sustainable, eco-friendly, and renewable biosorbent for the effective removal of chromium from paint industrial effluent. Physiochemical characterization confirms that the biosorbent possesses a porous, structure with active adsorption sites for metal ion binding through biosorption mechanisms. SEM image revealed that the pores and cavities were partially filled and the surface become smoother, indicating the deposition of metal ions on the biosorbent surface. EDX analysis further confirmed the adsorption process by showing the appearance and increase of peaks. Higher efficiency of chromium metal removal is observed in column leaching setup than batch experiment. The study concludes that the column leaching method is more suitable and efficient for chromium removal using marigold flower waste. These findings demonstrated the potential of marigold flower waste as an economical and eco-friendly biosorbent for the large scale removal from industrial wastewater.

Keywords: Cr removal, Marigold flower waste, biosorbent, paint industrial effluent, heavy metal remediation.

Utilization of Geogrids for Improving the Strength of Coal Tailings

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ABSTRACT

Coal tailings are residues left after the extraction of valuable minerals. Due to the massive dependence on coal for energy production, a large quantity of coal tailings is being generated across the world. As the storage of coal tailings occupies a large space, it poses a risk to nearby communities, making ongoing maintenance and monitoring challenges. Therefore, incorporating coal tailings in geotechnical applications offers a sustainable solution. The present study investigates the efficacy of coal tailings for geotechnical applications using California Bearing Ratio (CBR) and triaxial compression tests. A biaxial geogrid was used as a reinforcement to enhance strength. Additionally, morphological studies were carried out using Field Emission Scanning Electron Microscopy (FESEM). Test results indicate that the coal tailings are classified as silty sand with 34% of water absorption capacity and 35% of organic content. With a single-layer geogrid reinforcement, the CBR value was increased up to 35% in the soaked state and around 42% in the unsoaked condition. Similarly, a significant increase in shear strength was observed during the triaxial compression test with geogrid reinforcement. The peak deviator stress was found to be 68% higher at a confining pressure of 150 kPa for specimens reinforced with three layers. In comparison, the unreinforced coal tailings specimen exhibited a lower peak deviator stress. The geogrid reinforcement confines tailings, generates frictional resistance, and prevents lateral movement, thereby enhancing the strength of the coal tailings.

Keywords: *coal tailings, 3D printed geogrid, CBR test, triaxial test, subgrade.*

Characterization of Gold Ore Tailings and Assessment of Mechanical Properties of Geopolymer Concrete Produced Using Gold Ore Tailings

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ABSTRACT

Mining industry generates numerous wastes, such as tailings of zinc, copper and gold have adverse effect on the environment which creates the landfill problems, soil erosion, air pollution etc. The gold ore tailings (GOTs) are one of the waste materials produced from mining industry obtained during the extraction of calaverite ore. In this research work, the GOTs can be used as partial replacement material to the river sand in the manufacture of geopolymer concrete (GPC). The chemical and morphological properties of GOTs was determined using Field Emission Microscopy (FESEM) analysis. The GPC was produced using GOTs along with Recycled Coarse Aggregates (RCAs) were tested in which compressive strength of 35.8 MPa, split tensile strength of 2.16MPa and flexural strength of 4.01MPa was achieved. Similarly, the GPC samples were prepared using NCAs achieved a maximum compressive strength of 43.71 MPa, split tensile strength of 4.17 MPa and flexural strength of 6.13 MPa. Hence, this research concluded that GPC could be effectively manufactured using GOTs with RCAs when compared to NCAs with desired strength properties.

Keywords: *Gold Ore Tailings, Mechanical Properties, Mine Waste Management, Tailings Dams.*

A Physics-Informed Neural Network Framework for Early Detection and Localization of Toxic Seepage in Tailings Dams

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ABSTRACT

Toxic metal seepage from tailings dams poses significant environmental and safety risks, particularly when they reach the surrounding soil and groundwater systems. Early detection and localization of this seepage remains challenging, as conventional monitoring techniques rely heavily on sparse measurements and threshold-based alarms, which provide very limited insight into subsurface processes. This paper presents a physics-informed neural network framework for detection and localization of toxic seepage in tailings dams. The framework enables continuous reconstruction of hydraulic head and contaminant concentration fields within the subsurface domain using sparse pore pressure and contaminant concentration measurements from synthetic sensors while ensuring consistency with the underlying physics equations with the help of the physics-informed system. This allows the spatial seepage behavior to be captured without the need for dense instrumentation. Seepage is detected and localized through analysis of Partial Differential Equation (PDE) residuals, which highlight breaches and preferential flow paths within the dam. The framework achieves a hydraulic head reconstruction R^2 of 0.9980 (RMSE = 0.527 m) and a concentration reconstruction R^2 of 0.9817 (RMSE = 0.053), with the top 5% highest-risk cells localizing the breach zone at $x \approx 260$ -300 m before contaminants reach downstream monitoring locations. This demonstrates the potential of physics-informed neural networks for predictive, model-aware subsurface monitoring, and establishes the surrogate modelling and anomaly detection components required for a future physics-informed digital twin.

Keywords: *Physics-Informed Neural Networks, Tailings Dams, Seepage Detection, Anomaly Localization, Subsurface Contaminant Transport.*

Waste-to-Resource Subgrade Materials for Low-Carbon Pavement Infrastructure

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ABSTRACT

The integration of recycled and waste-derived materials in pavement subgrade construction offers a sustainable pathway for infrastructure development. This study evaluates a modified subgrade mix (SR20), composed of natural soil and recycled concrete aggregate in an 80:20 proportion, treated independently with varying dosages of fly ash (FA) and sugarcane bagasse ash (BA). These mixes are examined using an integrated multi-criteria framework addressing engineering performance, pavement design suitability, economic feasibility and environmental impacts. Environmental sustainability is quantified using indicators related to carbon emission, non-renewable resource scarcity impact and public health risk index. Results indicate that while both Fly ash (FA) and Bagasse Ash (BA) enhance the performance of modified soils and offer environmental benefits, the SRB10 mix demonstrated the most significant enhancement in performance. Furthermore, incorporation of BA contributed to a reduction in environmental impacts by lowering carbon emissions. The use of this mix also promotes circular economy principles, as the utilization of industrial waste materials significantly reduces the quantity of waste being disposed of in landfills through their application in pavement subgrade construction. As a result, the overall environmental burden is reduced by fostering more sustainable practices and contributing to a cleaner environment.

Keywords: Sustainable pavement, Environmental Indicators, Low-Carbon subgrade materials

Comparative Evaluation of Empirical Rock Slope Stability Methods Along Dedicated Freight Railway Corridor in Aravalli Hills, India **[TH02-23]**

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ABSTRACT

Rock cut slopes developed for a high-speed transportation corridors in rocky terrains frequently exhibit structurally controlled failures, posing long-term safety and maintenance challenges. This study presents a systematic comparative assessment of two established empirical classification approaches i.e. Landslide Hazard Evaluation Factor (LHEF) and Slope Mass Rating (SMR) applied to newly excavated rock slopes along a segment of the Western Dedicated Freight Corridor (WDFC) near Raipur, Sohna, Gurgaon, within the Proterozoic Aravalli Hill range of India. The investigated slopes were formed through controlled blasting and mechanized excavation, producing steep to near-vertical cut faces in predominantly quartzite interbedded with schist and phyllite rocks. Detailed field investigations were conducted at four representative locations, involving systematic measurement of discontinuity orientation, spacing, persistence, aperture, infilling condition, groundwater state, and slope geometry in accordance with IS:11315-2023 guidelines. Laboratory testing, including Uniaxial Compressive Strength (UCS) and petrographic analysis, was performed to characterize intact rock behavior.

LHEF-based Total Estimated Hazard (TEHD) values indicate hazard classes ranging from Moderate to Very High, reflecting the combined influence of lithology, slope morphology, land cover, and structural disposition. In contrast, SMR results reveal variability in stability classes primarily governed by discontinuity–slope interaction and excavation method, identifying potential planar and wedge-controlled failure mechanisms.

The comparative analysis demonstrates that LHEF is effective for macro-level hazard zonation, whereas SMR provides enhanced sensitivity to structurally controlled instability in engineered rock cuts. The LHEF is more sensitive in evaluating the susceptibility as compared to the SMR system. The study highlights that the Location 2 has the highest vulnerability, followed by Location 3, 1 and 4. The SMR may be used to employ the mitigation measures which is not available with any other method, including LHEF. The necessity of reliable stability appraisal and mitigation for such critical railway infrastructure in rocky terrains, thereby contributing to resilient corridor design and risk-informed slope management.

Keywords: Rock Slope Stability; Landslide Hazard Evaluation Factor (LHEF); Slope Mass Rating (SMR); Railway Corridor Infrastructure.

Infrared Thermographic Signatures of Rock Damage: A Focused Review from a Rock Mechanics Perspective

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ABSTRACT

Rock materials exhibit progressive damage when subjected to mechanical loading, starting with the initiation of microcracks and progressing to crack growth, coalescence, and ultimately, failure. Understanding how these damage processes develop is important for interpreting rock behavior prior to instability. In many laboratory studies, infrared thermography (IRT) has been used to record surface temperature changes that occur during rock deformation. These temperature changes are often associated with stress concentration, crack activity, and frictional processes. However, the physical meaning of the observed thermal patterns is not always clearly explained, and their interpretation frequently remains case-specific. This paper presents a focused interpretative review of infrared thermo-graphic signatures of rock damage from a rock mechanics perspective. Attention is focused on relating commonly reported thermal responses, such as localized temperature increases and evolving thermal heterogeneity, to underlying damage mechanisms, primarily associated with microcrack development, crack interaction, frictional sliding, and strain localization. Published experimental observations on selected rock types and loading conditions are reviewed to understand how thermal responses evolve before failure and after peak stress. The influence of experimental factors such as boundary conditions, loading rate, surface characteristics, and ambient environment on the recorded infrared signatures is discussed.

Keywords: *Infrared Thermography, Rock damage Mechanism.*

A Physics-Informed Digital Twin Framework Integrating Finite Element Modelling and Synthetic Slope Stability Radar Data for Weak Zone Detection and Failure Time Prediction in Open-Pit Coal Mines

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ABSTRACT

Open-pit mine slopes fail progressively, yet conventional point sensors capture only a fraction of the deformation field, leaving dangerous blind spots and insufficient warning time before collapse. This paper presents a three-stage Physics-Informed Digital Twin (PIDT) framework combining a 3D finite element model, synthetic Slope Stability Radar (SSR) data, and a Physics-Informed Neural Network (PINN). In Stage 1, a 3D finite element model of a Gondwana open-pit slope (234 m × 50 m × 150 m) is solved under gravitational loading, identifying the coal seam interface as the critical weak zone with local and global Factors of Safety of 2.39 and 3.00. Stage 2 projects this geomechanical output onto a synthetic SSR displacement field on an 80×60-pixel grid over 100 epochs at 0.5-hour resolution incorporating Voight accelerating creep, Gaussian noise, atmospheric phase ramps, and coherence masking to replicate realistic radar conditions. Stage 3 trains the PINN on sparse observations from 39 sensor locations, using the Voight ordinary differential equation enforced at 6,000 interior collocation points to reconstruct the full deformation field from what a real radar installation would provide. The framework reconstructs displacement with a maximum spatial RMSE of 2.54 mm and MAE of 1.92 mm. Inverse-velocity extrapolation predicts the true 60.0-hour failure time with only 0.60 hours of absolute error with a 79% improvement over a data-only baseline. These results demonstrate that embedding physical constraints enables reliable extrapolation through the unobserved acceleration phase, making meaningful failure forecasting possible from sparse, noisy radar observations alone.

Keywords: *Physics-Informed Neural Network (PINN), Digital Twin, Slope Stability Radar (SSR), Slope Stability Analysis, Open-Pit Mining.*

Fracture & fragmentation analysis using Fragalyst software of failed rock samples subjected to cyclic loading in uniaxial compression

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ABSTRACT

Structures made in Rocks or rock masses were subjected to the dynamic or cyclic loading conditions. Few examples are drilling, blasting, earthquakes, landslides, rock-bursts, oil well fracturing and the defense engineering involving the nuclear blasting etc. It is well reported in the literature that the rocks or rock masses were fractured at the wide varied loading rates. Hence, it is of the great significance to investigate the effect of the loading rate on the rock fragmentation, fracturing and the failure process.

In the present study, using MTS 816 Rock Test System in the laboratory sandstone rock samples obtained from the Ostrava-Karvina Coalfields were subjected to the cyclic loading in uni-axial compression. The fatigue strength of tested sandstone and other properties were determined at the various loading frequencies and amplitude. The samples tested in such loading conditions were large enough, however, few failed rock samples were studied for its fracture and fragmentation analysis using image analysis technique from the thin sections prepared. The obtained results from the rock fracture showed that fragmentation of the rock was increased in the case of the low loading frequency as compared to that at high. The micro-observations for the fractured rock specimens indicated that, in thin section prepared (which was parallel to the loading direction) of a specimen subjected to a cyclic loading, there were clear crack branching or bifurcation, and the lower the loading frequency were, the more branching cracks were occurred. Again, it was observed that at the low loading frequencies the rock specimen was broken into the several fragments rather than only the two halves or so.

Finally, some applications of findings in engineering practices involving rock and rock mass were discussed. From the presented results, it could be emphasized that, if the energy losses due to the reflected stress waves, the transmitted waves and the flying of the fragments cannot be decreased to zero or not utilized in the rock fracture process, then the most efficient method for the rock drilling, excavation, fragmentation and crushing could be the static loading or at the low-speed loading means the low frequency with high amplitude or so. Also, most of the earthquakes recorded in the history of the man-kind are being reported to occur at the low frequencies generally at around 1 Hz. Around these frequencies, the earthquakes were reported to produce the more damages on the earth planet and to the man-kind. The presented study helped to put more emphasized on due consideration of the dynamic disturbances which is generally being reported and mostly occurring in the rock engineering field that could be incorporated at the initial stage itself for their fool-proof and safe design.

Keywords: *Cyclic Loading, Fracture & Fragmentation, Rock Engineering, Image Analysis, Sandstone Rocks.*

A deep learning framework for predicting thermal performance of geothermal energy piles

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ABSTRACT

Geothermal energy pile is an environmentally sustainable and economically viable technology that harnesses geothermal energy from shallow depths of the ground to provide renewable heating and cooling for the thermal comfort of buildings. It also serves as the primary function of supporting the structural load of the superstructure.

Thermal conductance (T_c) of geothermal energy pile (GEP) depends on several influencing factors such as environmental conditions, soil properties, pile geometry etc. Identifying the most critical parameters influencing the thermal performance of GEP system and optimizing its configuration for improved performance are essential.

In the present study, Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM), and Recurrent Neural Networks (RNN) algorithms were developed and analyzed to predict the thermal conductance of GEP, and their performance and accuracy were compared to identify the optimal model.

A dataset comprising 284 data points was collected from the literature and divided into training (80%) and testing (20%) subsets for model development and evaluation. Sensitivity analysis (SA) is also conducted to identify the most influential features affecting the Thermal conductance of GEP. These features include the number of tubes, diameter of the energy pile, inner diameter of the tube, thickness of the tube, thermal conductivity of the energy pile, thermal conductivity of the soil, thermal conductivity of the tube, and velocity of the fluid inside the tube. A thorough comparative analysis is carried out to assess the performance and effectiveness of these developed models using various statistical performance parameters including R^2 , WMAPE, WI, RMSE, VAF, and PI, were used to assess performance differences in prediction across the produced deep learning algorithms., and Taylor diagram.

Analysis of the results shows that RNN model demonstrates the highest prediction accuracy with R^2 value of 0.997 and RMSE of 0.8333, outperforming both CNN and LSTM models. Scatter plots comparing the actual and predicted thermal conductance of GEP for both the training and testing datasets further demonstrated that the RNN model was the most suitable architecture for this study. Based on the evaluation of correlation, RMSE, and standard deviation presented in the Taylor diagram, the RNN model demonstrated the best performance among the other models during both training and testing phases, followed by CNN, and LSTM models.

The SA using cosine-based sensitivity approach revealed that K_p significantly affects the thermal conductance of GEP, followed by d_p , d_i , K_t , n , t , K_s , and v input variables.

Therefore, the present study demonstrates that RNN model is highly reliable and accurate soft-computing techniques for predicting thermal conductance of GEP.

Keywords: *Geothermal energy pile, Deep learning algorithms, Thermal performance analysis, Renewable energy.*

Influence of Embankment Height and Train Speed on the Dynamic Behavior of Railway Embankments over Soft Coastal Clay

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ABSTRACT

With a growing population, rapid urbanization, and the need for faster transportation, the demand for high-speed rail has increased, especially in Kerala. Coastal soils in the region exhibit high compressibility, low shear strength, and low permeability, making them prone to deformation under cyclic loading from fast-moving trains. The construction of railway embankments in such areas is challenging due to high-water tables and soft, saturated soils, which can lead to settlements over time, causing uneven tracks and higher maintenance requirements. This study investigates the dynamic behavior of railway embankments constructed over soft marine clay subgrades, considering embankment heights of 2 m, 3 m, and 4 m under train speeds of 50 kmph, 100 kmph, and 150 kmph, using PLAXIS 3D simulations. The results indicate that embankment height is a dominant factor influencing settlements, with taller embankments producing greater settlements due to increased effective stress on the soft clay subgrades. Train speed also significantly affects dynamic response, with maximum settlements occurring near the critical speed, which decreases as embankment height increases. The critical speed decreased as the embankment height increased. The 4 m embankment experienced critical effects near train speed of 50 kmph, while for the 2 m embankment, it was observed at 150 kmph. These effects are more pronounced for a 4 m high embankment. The findings underscore the need to carefully evaluate the influence of train speed and embankment height in the design of high-speed rail embankments on soft-clay subgrades. The study recommends suitable ground improvement techniques or embankment reinforcement, particularly for taller embankments, to ensure stability and long-term performance.

Keywords: *High-speed rail, Coastal soils, Railway embankment, Dynamic loading, Numerical analysis.*

Load Sharing and Settlement Reduction Analysis of Piled Raft Foundations on Soft Black Cotton Soil

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ABSTRACT

Black Cotton soil, prevalent across India, is highly clayey and prone to swelling and shrinkage, leading to low shear strength, high compressibility, and severe settlement issues. This study investigates the load–settlement behaviour of raft and piled raft foundations on laboratory-prepared soft clay simulating Black Cotton soil.

A square test tank (500 mm × 500 mm) was prepared, with soil compacted in 80 mm layers to achieve maximum dry density and an unconfined compressive strength (UCS) of ~25 kPa. After two days of consolidation, a 100 mm × 100 mm raft foundation was tested under static loading.

Performance of raft and piled raft systems with four, six, and nine piles was evaluated using load–settlement response, load improvement ratio (LIR), load sharing ratio (LSR), and settlement reduction ratio (SRR). Results showed that piled rafts reduced settlement by up to 77% compared to plain rafts. The six-pile configuration achieved optimal performance, improving load capacity by 30% and reducing settlement to 3.2 mm. In contrast, the nine-pile system, despite attaining a higher load capacity (3.62 kN, LIR = 1.66), exhibited reduced efficiency at higher loads due to pile–soil interaction.

The study concludes that piled raft foundations provide a viable solution for mitigating settlement in expansive soils, with the six-pile arrangement offering the most balanced performance. These findings highlight the importance of optimizing pile configuration to achieve both structural efficiency and cost-effectiveness in problematic soil conditions.

Keywords: Black Cotton soil, Piled raft, Load–settlement behaviour, Settlement reduction, Load sharing

Enhancing Engineering Students' Engagement Through An Experience Based Approach in The Era of Artificial Intelligence

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ABSTRACT

In the modern educational landscape, traditional classroom engagement is increasingly ineffective as students, accustomed to instant access to information through digital devices, show reduced interest in conventional teaching methods. The integration of Artificial Intelligence (AI) into everyday life has further intensified this trend, with students relying heavily on screens for problem-solving. This poses a significant challenge in engineering education, where graduates are expected to develop strong cognitive and problem-solving skills for real-world applications. To address this disconnect, teaching methodologies must evolve in line with changing learner profiles.

An experience-based learning approach offers a promising solution by enabling students to construct physical models, observe real-world phenomena, and evaluate the effectiveness of mitigation strategies. This study addresses the issue through: (i) an analysis of the psychological profile of modern learners based on existing literature, (ii) a review of potential pedagogical interventions available to engineering educators, and (iii) an in-depth examination of the benefits of experience-based learning within engineering curricula. The approach has been implemented in undergraduate geotechnical engineering courses over the past five years. Observations indicate improved conceptual understanding and engagement among students. These findings can guide educators in enhancing teaching strategies to better align with contemporary learning needs. Hence, an Experiential Learning (EL) activity was initiated for the purpose of enhancing the student learning experience and assisting them in visualizing the physical application of concepts which they study as part of their curriculum. Performance in two Undergraduate courses of Civil Engineering, i.e., Soil Mechanics and Foundation Engineering, are chosen for understanding the effect of intervention. The conclusions drawn are based on performance assessment in EL for four year and compared with previous six years.

It is observed that the student learning is significantly enhanced by introducing them to a real-life problem like slope failure, and tasking them to find solution and demonstrate. The average scores in end semester exams improve by at-least 20% since slope stability EL, while improvement due to seepage EL is 15%. The students love the overall experience of working in team, construction by own hands and demonstrate by way of physical models. Students like to discuss with teacher which is more interactive than classroom lecture which are mostly a monologue.

Keywords: *Kolb's cycle, Experiential learning, Engineering education.*

Numerical analysis of non-linear consolidation

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ABSTRACT

This paper focuses on the numerical solution of non-linear consolidation of fine-grained soil. The governing differential equation (GDE) is formed by using the mass conservation principle, the continuity equation, Darcy's law, and the linear void ratio-effective stress relation (on a logarithmic scale), along with a constant load and compressibility equation. The GDE is solved numerically using the Finite Difference Method (FDM), in implicit form, and a suitable program is developed in MATLAB (R2025a). The non-linear problem is solved for pervious top-pervious bottom (PTPB) and pervious top-impervious bottom (PTIB), considering different loading magnitudes. A set of isochrones and consolidation curves are drawn for different drainage boundaries and loads. The stress-dependent compressibility slows down the consolidation process, especially for higher loadings.

Keywords: *Consolidation, Non-linear consolidation, Isochrones, PTPB, PTIB.*

Reliability-Based Design Optimization of Pile Foundations via Machine Learning under Stochastic Uncertainty

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ABSTRACT

Machine learning (ML) has increased usage in geotechnical applications, but the design of pile foundations based on reliability remains computationally cumbersome. This study bridges data-driven prediction of Pile Bearing Capacity (PBC) and Reliability-Based Design (RBD) of piles. An ML model with Artificial Neural Network was trained to predict PBC using diameter (d), pile length (L), angle of internal friction (ϕ), unconfined compressive strength of soil (C_u), skin friction (f_s), and unit weight of soil (γ). RBD is achieved through Sequential Order and Reliability Assessment (SORA) with a target reliability index ($\beta_T = 3$). The difference between predicted PBC at Most Probable Point of Failure (MPPF) and random variable load (Y) is the Performance Function (PF). MPPF for RBD is iteratively obtained by making PF=0 and minimizing the objective function (V =Volume of Pile). Developed model achieved higher accuracy, showcasing higher coefficient of determination (R^2) in training (TR- $R^2=0.999$) and testing phase (TS- $R^2=0.998$) and lower RMSE (TS=9.186 kN, TR=15.260 kN) in terms of PBC. While maintaining β_T , proposed approach produced an optimal design of diameter 0.3m and Length 13.2m, achieving a minimum $V=0.9331\text{m}^3$ at MPPF ($\phi=30.35$, $C_u=63.50$, $f_s=30.14$, $\gamma=20.23$ and $Y=499.37$). Importance factors (α) indicated load has the most contribution ($\alpha_Y = 63.59\%$) followed by skin friction ($\alpha_{f_s} = 30.00\%$) to failure. Second Order Reliability Method was employed as a verification tool and obtained ($\beta = 3.03$) curvatures ($K_1= 0.00679$, $K_2= 0.00944$, $K_3= -0.02009$, $K_4= 0.10534$). The proposed framework enables minimum-volume pile designs while explicitly satisfying target reliability requirements, demonstrating its potential for practical RBD.

Keywords: *Pile Foundation, Reliability Based Design, Machine Learning*

Intelligent Modeling of Underground Structures Using Computational Geomechanics and Deep Learning

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ABSTRACT

The rapid expansion of urban infrastructure has significantly increased the reliance on underground facilities such as metro tunnels, deep excavations, underground transit stations, and utility corridors. The safe design and long-term performance assessment of these structures remain challenging due to complex soil–structure interactions, geological variability, and uncertainties associated with subsurface conditions. Conventional computational geomechanics techniques, including finite element, finite difference, and discrete element methods, have been extensively employed to simulate underground behavior with high accuracy. However, these methods often demand substantial computational effort and are not well suited for real-time decision-making and monitoring applications.

This study proposes an integrated intelligent modeling framework that combines computational geomechanics with deep learning techniques to enhance the prediction and management of underground structures. The proposed hybrid approach utilizes datasets generated from high-fidelity numerical simulations together with field monitoring information to train data-driven models capable of rapidly predicting critical geotechnical responses. Various deep learning architectures, including Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Gated Recurrent Units (GRU), are explored for applications such as settlement prediction, deformation forecasting, tunnel lining assessment, and seismic response evaluation.

The methodology employs numerical simulations to generate representative training datasets that capture the nonlinear behavior of geomaterials and soil–structure interaction effects. The trained deep learning models act as surrogate predictors, significantly reducing computational requirements while maintaining acceptable engineering accuracy. Representative case studies involving tunnel-induced ground settlement, deep excavation performance, and underground structural response under dynamic loading demonstrate the effectiveness of the proposed framework.

The results indicate that deep learning-based surrogate models can reproduce numerical simulation outcomes with high reliability while reducing computation time by more than 95%. The hybrid framework supports rapid risk assessment, structural health monitoring, and real-time decision support for underground construction projects. Furthermore, emerging technologies such as Physics-Informed Neural Networks (PINNs) and digital twins are discussed as promising avenues for integrating physical laws, monitoring data, and artificial intelligence into a unified predictive environment.

The study concludes that the integration of computational geomechanics and deep learning provides a practical pathway toward intelligent, adaptive, and computationally efficient underground infrastructure management. Such hybrid approaches have significant potential to improve safety, sustainability, and resilience in future underground engineering projects.

Keywords: *Computational Geomechanics, Deep Learning, Underground Structures, Soil–Structure Interaction, Digital Twins*

A Review of Probabilistic Methods for Landslide Hazard

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ABSTRACT

Landslides remain one of the most serious geohazards in India, particularly in regions where intense rainfall, steep slopes, and complex ground conditions combine to make slope failure difficult to predict. Many traditional slope stability methods still rely on simplified deterministic assumptions, so they often miss the variability in soil behavior, groundwater conditions, and environmental change. Probabilistic approaches have therefore become increasingly important because they offer a more realistic way to estimate landslide risk by accounting for uncertainty.

This review brings together various studies from the past decade and group them into four main areas: stochastic methods, physically based models, machine learning approaches, and integrated multi-hazard frameworks. This literature shows that stochastic methods such as Monte Carlo Simulation remain reliable, but they can be slow and computationally demanding. Physically based models offer better insight into how slopes actually fail, yet they often need detailed input data and significant processing power. Machine learning methods are attractive because they can produce fast predictions, but their results are sometimes difficult to interpret in physical terms. Multi-hazard frameworks are especially relevant for India, where rainfall and seismic activity can interact to trigger landslides in vulnerable regions.

Overall, the review shows that probabilistic methods improve how uncertainty is handled, but their broader use is still limited by data shortages, model complexity, and the gap between technical results and practical decision-making. Future work should focus on hybrid frameworks that combine physical understanding, probabilistic reasoning, and data-driven tools with real-time monitoring to support better hazard mapping, engineering design, and early warning.

Keywords: *Probabilistic landslide hazard assessment, Slope stability , Uncertainty modeling, Machine learning*

Reliability-Based Slope Stability Analysis of Embankment Using Machine Learning Techniques in Pune Region

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ABSTRACT

Slope stability evaluation is critical to the safety and long-term performance of highway embankments. Conventional deterministic approaches typically assume fixed soil properties and do not adequately account for inherent variability and uncertainty, leading to unrealistic assessments of slope safety. To address this limitation, the present study investigates the reliability-based stability assessment of a highway embankment near Pune, Maharashtra, India, by integrating probabilistic analysis with machine learning techniques. The soil properties of the embankment, including cohesion (C), friction angle (ϕ), and unit weight (γ), are determined through laboratory testing and incorporated into a slope stability model developed in MS Excel using Bishop's Simplified Method. A deterministic analysis is first performed to identify the critical slip surface. Subsequently, soil parameter uncertainty is characterised statistically, and a dataset of 250 Factor of Safety (FOS) samples is generated. This dataset is used to develop and validate three machine learning models, namely Decision Tree Regression (DTR), Random Forest (RF), and Artificial Neural Network (ANN), to predict the FOS. Reliability analysis is then conducted using the First-Order Second-Moment (FOSM) method to assess the influence of soil variability on embankment performance. The predictive performance of the models is evaluated using statistical metrics and graphical analyses. The results show that all three machine learning models accurately predict the Factor of Safety; however, the Random Forest model consistently outperforms the ANN and DT models in predictive accuracy, robustness, and reliability. The reliability assessment further indicates that the embankment remains stable under the considered uncertainty levels. The study highlights the effectiveness of combining reliability analysis with machine learning for efficient slope stability prediction and demonstrates the advantages of ensemble learning in capturing complex geotechnical behaviour. The proposed framework provides a practical, computationally efficient tool for reliability-based slope-stability assessment and can support geotechnical engineers in making informed decisions about the design, evaluation, and maintenance of highway embankments under uncertain soil conditions.

Keywords: *Slope Stability, Reliability Analysis, RF, ANN, DTR*

SUSTAINABLE ENVIRONMENTAL FLOW ANALYSIS OF THE PUTHIMARI RIVER USING FLOW DURATION CURVE (FDC) AND TENNANT METHOD

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ABSTRACT

Sustainable river management requires maintaining natural flow patterns that supports river ecosystem while ensuring dependable water availability for human use, especially in monsoon-dominated regions. This study examines the environmental flow characteristics of the Puthimari River, a tributary of the Brahmaputra in Assam, using Flow Duration Curve analysis along with the Tennant method. Long-term daily discharge data were analysed to understand changes in river flow behavior over time. Annual and seasonal Flow Duration Curves were developed to describe discharge variation during pre-monsoon, monsoon, post-monsoon, and winter seasons, highlighting both high-flow conditions during the monsoon and critical low-flow conditions during dry months. The results show an increase in monsoon-season flows in the recent period, indicating stronger runoff response and higher flood potential, while low-flow availability during non-monsoon seasons has become increasingly constrained. These low-flow conditions directly affect aquatic habitats, water quality, and the reliability of water resources for agriculture and river-dependent communities. The Tennant method was employed to validate the environmental flow estimates derived from the flow duration curve establishing a relationship between hydrological flow characteristics and ecological habitat requirements.

Keywords: *Environmental flow, Flow Duration Curve, Sustainable River management, Monsoon rivers, Tennant method*

“Seismic Performance of Soil Foundation Structure Interaction and structure soil structure interaction in Dense Urban Areas”

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Abstract :

This study evaluates the seismic performance of reinforced concrete buildings by explicitly incorporating Soil–Foundation–Structure Interaction (SFSI) and Structure–Soil–Structure Interaction (SSSI) using FEA analysis, by examining recent developments and applications in the structures. Conventional seismic analysis typically assumes fixed-base conditions, where foundations are considered rigid and perfectly attached to immovable ground. However, extensive experimental and analytical studies have shown that dynamic interaction among soil, foundation, and structure can significantly modify seismic response. In this work, the supporting soil is modelled through equivalent translational and rotational springs at the foundation level, with stiffness values derived from soil properties rather than assuming a rigid base. Several building models with different heights and bay widths are analysed to evaluate the influence of soil stiffness and structural seismic behaviour. Linear dynamic analysis is carried out in accordance with IS 1893 latest provisions, and key response parameters—natural period, base shear, storey displacement, and inter-storey drift—are compared for fixed-base, SFSI, and SSSI conditions.

Recent studies indicate that modelling soil flexibility increases the fundamental period by about 10% for structures on stiff soils and more than 40% for those on soft deposits. Correspondingly, base shear may decrease by up to 40% or increase by about 27%, depending on the spectral position of the modified period. These results show that SFSI effects depend on soil and structural characteristics rather than being uniformly beneficial. Furthermore, SSSI becomes significant when the spacing between adjacent buildings is less than about 0.3 times the foundation width, especially on soft soils, leading to notable variations in displacement and drift. The findings highlight the limitations of fixed-base assumptions and the need for simplified SFSI and SSSI in the case of seismic design.

Keywords :

Soil–Foundation–Structure Interaction (SFSI) , Structure–Soil–Structure Interaction (SSSI), Seismic response, Base shear.

Site-specific probabilistic seismic hazard assessment of the Mullaperiyar dam in peninsular India

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ABSTRACT

The Mullaperiyar Dam, a 130-year-old lime-surki masonry dam located in the Western Ghats of Kerala, is a critical ageing structure whose seismic safety requires renewed evaluation. Although Peninsular India is often treated as a stable continental region, damaging intraplate earthquakes and reservoir-associated seismicity have shown that the seismic hazard to old dams cannot be assessed solely from broad zonation maps. Regional hazard estimates may also average out the local effects of nearby lineaments, source geometry, and attenuation characteristics. This study aims to develop a site-specific probabilistic seismic hazard assessment (PSHA) for the Mullaperiyar Dam and to estimate peak ground acceleration (PGA) and spectral acceleration ordinates relevant to safety assessment and future retrofitting decisions.

The assessment was carried out using an earthquake catalogue compiled from USGS, ISC, and NCS records for events within a 500 km radius of the site. The catalogue, covering the period from 1800 to 2025, was homogenised to moment magnitude and declustered to retain statistically independent mainshocks. Active faults, lineaments, and seismotectonic information were integrated to delineate five seismogenic source zones around the dam. Gutenberg-Richter recurrence parameters were estimated for each zone using a maximum-likelihood approach, and maximum credible magnitudes were evaluated using an iterative statistical procedure. The hazard calculation was performed in the OpenQuake engine using area-source models and the selected region-appropriate ground motion prediction equation.

The analysis indicated that moderate but non-negligible seismic demand at the dam site. For the 475-year return period, representing a 10% probability of exceedance in 50 years, the estimated PGA was 0.073 g. For the 2,475-year return period, representing a 2% probability of exceedance in 50 years, the PGA increased to 0.117 g. The corresponding 5%-damped spectral acceleration at 0.2 s was 0.103 g and 0.167 g, respectively. Comparison with a recent regional PSHA for Kerala showed close agreement at the 475-year level but a lower site-specific estimate at the 2,475-year level, highlighting the influence of refined source zonation and local attenuation assumptions on high-return-period hazard.

The results showed that site-specific seismic hazard assessment is essential for high-consequence ageing infrastructure. Even though the estimated PGA levels were lower than some regional projections, the dam's age, lime-surki masonry construction, and potential vulnerability under strong dynamic loading make continued seismic safety evaluation necessary. However, limitations persist regarding uncertainties in regional Ground Motion Prediction Equations and the current lack of site-specific borehole data. These results necessitate urgent intervention for ageing masonry infrastructure. Overall, the work shows the need to reassess historic masonry dams in Peninsular India using current

Keywords: *Probabilistic Seismic Hazard Assessment, Mullaperiyar Dam, Critical Infrastructure, Seismic Zonation*

Experimental Investigation of Shock Wave Propagation in Sand Using a Vertical Shock Tube

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ABSTRACT

This study investigates the propagation characteristics of blast-induced pressure waves in a granular medium using a laboratory-scale vertical shock tube. Experiments are conducted under controlled conditions to compare the pressure-time response in the absence and presence of a sand sample. Pressure signals are recorded at multiple sensor locations to examine wave propagation behavior, attenuation, and waveform modification.

The results show that the presence of sand significantly reduces the peak pressure and alters the waveform from a sharp shock-type response to a more gradual and damped profile. This behavior is attributed to energy dissipation through particle rearrangement and gas-solid interactions within the granular medium. Furthermore, repeated loading on the same sample indicates a reduction in pressure response, highlighting the influence of prior loading on the dynamic behavior of sand. The study provides insights into the role of granular materials in mitigating blast effects and improving protective systems.

Keywords: *Blast Wave, Granular Media, Shock Tube Experiments.*

Physics-informed earthquake early impact forecasting using digital twin and Unreal Engine

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ABSTRACT

Predicting earthquakes before they actually start is still very difficult, almost impossible in practical sense. But detecting them quickly right after they begin, and understanding how much damage they might cause, that can really help save lives and reduce destruction. In this work, Physics-Informed Earthquake Early Impact Forecasting System (PI-EEIFS), which combines Physics-Informed Neural Networks (PINNs) with a detailed digital twin of real-world environments is proposed. Once the first P-waves are detected by seismic stations, the system immediately starts working. The PINNs, which follow physical laws like wave equations and material behavior, try to estimate when the more dangerous S-waves will arrive and how strong the ground shaking. This happens within seconds, which is very important. The system uses a dynamic digital twin that represents things like terrain, soil conditions, buildings, and important places like hospitals and schools. All this information helps in predicting how different areas will be affected. For visualization, Unreal Engine 5 is used, which shows real-time simulation of wave movement, hazard zones, and even countdown alerts, making it easier for authorities to understand the situation quickly. To check the system is, validation is done using past earthquake data from datasets like PEER NGA-West2 and K-NET/KiK-net. The predicted results were quite close to actual recorded ground motion values, although not perfect always. Overall, the system shows good potential and could be useful for real-world earthquake warning systems and disaster management planning, if developed further. Validation results indicate PGA RMSE=0.031g, PGA MAE=0.022g, S-wave arrival-time MAE=1.4 s, and MMI classification accuracy=89%, demonstrating the effectiveness of the proposed framework.

Keywords: Earthquake Early Warning, Physics-Informed Neural Networks (PINNs), Digital Twin, Seismic Wave Propagation, Real-Time Impact Forecasting.

Static and Seismic Stability Assessment of Black Cotton Soil – Construction and Demolition Waste Mixture Slopes

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ABSTRACT

Black cotton soil (BCS) poses several serious problems for civil engineers. Civil engineering structures experience large scale damage due to heaving accompanied by loss of strength of these soils during rainy seasons and shrinkage during summer. The potential environmental and economic benefits of the utilization of construction and demolition waste (CDW) for ground improvement has gained significant attention in the past few years. This study investigates the effectiveness of using CDW materials for improving BCS and evaluates the factor of safety (FOS) values using Slide2 software.

In the present study, the assessment of stability is performed using numerical modelling for the slopes where CDW materials are applied to improve the engineering properties of BCS slopes. Under both the gravity loading and pseudostatic seismic loading conditions, the FOS values increase with increase in the proportion of CDW in the BCS-CDW mixture. FOS obtained for unstabilized BCS slope is compared with the stabilized BCS slope and it was seen that the stabilized BCS slope performs better under gravity and seismic loading conditions when compared to the unstabilized BCS slope. Moreover, it was observed that in both the cases of gravity loading and seismic loading, FOS values are highest for the slope material considered as 80 % BCS and 20 % CDW.

The application of brick waste, concrete waste and BCS taken as 10 %, 10% and 80% respectively can give the maximum improvement in case of slope stability. Thus, the present study reveals that diversion of CDW from landfills and its usage in BCS slopes can prove to be a suitable eco-friendly approach of ground improvement.

Keywords: *Black cotton soil, Construction and demolition waste, Slide2, Slope stability.*

Numerical Investigation of Seismic Response of RC Buildings on MSW Landfill Sites Considering Soil–Structure Interaction Effects

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ABSTRACT

Rapid urbanization and the scarcity of suitable construction land have led to the increasing utilization of reclaimed landfill sites for infrastructure development. However, landfill deposits are generally heterogeneous, highly compressible, and characterized by low stiffness, making them susceptible to significant soil–structure interaction (SSI) effects during seismic events. Conventional seismic design procedures often assume a fixed-base condition and may not adequately represent the actual response of structures founded on such challenging ground conditions. Therefore, understanding the influence of landfill site conditions on the seismic behavior of reinforced concrete (RC) buildings is essential for ensuring structural safety and serviceability.

The present study investigates the seismic response of low-rise (G+4), mid-rise (G+14), and high-rise (G+24) RC buildings resting on landfill site (LFS) deposits. The primary objective is to evaluate the effects of SSI on key structural response parameters, including pile-cap rocking, storey lateral displacement, inter-storey drift, and storey acceleration, and to compare these responses with those obtained under rigid-base conditions. The study also examines the influence of varying soil properties on the dynamic behavior of buildings founded on landfill deposits.

The buildings were designed and modeled using ETABS, detailed using CSI Detailing, and analyzed for soil–structure interaction using ABAQUS CAE. Numerical simulations were performed considering realistic landfill soil characteristics and pile-supported foundation systems. The seismic responses of buildings constructed on landfill deposits were compared with those founded on natural soil and fixed-base conditions. Validation of the numerical results was carried out through comparison with available experimental observations and published literature to ensure the reliability of the adopted modelling approach.

The results indicate that landfill site conditions significantly amplify structural responses compared to rigid-base assumptions. Increased lateral displacements, inter-storey drifts, pile-cap rotations, and storey accelerations were observed due to reduced soil stiffness and enhanced SSI effects. The influence of SSI was found to become more pronounced with increasing building height, highlighting the vulnerability of taller structures founded on landfill deposits. The comparative assessment demonstrates that neglecting SSI may lead to unconservative estimates of seismic demand.

The study concludes that landfill site conditions play a crucial role in governing the seismic performance of RC buildings. Incorporating SSI effects in the analysis and design process is necessary for achieving realistic predictions of structural behavior and for developing safer and more resilient infrastructure on reclaimed landfill sites in seismic regions.

Keywords: *Soil-Structure Interaction, Non-linear time history analysis Etabs, Abaqus, Municipal Solid waste (MSW), Landfill Site (LFS), dynamic properties of soil.*

Microstructural and Elemental Changes in Organic Leachate-Treated Soil: A Preliminary Study

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ABSTRACT

Sustainable waste management plays an important role in addressing climate change by using organic residues, which may provide conditions that support microbial activity. This study investigates an alternative waste valorization technique to prepare an organic nutrient-rich solution obtained from composted manure, agricultural residue, and composted plant residue, and evaluates microstructural and elemental changes relevant to possible biomineralization. These materials were mixed in equal proportions and soaked in water for 48 hours to release the leachate, which was extracted using centrifuge equipment. The leachate and soil were mixed and placed in a 43 cm × 30 cm tray with a 5 cm thick soil layer for the small-scale test. The leachate was applied evenly on the surface, and the samples were left to cure for 7, 14, and 21 days. Field emission scanning electron micro-copy observations of the untreated and treated soils showed noticeable changes after leachate addition, including an increase in calcium from 2% to 47.3%, a reduction in carbon from 23% to less than 1%, and minor variations in silica, suggesting microstructural changes in the soil matrix over time. Overall, the study gives an early indication that nutrient solutions derived from organic waste can influence calcium-bearing microstructural changes in soil.

Keywords: *Preliminary study, Leachate, Organic waste, Indigenous bacteria.*

Stabilization of Expansive Black Cotton Soil Using Copper Slag as a Sustainable Sub grade Material: A Micro structural and Mineralogical Study

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ABSTRACT

Black cotton soil exhibits high shrink-swell characteristics due to the presence of expansive clay minerals, making it unsuitable for pavement subgrade applications. Seasonal moisture variations cause significant volume changes, leading to cracking, reduced strength, and pavement distress. Therefore, effective stabilization methods are required to improve its engineering properties and long-term performance.

The need for durable and cost-effective pavement infrastructure has increased interest in sustainable soil stabilization techniques. Lime is widely used to reduce soil plasticity and swelling, while copper slag, an industrial by-product, has the potential to improve soil density and strength. Utilizing copper slag in soil stabilization not only enhances geotechnical performance but also promotes environmentally sustainable waste management by converting industrial waste into a useful construction material.

Specific objectives include to enhance soil strength properties and bearing capacity through stabilization. To compare the performance of untreated, lime-treated, and lime–copper slag-treated soils. To identify the optimum stabilizer combination for pavement subgrade applications. To assess microstructural and mineralogical changes using SEM and XRD analyses.

The study adopted a laboratory-based experimental approach using primary data generated through geotechnical testing. Black cotton soil was collected from the Bijapur, north Karnataka area, while lime and copper slag were obtained from commercial and industrial sources. Soil samples were prepared with different proportions of lime and copper slag and tested to evaluate their engineering performance. The laboratory programme included: Atterberg's Limits Tests to determine plasticity characteristics. Free Swell Tests to evaluate swelling behavior. Unconfined Compressive Strength (UCS) Tests to assess strength improvement. California Bearing Ratio (CBR) Tests to evaluate bearing capacity. Additionally, **Scanning Electron Microscopy (SEM)** and **X-ray Diffraction (XRD)** analyses were performed to examine microstructural and mineralogical changes in the stabilized soil. The results of untreated soil, lime-stabilized soil, and lime–copper slag-stabilized soil were compared to determine the most effective stabilization combination for pavement subgrade applications.

This study examines how lime and copper slag work together to improve the engineering property of expansive soil by comparing different amounts of stabilizers. Lime acts as a chemical stabilizer that reduces plasticity and starts pozzolanic reactions. Copper slag, which is a by-product of industry with high specific gravity, is added to improve compaction and structural strength. The laboratory tests included Atterberg's limits, Unconfined Compressive Strength (UCS), Standard Proctor compaction, California Bearing Ratio (CBR), and free swell tests.

The results show that lime significantly lowers the liquid limit and swelling potential through cation exchange and the formation of cement-like compounds. However, using lime on its own only leads to moderate improvements in density. In contrast, adding copper slag increases Maximum Dry Density (MDD) and lowers Optimum Moisture Content (OMC) because of its granular texture.

A comparative analysis shows that lime and copper slag mixtures have better strength and bearing capacity than untreated or lime-only samples. Scanning Electron Microscope (SEM) observations confirm a dense, cemented soil structure, while X-ray Diffraction (XRD) analysis reveals a decrease in expansive clay minerals and the formation of new cement-like materials. The best combination shows significant geotechnical improvement, offering a sustainable way to use industrial by-products in durable pavement sub grade applications.

Keywords: Black Cotton (BC) Soil, Copper Slag (CS), Lime, SEM, XRD.

Innovative Geocell and Geogrid Composite Foundation to Support Dry Zinc Tailings over Existing Wet Tailings Deposits

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ABSTRACT

Advancements in mineral extraction operations have led to a shift in the generation of dry tailings over the conventional wet tailings that have been used in the past. The conventional tailing dams are designed to store wet tailings. The stacking of dry tailings poses a significant challenge in the tailing dams due to the already existing wet tailings. Moreover, identifying a new tailing storage facility exclusively for dry tailings is both costly and time-intensive. To address these issues, the current study investigates the feasibility of stacking dry zinc tailings on top of the existing wet tailings in a tailings dam located in the state of Rajasthan, India. For the analysis purpose, downstream raised cross sections of the tailing dam were considered. These cross-sections of the dam were analysed using the limit equilibrium-based Spencer method using SLIDE software. For the analysis purpose, a dry stacking height of 4 m over the wet tailing, a berm width of 9 m, and a slope of 1:3 was considered. Additionally, other parameters, such as a pore pressure ratio of 0.4 and a horizontal seismic coefficient of 0.21g, were considered for the analysis. A composite foundation made up of mine muck, sand, geogrid, and geocell was used to support the dry stacking. The analysis revealed that the composite geocell foundation offers superior performance over the routine mine muck foundation with a factor of safety (FoS) of 1.967 and 1.162 in non-seismic and seismic conditions, respectively. The obtained FoS is greater than 1, indicating that the stacking of dry tailings over existing wet tailings is possible. In this way, the study recommends the use of innovative geocell composite foundation in tailing dams to offer cost-effective solutions.

Keywords: *Zinc tailings, SLIDE, Geocell, Geogrid, Stability analysis*

Strength Performance of Natural and Cement - Admixed Soils Modified with Nano clay

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ABSTRACT

The presence of weak soils at construction sites poses a significant challenge to the safety and serviceability of geotechnical structures. To improve the engineering performance of such soils, various ground improvement techniques—including stabilization, reinforcement, grouting, and the use of chemical admixtures—are commonly adopted. Among these methods, the particle size and fineness of stabilizing agents play a crucial role in enhancing soil behavior.

With recent advances in nanotechnology and its interdisciplinary applications, nanomaterials have emerged as promising additives for soil strength enhancement. This study investigates the influence of nano clay on the index properties, compaction behavior and strength characteristics of clayey soil, both in its natural state and when admixed with cement.

Nano clay was incorporated into the soil at varying contents of 0.5%, 1.0%, 1.5%, and 2.0% by dry weight. In addition, combined stabilization using nano clay and cement was examined to evaluate their synergistic effects. The results indicate that the addition of nano clay increases the plasticity characteristics of the soil, while leading to a reduction in maximum dry density and an increase in optimum moisture content.

The unconfined compressive strength of the soil–nano clay mixtures improved by up to 34% compared to untreated soil. A more pronounced strength enhancement was observed in soil–cement–nano clay mixtures, with an increase in unconfined compressive strength of up to 158%, demonstrating the beneficial interaction between nano clay and cement hydration products. Furthermore, the compression index of the soil decreased with the addition of an optimum nano clay content in both natural and cement-admixed soils. The study highlights the potential of nano clay as an effective supplementary stabilizing material for improving the strength and reliability of geosystems.

Keywords: *Nano clay, SEM, UC strength, Cement admixed soil.*

Interaction of 3D-Printed Geomembranes with Sand: A Comparison of Different Polymers

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ABSTRACT

The interaction of the geomembranes with soil critically controls the stability of containment slope applications. The advent of the 3D printing technique in recent years provides an opportunity to customize the geosynthetics for enhanced performance. The current study aims to 3D print the geomembranes from different polymers and evaluate their interface performance. Four different polymer filaments, Acrylonitrile Styrene Acrylate (ASA), Polylactic Acid (PLA), Polypropylene (PP), and Thermoplastic Polyurethane (TPU), were used to manufacture the geomembranes by the 3D printing technique. The aforesaid polymers were selected based on their varying tensile strengths. The interface shear tests using direct shear equipment were conducted to assess the performance of the geomembranes. In the interface tests, the shear box was modified by replacing the lower shear box with a 3D-printed polymeric block. The geomembrane was fixed to the block to enable systematic interface shearing. The upper box of the shear mould was filled with poorly graded sand. The interface coefficient (α) was used to compare the interface efficiency. Among the four geomembranes studied, the PP geomembrane exhibited the highest interface coefficient value ($\alpha = 0.65-0.79$). Similarly, ASA exhibited the lowest interface coefficient ($\alpha = 0.61-0.66$). As compared to the TPU geomembrane, the interface coefficient of the PP geomembrane was found to be 9 to 20% higher at different normal stresses. Additionally, a surface roughness test was conducted using a stylus profilometer to examine the surface characteristics. The surface roughness value, quantified as the arithmetic mean roughness (R_a), was found to be $4.899\ \mu\text{m}$ and $4.710\ \mu\text{m}$ for PP and ASA, respectively. These results indicate that interface shear behaviour is governed primarily by material composition and surface characteristics

Keywords: *Geomembranes, 3D-printing, Surface roughness, Interface shear strength, Tensile strength.*

Experimental Investigation of Enzyme-Induced Calcite Precipitation Using Soybean-Derived Urease for Strength Improvement of Fine-Grained Soils

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ABSTRACT

Enzyme-Induced Calcite Precipitation (EICP) is an emerging bio-mediated soil improvement technique that enhances soil strength through the precipitation of calcium carbonate (CaCO_3). This study investigates the effectiveness of EICP for improving the mechanical properties of fine-grained soils such as clay and silt. A low-cost urease enzyme extracted from soybeans was used to catalyze the hydrolysis of urea in the treatment solution. The reaction produces carbonate ions that combine with calcium ions to form calcium carbonate, which binds soil particles and improves soil strength. Laboratory experiments were conducted on untreated and treated soil samples to evaluate the improvement in strength properties. Unconfined Compressive Strength (UCS) tests were performed to compare the mechanical behavior of untreated and EICP-treated soils. The results show a noticeable increase in UCS values for treated samples compared to untreated soils, indicating the effectiveness of calcite precipitation in enhancing soil strength. The study also investigates the environmental aspect of the EICP process by examining the potential of activated charcoal to reduce ammonium ions generated during urea hydrolysis. The findings suggest that soybean-derived urease can be used as an economical enzyme source and that EICP has potential as an environmentally sustainable technique for improving fine-grained soils. The results provide insights into the application of bio-cementation techniques for sustainable ground improvement.

Keywords: *Enzyme-Induced Calcite Precipitation, Soil Stabilization, Clay Soil, Silt Soil, Bio-cementation, Unconfined Compressive Strength.*

Embankments over Soft Soils Improved by Stone Columns with and without Geogrid Encasement under Seismic Excitations

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ABSTRACT

Ground improvement is the important requirement for the present construction industry in order to overcome the various demands such as poor soil conditions, land restrictions, heavy and dynamic loading conditions etc. Among many ground improvement techniques, stone column technique is a very useful method of improving the strength parameters of soft soils like bearing capacity and reducing the consolidation settlement. From literature, it is noticed that these stone column improved grounds could perform better even during seismic loading conditions. In addition to stone column alone, the encasement of geogrid along the length of stone column could able to give additional confinement and increase its strength.

In the present paper an attempt is made to discuss the displacements and stress concentration of stone column supported embankment subjected to seismic loading conditions using 3- dimensional finite element analysis. A 6 m high embankment with 20 m crest width supported over 20 m thick, soft clay is considered for the time-history analysis. The soft-clay is improved with 800 mm diameter stone columns of length 15 m. Stone columns having three times the diameter as spacing (3D) arranged in square grid pattern are considered for the analysis. A comparative study is conducted for stone column with and without geogrid encasement. Geogrid is modelled as linear elastic material having the tensile modulus equal to 4000 kN/m and Poisson's ratio 0.3 for both geogrid as basal reinforcement and stone-column encasement.

From the time-history analysis it shows that, the provision of geogrid encasement increases the vertical stress distribution on stone columns and reduces the lateral displacements of embankment under seismic loading conditions.

Keywords: Stone-columns, Geogrid encasement, Soft-clay, Seismic loading.

Study on performance of Red and Black Soil with and without application of Geo-Textile

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ABSTRACT

The performance of pavements and foundation systems is significantly influenced by the engineering properties of the supporting soil.. Red soil and Black cotton soil are widely available in many regions of India and are frequently used as subgrade materials. However, Black cotton soil exhibits high shrink-swell characteristics due to its expansive clay minerals, leading to volume changes, cracking, and reduced structural stability. Although Red soil generally possesses better engineering characteristics, its strength may still be insufficient for supporting heavy loads over long periods. These limitations highlight the need for suitable soil improvement techniques that can enhance strength and bearing capacity while remaining economically feasible.

Rapid infrastructure development has created a growing demand for effective ground improvement methods that are both economical and environmentally sustainable. Geotextiles have emerged as a promising solution because of their ability to reinforce soil, improve drainage, and distribute applied loads more efficiently. Non-woven geotextiles are particularly attractive due to their ease of installation and multifunctional performance. Despite their increasing use in geotechnical applications, the degree of improvement achieved in different soil types and the influence of reinforcement placement are not fully understood. This study is therefore undertaken to investigate the reinforcing effect of non-woven geotextiles on Red soil and Black cotton soil and to establish their suitability for subgrade stabilization.

Both soil types were fully characterised through standard geotechnical tests: specific gravity, Atterberg limits, mechanical sieve analysis and California Bearing Ratio (CBR).

A 150 GSM non-woven needle-punched geotextile (2 mm thick) was placed at different layer positions inside the CBR mould to assess its reinforcing effect. For Red soil, CBR improved from 16.40% (unreinforced) to 18.40% with geotextile in the 1st layer; Black cotton soil improved from 6.20% to 8.00%. Geotextile in the 1st layer consistently yielded the highest strength gain. A comprehensive comparison of both soil types — with and without geotextile — is presented in terms of plasticity, bearing capacity, drainage, shear strength, and pavement suitability.

The study confirms that non-woven geotextile is an effective and economical solution for subgrade stabilisation, reducing pavement thickness requirements and improving service life.

Keywords: Geotextile, Red Soil, Black Cotton Soil, California Bearing Ratio (CBR), Atterberg Limits, ...

Encased Stone Column Technology

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ABSTRACT

Since the past decade there is lot of growth in infrastructure and now it is becoming very difficult to find suitable soils for construction purpose, hence this has forced geotechnical engineers to take up the challenge of constructing structures even on weak soft soils. The characteristics of soft clay are highly compressible, low shear strength and low permeability. General construction problem in this soil are insufficient bearing capacity, excessive post construction settlement and instability on excavation. Among various technologies implemented by engineers, stone columns are the most beneficial method for modification of weak soil. The stone columns and the granular pile derive their load carrying capacity from the confinement offered from the surrounding soil. But in very soft soil this lateral confinement from the surrounding soil may not be adequate for the stone column. Hence wrapping the granular pile with geotextile is one of the techniques to improve the performance of stone column. The idea of this encased stone column is to increase the bearing capacity and reduce the amount of settlement. In this paper an attempt is been made to study the effect of encasement on end bearing and floating stone column using a finite element analysis called Plaxis 2D.

Keywords: geotextile, soft soil, encased stone column.

Experimental and Analytical Investigation on Sand Bed Reinforced with Coir Geocell and Basal Planar Reinforcement

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ABSTRACT

The application of geosynthetic reinforcement for improving ground has attracted growing interest due to its proven ability to enhance soil load-bearing capacity. This study explores the application of coir geocells, a natural and sustainable alternative, for reinforcing sandy soil. Coir geocells fabricated from geotextiles with a mass per unit area of approximately 900 gsm were tested through laboratory experiments on unreinforced and reinforced sand beds. The experimental outcomes indicated substantial gains in load carrying capacity and reduced settlement, driven by the geocell's confinement effect. Performance was further enhanced by incorporating a planar coir geotextile beneath the geocell, resulting in 117.77% improvement in bearing capacity compared to geocell-only reinforcement. An analytical model accounting for lateral resistance and vertical stress dispersion was developed to foresee the pressure–settlement behaviour of reinforced soil. The comparison between analytical and experimental results showed that the analytical approach consistently predicted a higher load-carrying capacity. The analytical model overestimated the experimental load carrying capacity by about 25%. While the model captured the general effectiveness of coir geocell reinforcement, discrepancies with experimental data were attributed to material variability, idealized assumptions, and scale effects. The findings demonstrate the promise of coir geocells as a sustainable reinforcement method, while emphasizing the need to advance analytical approaches for accurate field-scale representation.

Keywords: *Coir Geocell, Coir Geotextile, Plate load test, Bearing capacity, Settlement, Analytical study*

Experimental study on improvement of sand strength using Geofoam and Sawdust based on California Bearing Ratio (CBR) Test

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ABSTRACT

This research presents an experimental investigation into the enhancement of soil bearing capacity through the addition of innovative stabilizing materials. The California Bearing Ratio (CBR) test was conducted on natural soil samples and on soil samples modified with two innovative materials: geofoam and sawdust. The study evaluates the potential of these materials to improve the mechanical properties of soil, particularly for road construction applications. Results demonstrate that the incorporation of geofoam at 10% by weight and sawdust at a mass of 500 g significantly enhance the CBR values compared to natural soil. The findings suggest that these innovative materials can be effectively utilized in pavement design and road construction to improve bearing capacity, reduce costs, and provide environmentally sustainable solutions. This paper presents a detailed analysis of the experimental methodology, results, and interpretation of findings with comparative evaluation of the three soil conditions studied.

KEYWORDS: *California Bearing Ratio (CBR), Geofoam, Sawdust, Soil stabilization, Subgrade Improvement, Waste utilization in Civil Engineering*

Evaluation of deformability characteristics and correlation between in-situ and geophysical moduli in a stylolitic limestone terrain

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ABSTRACT

The deformability properties of rock mass are crucial for design of foundation and underground structures of any hydropower projects, on or in the rock mass. There are several methods to determine the deformability properties of rock mass like direct method viz., conducting in-situ field tests (such as Borehole Jacking), which provide precise modulus of deformation at various depths and different direction in a borehole but are challenging, costly and time-consuming as well, on the other hand modulus value estimated from indirect methods are relatively easy, more accessible and can be adopted from relevant research work.

The present study aims to examine lithological heterogeneity of Flaggy Stylolitic limestone with depth and correlate modulus of deformation of rock mass with modulus value calculated from non-invasive engineering geophysical method of Vindhyan Supergroup (eastern belt), which includes limestone-rich formations. Usually, modulus of deformation of rock mass depends upon mineralogical composition, texture, structure, weathering conditions and other geological factors, this results in variations in the deformation modulus. The paper presents the comparison in evaluating the deformability characteristics direct from the borehole jacking tests (In-situ test) and the modulus evaluated from the geophysical method of testing - Multichannel Analysis of Surface Waves (MASW) within the studied site region. The modulus of deformation determined by borehole jacking test ranges from 13 GPa to 21 GPa upto the depth of 60 m on the other hand a relation using the shear wave velocity derived from the engineering geophysical study yields the modulus values ranging between 2 GPa to 41 GPa carried out upto the depth of 35 m within the site region. Moreover, a high degree of non-linear correlation is proposed within the primary investigation depth of 15 to 35 meters of site specific region between the in-situ modulus of rock mass with geophysical modulus, derived from Multichannel Analysis of Surface Waves (MASW). The paper also discusses about the use of different moduli for the design and their merits.

Keywords: *Flaggy Stylolitic Limestone, Engineering Geophysical Analysis, In-situ Borehole Jack Test, Correlations Study.*

Strength and Energy Absorption Characteristics of High-Plasticity Clay Stabilized with Cow Dung Ash and Fly Ash

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ABSTRACT

The stabilisation of high-plasticity clayey (HPC) soils using sustainable and low-cost materials has gained increasing attention in geotechnical engineering. This study investigated the potential of cow dung ash (CDA), an agricultural byproduct, for stabilising HPC soil, both as a standalone stabiliser and in combination with fly ash (FA), an industrial byproduct. Laboratory investigations were conducted by partially replacing the HPC soil with CDA at replacement levels of 5%, 7.5%, 10%, and 12.5% by dry weight. In addition, FA was incorporated through soil as additions ranging from 1% to 5% while maintaining the optimum CDA content. The strength response indicated an optimum CDA replacement level of 7.5%, yielding strength enhancements of 96% and 135% after 7 and 28 days of curing, respectively, compared to the untreated HPC soil. The addition of FA alongside CDA further enhanced strength, with an optimum FA content of 5% producing increases of 296% and 564% after 7 and 28 days of curing, respectively. In addition to strength enhancement, the treated soils exhibited notable variations in energy absorption capacity, which increased at the optimum CDA and CDA–FA combination, reflecting improved resistance to deformation under loading. Morphological characteristics revealed significant modifications in the soil fabric of the treated samples, characterised by the formation of pozzolanic reaction products that promoted cementitious bonding between soil particles.

Keywords: *High plasticity clayey soil, Cow dung ash, Fly ash, Energy absorption, Scanning electron microscopy*

Effect of loading waveform and drainage on the cyclic triaxial response of granular sand: a DEM study

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ABSTRACT

Granular soils under dynamic loading exhibit complex behaviour characterised by stiffness degradation, energy dissipation, and accumulation of permanent deformation. While shear modulus and damping ratio are the primary descriptors of such response, the influence of loading waveform, an essential yet received limited attention in cyclic soil testing. Experimental investigation of waveform effects is inherently constrained by boundary conditions and the inability to observe particle-scale mechanisms directly. This study aims to systematically investigate the effects of loading waveform (sinusoidal vs. triangular), drainage condition (drained vs. undrained), and density state on the cyclic triaxial response of granular sand using three-dimensional Discrete Element Method (DEM) simulations, and to relate macroscopic stiffness and damping behaviour to underlying micromechanical mechanisms.

A three-dimensional DEM model is developed within the open-source framework YADE. A periodic specimen with a length-to-diameter ratio of 2 is subjected to strain-controlled cyclic loading over strain amplitudes ranging from 0.05% to 2%, at a confining pressure of 100 kPa. Two density states are considered: loose ($D_r = 30\%$) and medium-dense ($D_r = 60\%$). Particle shape effects are incorporated through a calibrated rolling-resistance formulation and benchmarked against clump-based particles, with the particle size distribution matched to laboratory measurements. Undrained conditions are simulated using a constant-volume formulation. Shear modulus and damping ratio are computed from stabilised stress-strain hysteresis loops, and micromechanical analysis is conducted through the evolution of coordination number.

Results indicate that loading waveform exerts a noticeable influence primarily in the medium-strain regime. Triangular loading produces marginally higher initial stiffness, while sinusoidal loading yields slightly greater damping at comparable strain amplitudes. These waveform-induced differences diminish progressively with increasing strain amplitude and density, indicating a transition to a fabric-controlled response governed by particle rearrangement rather than loading path. Undrained conditions amplify stiffness loss and damping relative to drained conditions due to contact degradation under volume constraint; however, damping exhibits a non-monotonic trend under undrained loading, decreasing at large strains following fabric collapse. Micromechanical analysis reveals that the continuous reduction in coordination number under undrained conditions underpins the accelerated macroscopic stiffness loss and energy dissipation. The rolling-resistance spherical model faithfully reproduces laboratory trends at substantially lower computational cost than clump-based particles, making it suitable for large-scale parametric DEM investigations.

The study establishes that over the mechanically relevant strain range, cyclic stiffness degradation and energy dissipation are governed primarily by fabric-controlled mechanisms rather than the imposed loading waveform, irrespective of density state. Drainage condition significantly alters both the magnitude and trend of damping at large strains. These findings provide quantitative micromechanical insights that complement experimental characterisation of dynamic soil properties and support improved modelling of ground response under seismic and machine-induced loading.

Keywords: *Loading waveform, Shear Modulus, Damping Ratio.*

Correlation of hydraulic conductivity with index properties of in-situ polymerized bentonites under diverse chemical environments

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ABSTRACT

In-situ polymerized bentonites (IPBs) have evolved as promising barrier materials for waste containment applications, offering enhanced chemical resilience and sustained low hydraulic conductivity (k). However, despite their demonstrated potential, a detailed characterization of IPBs in terms of index properties and their correlation with k across diverse chemical environments has not yet been systematically conducted. Understanding the applicability of conventional index properties for predicting hydraulic performance is essential to advancing next-generation barrier technologies. With increasing reliance on polymerized bentonites, it is imperative to establish mechanistic clarity regarding how polymer incorporation alters hydraulic behavior under chemically aggressive conditions. This study was therefore conducted to bridge this knowledge gap and establish a mechanistic understanding that informs the design of chemically resilient polymer-modified bentonites.

Given this, the present study investigates the relationship between k and key index properties, namely the free swell index (FSI) and liquid limit (LL) of IPBs permeated with several pore fluids, including distilled water, NaCl, CaCl₂, and AlCl₃ solutions at concentrations ranging from 5 to 1000 mM, 1 M NaOH, 1M HNO₃, as well as coal combustion product leachates. Comparative analyses with pristine sodium bentonite (NaB) were conducted to elucidate mechanistic differences in hydraulic behavior.

Results demonstrate that NaB exhibits a strong inverse correlation between k and FSI, consistent with osmotic swelling as the principal governing mechanism. In contrast, IPBs maintain low k values ($<1 \times 10^{-10}$ m/s) across a wide range of FSI (3 to 30 mL/2g), indicating that osmotic swelling is not the dominant mechanism. Similarly, while NaB shows a clear inverse relationship between k and LL ($R^2 = 0.93$), IPBs show no distinct relationship, further confirming that different mechanisms govern their hydraulic behavior. The polymer dose played a crucial role because for doses $\leq 15\%$, IPBs exhibited variability in k under extreme chemical conditions, whereas for doses $>15\%$, it consistently achieved low k values (10^{-11} to 10^{-12} m/s), highlighting the threshold effect of polymer incorporation. Scanning electron microscopy images of specimens permeated with NaOH and HNO₃ solutions reveal microstructural evidence of pore clogging and clay-polymer encapsulation, supporting the observed insensitivity of k to conventional index parameters.

Overall, the study establishes that traditional indicators such as FSI and LL are inadequate for predicting the hydraulic performance of IPBs. Instead, polymer dose emerges as the critical design parameter, enabling the development of chemically resilient barrier materials tailored for diverse environmental conditions. These findings provide mechanistic clarity, methodological rigor, and practical guidance for advancing durable polymer-modified clay barriers in geoenvironmental engineering.

Keywords: *Hydraulic conductivity, Liquid limit, Swell index.*

(Use minimum three and maximum five keywords).

Geophone Directionality Effects on Surface Wave Amplitudes over Slopes

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ABSTRACT

Most MASW surveys are conducted on relatively flat soil surfaces where vertical geophones can be planted directly into the ground using spikes. On sloping surfaces, accurate wavefield acquisition is strongly influenced by geophone orientation and ground-contact conditions, but very limited studies are available. Misuse and Misalignment of geophones' axes on inclined surfaces can alter the recorded amplitude and frequency content of the signals, which may affect Fourier amplitude spectra (FAS) and dispersion image clarity, ultimately influencing the accuracy of shear wave velocity (V_s) estimation. Therefore, a systematic evaluation of geophone directionality and proper installation orientation is necessary to improve data acquisition strategies for MASW surveys conducted on sloping ground surfaces. This study investigates the influence of geophone orientation and natural frequency on wavefield quality on sloping PCC surfaces using FAS analysis by comparing conventional vertical geophones with omnidirectional geophones.

The effect of a geophone directly on a sloped surface is investigated using vertical and omnidirectional geophones. Vertical geophones (with natural frequencies of 4.5 Hz and 50 Hz) and omnidirectional geophones (with a natural frequency of 14 Hz) installed normal to the slope are installed, and the surface wave is recorded and analysed. Based on the available slope length, nine geophones were deployed at a 3 m offset to record the wavefield for 0.3 s at a sampling frequency of 8000 Hz. The effects of geophone directionality on wavefield amplification and attenuation are illustrated using Fourier amplitude spectra and Rayleigh-wave dispersion characteristics.

The study found that vertical geophones exhibit Misalignment of their sensitive axes, leading to distorted wavefield recordings and unreliable estimates of shear-wave velocity (V_s). In contrast, omnidirectional geophones provide improved wavefield capture and better alignment with the direction of source excitation. Based on these observations, practical recommendations are proposed for selecting the geophone type, illustrating the Geophone's natural frequency, and specifying the installation orientation to enhance V_s profiling on sloping ground surfaces, such as concrete and stone masonry dams.

Keywords: *Seismic wave; Geophone orientation; Sloping ground; Fourier amplitude spectra; MASW*

Energy-Dependent Behaviour of SPT N-Values: Insights from Simultaneous Measurement of Hammer Efficiency and Shear Wave Velocity

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ABSTRACT

The Standard Penetration Test (SPT) is widely used in geotechnical investigations, where the measured N-value serves as a primary index for estimating soil properties and developing empirical correlations. However, variability in hammer energy delivery, arising from differences in equipment and field practices, introduces significant uncertainty into measured N-values. Despite this, most conventional correlations are applied without explicitly accounting for energy transfer efficiency. This study examines the influence of measured hammer energy on the interpretation of SPT results and their correlation with shear wave velocity (V_s). A comprehensive field investigation was carried out in which SPT tests with direct energy measurement were performed in accordance with ASTM D4633 (2016), alongside V_s profiling using Multichannel Analysis of Surface Waves (MASW). Hammer energy transfer efficiency was quantified using the SPT-Hammer Energy Measurement Apparatus (SPT-HEMA). Energy evaluation was performed using both the conventional force-velocity (FV) method and the force-velocity change-in-direction (FVCD) approach, which captures the effective transferred energy more realistically. The analysis compares measured N-values across different energy levels with corresponding V_s profiles, highlighting inconsistencies that arise when energy variations are neglected. The results show that N-values are highly sensitive to energy transfer, whereas V_s remains relatively stable, resulting in discrepancies in conventional N- V_s relationships. This indicates that reliance on uncorrected N-values may lead to misinterpretation of soil stiffness. The study highlights the importance of incorporating measured energy into SPT-based interpretations and proposes an energy-informed approach to improve the reliability of N- V_s correlations in geotechnical practice.

Keywords: *Standard Penetration Test (SPT), Energy Transfer Ratio (ETR), Force-Velocity Change-in-Direction (FVCD) method, Shear Wave Velocity (V_s).*

Estimation of Erosion Rate in Goa using Hole Erosion Test

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ABSTRACT

Internal erosion is a critical failure mechanism in earth structures, particularly in regions dominated by lateritic soils, where experimental data are limited. This study investigates the internal erosion behaviour of lateritic soils collected from Rayesh Chambers, Margao and Cortalim, Goa, using the Hole Erosion Test (HET). Lateritic soils are widely distributed in Goa and are extensively used as foundation and construction materials; however, their susceptibility to internal erosion under seepage conditions has not been adequately investigated. Understanding the erosion characteristics of these soils is essential for assessing their long-term stability and performance in geotechnical applications. Therefore, this study was motivated by the need to evaluate the erosion resistance and erodibility of lateritic soils from the Cortalim and Rayesh regions of Goa using the Hole Erosion Test (HET). Internal erosion is one of the major causes of failure in earth structures such as embankment dams, levees, road embankments, and retaining structures. Lateritic soils are widely distributed in Goa and are extensively used as foundation and construction materials; however, their susceptibility to internal erosion under seepage conditions has not been adequately investigated. Understanding the erosion characteristics of these soils is essential for assessing their long-term stability and performance in geotechnical applications. Therefore, this study was motivated by the need to evaluate the erosion resistance and erodibility of lateritic soils from the Cortalim and Rayesh regions of Goa using the Hole Erosion Test (HET). The objective of the study was to conduct hole erosion test on soil samples collected from Cortalim & Rayesh chambers, Margao in Goa, where the deposits predominantly consist of lateritic soils. The laboratory experiments were carried out under hydraulic heads of 110 cm and 125 cm with test durations of 15, 25, and 30 minutes. The hydraulic heads of 110 cm and 125 cm were selected to produce controlled seepage forces capable of inducing measurable internal erosion without causing instantaneous specimen failure. The test durations of 15, 20, and 30 minutes were adopted to study the progressive development of erosion with time under varying hydraulic conditions. The Hole Erosion Test (HET) apparatus consists of a constant-head reservoir, an inlet chamber filled with 20 mm coarse aggregates, a mould containing the soil specimen, standpipes for measuring upstream and downstream heads, an air vent, an overflow unit, and a collection tank. Water is supplied continuously from the reservoir to maintain a constant hydraulic head. The aggregates dissipate flow energy, while a wire mesh prevents them from entering the specimen. Discharge is determined by collecting and measuring the effluent water at specified intervals. The test is terminated when either a stable flow condition is reached or a significant enlargement of the hole occurs due to erosion. The results showed a progressive increase in discharge, hole enlargement, hydraulic shear stress, and erosion rate with time for both sites. For the Rayesh Chambers, Margao samples, discharge increased from 0.00005 m³/s to 0.0000761 m³/s, while hole diameter expanded from 13 mm to 25 mm. Hydraulic shear stress ranged from 35.7 N/m² to 76.8 N/m², and erosion rates increased from 0.00039 kg/m²/s to 0.00057 kg/m²/s. The coefficient of erosion and erosion rate index were 4.6×10^{-3} and 3.66, respectively, indicating moderately rapid erosion. Similarly, the Cortalim samples exhibited discharge values from 0.000036 m³/s to 0.000083 m³/s, with hole diameters increasing from 15 mm to 38 mm. Hydraulic shear stress increased from 59.7 N/m² to 82 N/m², and erosion rates ranged from 0.000508 kg/m²/s to 0.00064 kg/m²/s. The coefficient of erosion was 2.1×10^{-5} . An erosion rate index of 5.33 also classified the soil as a very slow rate of erosion. The findings highlight the high vulnerability of lateritic soils in Goa to internal erosion and provide valuable baseline data for erosion modelling and the development of mitigation strategies for earth structure.

Keywords: *Hole erosion test, hydraulic shear stress, hole diameter, coefficient of erosion*

Dynamic Tensile Strength and Fragmentation Characteristics of Cemented Sandstone under Impact Loading

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ABSTRACT

The dynamic behavior of brittle geomaterial under high-strain loading conditions is mainly influenced by tensile fracture and subsequent fragmentation. However, experimental studies on strain-rate dependence and fragmentation characteristics are still limited. This study examines the quasistatic and dynamic indirect tensile strength and fragmentation behavior of cemented sandstone. The Brazilian disk test uses both a compression testing machine and a Split Hopkinson Pressure Bar (SHPB) system. The quasistatic experiment set the baseline tensile strength at 12 MPa. Brittle tensile failure is observed with clear diametric splitting. Dynamic tests are conducted under validated stress equilibrium conditions to ensure reliable results. The dynamic tensile stress time history shows rapid stress buildup, followed by abrupt post-peak failure. This indicates high-strain-rate tensile fracture. Dynamic tensile strength increases significantly to 22-30 MPa at a strain rate of 30-60 s⁻¹. This represents an enhancement of approximately 2.5-3 times the quasistatic result. Delayed crack initiation and inhibited micro-crack coalescence under fast loading conditions cause this enhancement. After the SHPB test, fragments from each sample are systematically collected. Sieve analysis combined with the Weibull distribution indicates a progressive reduction in the mean fragment size with increasing strain rate. Image-based analysis is performed in ImageJ to quantify the morphology of the fragments. Parameters assessed include the Circularity index, Aspect ratio, roundness, and solidity. Results show a transition from angular, elongated fragments at lower strain rate to finer, more quantitative fragments at higher strain rate. This indicates increased crack-branching fragmentation intensity. The thorough evaluation of quasistatic and dynamic tensile strength, along with fragmentation analysis, provides insight into strain-rate-dependent failure mechanisms in cemented sandstone. These findings have direct implications for blasting, tunneling, and dynamic loading in rock engineering.

Keywords: *Cemented sandstone, Dynamic tensile strength, Split Hopkinson Pressure Bar (SHPB), Strain-rate dependency, Fragmentation analysis, Image processing (ImageJ)*



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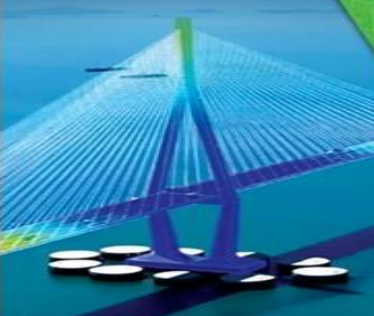


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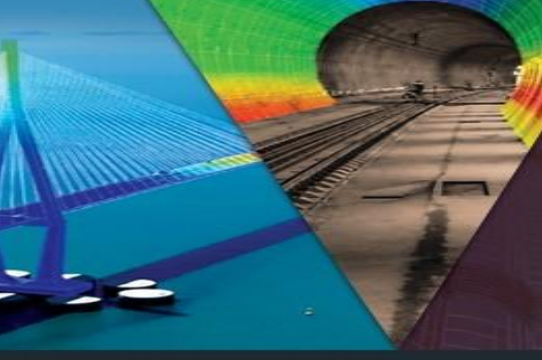
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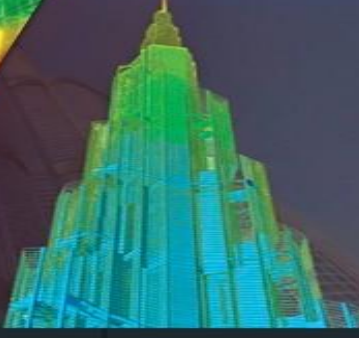
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