



DEPARTMENT OF CIVIL ENGINEERING



Proceedings of
CIVIL ENGINEERING
Research Symposium 2023

CERS 2023

BOOK OF ABSTRACTS



Department of Civil Engineering
University of Moratuwa

September 2023

CIVIL ENGINEERING RESEARCH SYMPOSIUM
2023

27th September 2023

Department of Civil Engineering

University of Moratuwa

Sri Lanka

Dedicated to

Professor Malik Ranasinghe

Professor Athula Kulathilaka

Professor Anura Nanayakkara

Professor Ruwan Weerasekera

formally retiring from University of Moratuwa on 30th September 2023.

Proceedings of the Civil Engineering Research Symposium - 2023

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Civil Engineering Research Symposium 2023

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Message from the Head of the Department

As the Head of the Department, I am delighted to present the proceedings of the Civil Engineering Research Symposium (CERS) 2023. The proceedings consist of the research outputs of undergraduate students of 2018 Intake, a selected group of researchers from National Building Research Organisation (NBRO) and a selected group of postgraduate students.



This event stands as a testament to the incredible dedication, innovation, and passion that our department embodies. The field of civil engineering plays an indispensable role in shaping the world around us. It is not merely about constructing buildings but about creating a sustainable and resilient future for generations to come. This symposium serves as a platform for us to celebrate the relentless pursuit of knowledge and sharing of groundbreaking research that will drive our profession forward. This forum is an opportunity to exchange ideas, foster collaboration, and inspire each other to push the boundaries of what civil engineering can achieve. Since our department is at the forefront of research in multi-faceted areas, I am confident that the presentations and discussions at the Symposium will provide valuable insights and solutions.

Another unique feature of CERS 2023 is that the Symposium is dedicated for four of our own eminent professors who retire from the service on 30 September 2023, Prof. Malik Ranasinghe, Prof. Anura Nanayakkara, Prof. Athula Kulathilaka and Prof. Ruwan Weerasekera. All four retiring professors have been the pillars of knowledge, wisdom, and inspiration in our academic journey. Your tireless dedication to teaching, research, and mentorship has left an indelible mark on all of us. Your contributions to the field of Civil Engineering have not only advanced the science and technology of our discipline but have also paved the way for countless students to embark on their own paths to success.

Finally, I would like to express my deepest gratitude to all the researchers, students and industry professionals who have dedicated their time and expertise to contribute to make this event a success. Your passion for advancing the field of civil engineering is truly inspiring. I also want to thank our sponsors and partners for their unwavering support. Your contributions enable us to organise a symposium of this calibre and facilitate knowledge sharing that has the potential to shape the future of civil engineering. In closing, I am excited about the wealth of knowledge that will be shared during this symposium and the positive impact it will have on our field.

Prof. (Mrs.) Chinthia Jayasinghe

Senior Professor in Civil Engineering
Head of the Department of Civil Engineering
University of Moratuwa

- Dedicated to -

Professor Malik Ranasinghe

Professor Athula Kulathilaka

Professor Anura Nanayakkara

Professor Ruwan Weerasekera

Professor Malik Ranasinghe

Professor Ranasinghe was appointed to the Department of Civil Engineering at the University of Moratuwa as a Probationary Assistant Lecturer in June 1984. In 1985 he won an Open Canadian Commonwealth Scholarship for his postgraduate studies. In 1986 he obtained his MASc degree and in 1990 his PhD degree in Civil Engineering Economics from the University of British Columbia, Vancouver, Canada. After completing his doctoral degree, Professor Ranasinghe returned to the University of Moratuwa in October 1990, and he was appointed as a Senior Lecturer Grade II.



In June 1996, Professor Ranasinghe was promoted on merit to Associate Professor in Civil Engineering. In August 2000, he was promoted on merit as Professor in Civil Engineering and in August 2008, he was promoted to Senior Professor. His research focus was to combine civil engineering economics, risk analysis and environmental economics with project management. He has 140 research publications, of which over 75 are international refereed publications. He is a Sri Lanka Tier 4* researcher and his Hirsch Index (h-Index) for research publications is 19.

In April 2000, Professor Ranasinghe was appointed as Head, Department of Civil Engineering. In March 2001, he was elected as the Dean of the Faculty of Engineering. It was a challenging period as the new Semester system was introduced to the Faculty of Engineering. He effectively managed the transition to the Semester system, the students as well as the staff members. In March 2004 he stepped down as Dean of the Faculty of Engineering after one term.

In November 2005, Professor Ranasinghe was appointed as Vice Chancellor of the University of Moratuwa. He served two terms as the VC. His End of Term report approved by the University Council concluded that during the last six years (2005-2011), the image of University of Moratuwa had improved significantly, had earned accolade from the Auditor General and the Chairman of the Committee on Public Enterprises (COPE) as one of the best managed public enterprises in Sri Lanka, and was reflected in the latest global ranking, the perception of the employers and the Society.

Professor Ranasinghe was a former member of the University Grants Commission, a Council Member of the National Research Council, a former Chairman of the Committee of Vice-Chancellors and Directors (CVCD), a former Council Member of the Association of Commonwealth Universities, and former Chairman, Centre of Excellence in Project Management at the University of Moratuwa. He was a Fellow at the National University of Singapore during his sabbatical leave.

In 1999, Professor Ranasinghe was awarded the SLASS General Research Committee Award for Outstanding Contribution to Sri Lankan Science, UGC and Hiran Tillekaratne Research Fund Award for Outstanding Postgraduate Research – 2000 in the academic discipline of Engineering for the period 1975 to 1999, Professor E O E Pereira Award for the Best Paper presented at the Annual Sessions 1998/99 of the IESL. Professor Ranasinghe was awarded the

Trinity Prize for Engineering for 2004 in recognition of the outstanding contributions made to his chosen profession, the CVCD awarded its biennial Most Outstanding Senior Researcher in Technology and related Sciences including Engineering, Architecture, Quantity Surveying and Information Technology award in 2012. World Education Congress 2012, Mumbai, India honoured him with the award for Outstanding Contribution to Education. At the 4th Asia's Best B-School Awards 2013 held in Singapore, he was honoured with the prestigious Education Leadership Award. In January 2022 Professor Ranasinghe delivered the inaugural Rev. A.G Fraser Memorial Oration as the main event of the 150th Anniversary celebrations of Trinity College, Kandy.

Professor Ranasinghe is a Chartered Engineer, International Professional Engineer and Fellow of the Institution of Engineers, Sri Lanka, Fellow of the National Academy of Sciences, Sri Lanka, Fellow of the Institute of Project Managers, Sri Lanka and Graduate Member of Sri Lanka Institute of Directors. He is the Chairman of the Information and Communication Technology Agency (ICTA) of Sri Lanka.

Since 2003 Professor Ranasinghe has been an Independent non-Executive Director of Public Listed Companies (PLCs). At present he is an independent non-Executive Director of Access Engineering PLC, Resus Energy PLC, Teejay Lanka PLC and United Motors Lanka PLC. He was a former Chairman of Sampath Bank PLC and former non-executive Director of the Colombo Stock Exchange, Sampath Bank PLC, Hemas Power PLC, and Lanka IOC PLC.

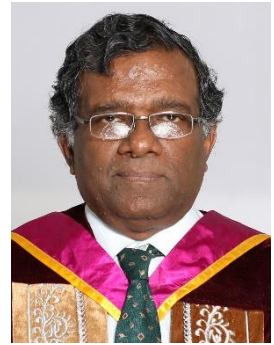
Professor Ranasinghe along with the Director, CODL helped to launch the online education initiative open.uom.lk platform on 22 February 2022, a free of charge platform to prepare school leavers to be employable Trainee Full Stack Developers. Today, the open.uom.lk platform has over 220,000 students registered on it, exponentially exceeding the modest expectations UoM had at its launch. In October 2022 open.uom.lk and its developers including Professor Ranasinghe were awarded the prestigious 8th European eLearning Excellence Award for 2022.

Professor Athula Kulathilaka

Professor Kulathilaka obtained BSc Eng (Hons) in Civil Engineering from the University of Moratuwa with first class honours in 1981. He joined the Department of Civil Engineering as a Probationary Assistant Lecturer in July 1981 and proceeded for postgraduate studies in 1984 on receiving a Scholarship from Monash University, Australia.

Professor Kulathilaka obtained his doctoral degree from Monash University specialising in the field of Geotechnical Engineering. Upon his return, he was appointed Senior Lecturer Grade II in April 1991.

He was promoted Senior Lecturer Grade I in April 1997, Professor on merit in April 2006 and Senior Professor in 2014. He is a Chartered Engineer since 2004.



Professor Kulathilaka was the Head of the Department of Civil Engineering from March 2019 to June 2021. He served the University as Chairman - Staff Development Centre, from September 2008 to September 2013 where a Centre for IT skills with 35 computers was developed with special funding from University Grants Commission.

Professor Kulathilaka pursued research in the areas of Earth Retaining Structures, Ground Improvement Techniques, Unsaturated Soil Mechanics, Rain induced Slope Failure and Stabilisation of Slopes. He has supervised many undergraduate projects in these areas and more than 30 postgraduate projects. He has published over 100 refereed research articles in conferences and refereed journals.

Professor Kulathilaka has provided guidance to Road Development Authority and National Building Research Organisation (NBRO) through his expertise in the field of geotechnical engineering in construction of expressways in the country in the areas of Soft Ground Improvement and Stabilisation of Cut Slopes. The experience gained through these projects led to the upgrading the teaching materials and formulating research projects, thus benefitting both undergraduate and postgraduate students. He won the Commonwealth Research Fellowship to University of Newcastle Upon Tyne in the UK in 2004.

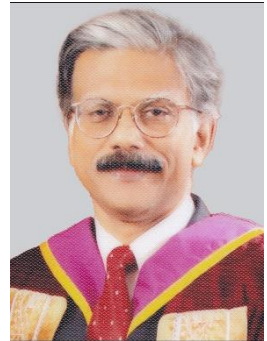
Professor Kulathilaka has provided expert guidance to NBRO in many Landslide Rectification projects throughout the country. He has guided young Engineers in the design measures for many potential landslides and post landslide rectifications. Professor Kulathilaka has contributed immensely to the advancement of Geotechnical Engineering through numerous activities conducted by the Sri Lankan Geotechnical Society. He held the posts of Honorary Secretary from 1994-2004, Vice President from 2005-2011 and President from 2011 to 2021. During this period, the Geotechnical Society organised several activities to advance the field of Geotechnical Engineering in the country. Three International conferences were organised in 2007, 2015 and 2021 with the participation of world renowned academics and practitioners as keynote speakers and resource persons along with Sri Lankan Geotechnical Engineers. Workshops were conducted with leading international experts to transfer new knowledge. Events such as Project Day (conducted annually uninterrupted from year 2000) – a competition

among undergraduate students doing research projects in the field of Geotechnical Engineering were organised to enhance their research and presentation skills.

Professor Kulatilaka is among those who entered the portals of the University of Moratuwa, then a fledgling university as a young undergraduate. His uninterrupted service of dedication and commitment to the University, in the fields of teaching, research and consultancy, for a period of over four decades is an inspiration to his colleagues who consider him a mentor and role model.

Professor Anura Nanayakkara

Professor Nanayakkara obtained BSc Eng (Hons) in Civil Engineering from the University of Moratuwa in 1982. He was recruited to the academic staff of the university immediately thereafter as a Probationary Assistant Lecturer in the Department. He proceeded to the University of Tokyo in 1985 from where he obtained both an M.Eng degree in 1987 and a D.Eng degree in 1990. His doctoral dissertation was on the topic of “Computational model for pumpability of concrete”. Professor Nanayakkara returned to the University of Moratuwa in 1990 as a Senior Lecturer Grade II and was promoted to Professor on merit in 2006 and Senior Professor eight years thereafter.



Professor Nanayakkara served as Head of the Department of Civil Engineering from 2013 to 2016. During this period, he was also required to act as dean of the Faculty of Engineering on four occasions. It was during his tenure as Head of Department, that the Department of Civil Engineering obtained full accreditation from the Institution of Engineers Sri Lanka for its undergraduate degree which granted recognition among the Washington Accord signatories.

Professor Nanayakkara’s research is in the area of Concrete Technology focusing on the use of alternative ingredients used in making of concrete, mitigation of early age thermal cracking, and durability of concrete. The research carried out by Professor Nanayakkara and his collaborators has impacted the Sri Lankan construction industry beneficially. The use of offshore sand as an alternative to river sand, the use of fly ash in concrete (both to utilise a waste material and to improve concrete durability), and the mitigation of plastic shrinkage cracking in ready-mixed concrete pours have all been driven by their research. His research collaboration with National Building Research Organisation led to the patent on a highly permeable and energy absorbing paving block made from polyester spandex fabric waste where he is one of the three inventors.

Professor Nanayakkara’s research has led to many publications and at present he counts 70 publications in refereed journals and conference proceedings. He won the Anton Award for the best technical paper on “Water related infrastructure” at Annual Sessions of IESL in 2006. He was the co-author of the paper that was adjudged as the best paper at the Annual Sessions of the Society of Structural Engineering Sri Lanka in 2018 which was awarded the Gold Medal. Professor Nanayakkara won the Commonwealth Academic Fellowship to Imperial College of Science Technology and Medicine, University of London in the UK in 2004 while in 1999 he secured the AIEJ (Association of International Education, Japan) Research Fellowship. He is the recipient of many awards for his outstanding contribution to industry and the Profession of Structural Engineering which includes the President’s Award for his Scientific Research contribution in 2010 and 2017.

Professor Nanayakkara has contributed immensely to the development of national standards relating to building materials over the past 25 years having served and chaired working groups and sectoral committees of the Sri Lanka Standards Institution. Professor Nanayakkara was a committee member and Chairman of the committee set up to develop the Model Code for

Concrete in Asia from its formative stages. His expertise was sought by the NBRO where his shared knowledge, skills, and experience have enabled their research teams to achieve tangible outcomes. Professor Nanayakkara has made a significant contribution to the research and development programme at NBRO over the last ten years. Preparation of Handbooks for the selection of materials and products for the construction industry, development of alternative fibres for roofing sheets, and investigation of the suitability of Fly Ash Blended Cement for construction of concrete water storage tanks are some of his significant contributions.

Professor Nanayakkara's skills as an organiser and as chairperson have contributed to the success of many a conference both in Sri Lanka and overseas. He also serves as a reviewer of prestigious journals such as the Journal of the American Society of Civil Engineers Journal of Materials in Civil Engineering and the Construction and Building Materials Journal.

Professor Nanayakkara is a chartered engineer, of the Institution of Engineers, Sri Lanka, and an Honorary Fellow of the Society of Structural Engineers, Sri Lanka. He has been involved in many structural assessment projects for industry. He was a Senior Structural Engineering Consultant for the Project Consultancy Unit, University of Moratuwa on the design review and approval of the Colombo Lotus Tower Project. Assessment of properties of PFA blended cement in concrete in 2000, assessment of suitability of offshore sand, manufactured sand and quarry dust for concrete plastering work in 2002, development of an inorganic polymer concrete material for walling units in 2004, investigation of pile cap cracking of Southern Transport Development Project in 2009 and review of structural design of rapid sand filter house of Chilaw water treatment plant in 2012, are some of his other notable contributions.

An alumnus of the University of Moratuwa, Professor Nanayakkara counts over forty years of uninterrupted service to the University, in the fields of teaching, research and consultancy. His commitment and excellence in research in Concrete Technology is unparalleled.

Professor Ruwan Weerasekera

Professor Weerasekera obtained BSc Eng (Hons) in Civil Engineering from the University of Moratuwa in 1982 and joined the Department of Civil Engineering as a Probationary Assistant Lecturer in July 1983. He proceeded for postgraduate studies in 1985 upon receiving a Scholarship from the University of Calgary, Alberta, Canada.



Professor Weerasekera obtained his doctoral degree from University of Calgary specialising in the field of Structural Engineering in 1991 and returned to the University of Moratuwa as a Senior Lecturer Grade II. He was promoted Professor on merit in 2009 and Senior Professor in 2017. He obtained charter status from the Institution of Engineers Sri Lanka in 2006.

Professor Weerasekera led the Building and Structural Engineering Group of the Department for over seven years and contributed to the improvement of structural analysis and design modules of the undergraduate programme. He played a pioneering role in the commencement of the postgraduate course in Structural Engineering Design and served as its first coordinator. He taught a number of modules on the course and even those on the Highway Engineering postgraduate programme.

Professor Weerasekera also served as the first Director, Quality Assurance of Faculty of Engineering for 3 years. He introduced a process of documentation that enhanced the quality of teaching and assessment within the faculty.

Professor Weerasekera's research interests are in Structural Engineering and encompasses Analysis, Design and Materials Technology. His research has won awards. He is also the co-author of over 60 research papers.

Professor Weerasekera was also a resource person and the organiser of several short courses organised by the Department of Civil Engineering under the auspices of Uni-Consultancy Services of the Faculty of Engineering. The topics covered were Bridge Structures, Water-retaining Structures, Transmission line Structures and Finite Element Analysis. Some of these courses were repeated due to the heavy demand in the Industry and Academia with the support of ACECOMS, AIT of which Society of Structural Engineers acted as a Satellite Centre.

Having held several posts in the Society of Structural Engineers for well nigh twenty five year including that of Honorary Secretary for seven years, Professor Weerasekera was elected to the coveted position of President for four consecutive years (2012-2015). In the year 2015, he had the privilege of being Chair, of the Silver Jubilee International Conference in Structural Engineering in Colombo, on the theme "Towards Excellence in Structural Engineering". A conference well attended by world reputed professionals in Structural Engineering. In recognition of his overall career achievements and his dedicated service to the Structural Engineering community, he was conferred an Honorary Fellowship in 2017 by Society of

Structural Engineers, Sri Lanka. He has also been a practising Structural and Civil Engineer for several projects in Sri Lanka.

An alumnus of the University of Moratuwa, Professor Weerasekara's service spans forty years. His pioneering activities within the university and with the structural engineering fraternity is exemplary.

Symposium Agenda

08:30 – 08:35	Lighting the Oil Lamp
08:35 – 08:40	Opening remarks by the Head of the Department
08:40 – 08:55	Address by the Chief Guest, Mr.Daniel Bood, Chargé d’Affaires (acting), Canadian High Commission
08:55 – 09:30	Keynote Address by Eng. (Dr) Asiri Karunawardena, Director General, National Building Research Organisation
09:30 – 10:00	Morning Tea Break
10:00 – 10:40	Research Presentations: Technical Session 1 ¹
10:40 – 11:00	Panel Discussion for Technical Session 1
11:00 – 11:40	Research Presentations: Technical Session 2 ²
11:40 – 12:00	Panel Discussion for Technical Session 2
12:00 – 12:40	Research Presentations: Technical Session 3 ³ - NBRO
12:40 – 13:00	Panel Discussion for Technical Session 3
13:00 – 14:00	Lunch Break
14:00 – 14:25	3-MT Challenge Video Presentation and Award Ceremony
14:25 – 16:30	Farewell Lectures by Four Retiring Professors Prof. Malik Ranasinghe Prof. Anura Nanayakkara Prof. Athula Kulathilaka Prof. Ruwan Weerasekera
16:30	Concluding Remarks and Vote of Thanks by Conference Secretary

¹ Research Presentations: Technical Session 1 (10:00 – 10:40)

- 10:00 – 10:10 Analysis of curved crease origami structures by K.A.L.H. Kuruppu
- 10:10 – 10:20 Developing a masonry block by using glass waste as an alternative material by O.M. Hasaranga
- 10:20 – 10:30 Vulnerability of Colombo suburbs for Kelani river floods by P.G.T.N. Geeshan
- 10:30 – 10:40 Development of an economical level of service estimation model using GPS data in a mixed traffic condition by S.S. Jayawardhana

² Research Presentations: Technical Session 2 (11:00 – 11:40)

- 11:00 – 11:10 Finite element analysis of a deep excavation supported using a secant pile wall: a case study by V.S.S.D. Silva
- 11:10 – 11:20 Prediction and uncertainty quantification of mechanical properties of homogenised woven composites by G. N. C. Ariyasinghe
- 11:20 – 11:30 Assessing the readiness for digital technologies adoption for enhancing productivity in the Sri Lankan construction industry by I.H.N. Chathuranga
- 11:30 – 11:40 Evaluation of environmental impacts of solar PV systems with conceptual life cycle assessment and recycling of end-of-life PV panels by A.R.I. De Alwis

³ Research Presentations: Technical Session 3 from NBRO (12:00 – 12:40)

- 12:00 – 12:10 Development of fibre-reinforced paving block for outdoor sports surfaces by G.K.B.M. Gannoruwa
- 12:10 – 12:20 Development of ISO standard sand from local silica sand deposits for cement testing by E.G.H.D.B. Ellegama
- 12:20 – 12:30 Roadside slope risk assessment in Sri Lanka by V.G.D. Gangani
- 12:30 – 12:40 Validation of rain-induced failure of unsaturated colluvium slopes: a case study by M.P. Amarasinghe

Keynote: An insight into the advances of Geotechnical Engineering in Landslides and soil improvement technology in Sri Lanka



About the Keynote Speaker

Eng. (Dr.) Asiri Karunawardena is the Director General/Chief Executive Officer of the National Building Research Organisation (NBRO) of Sri Lanka. NBRO is the main focal point for landslide disaster risk reduction in Sri Lanka and it is taking a leading role in promoting resilient and safe infrastructure construction in the country.

Dr. Karunawardena graduated as a Civil Engineer and obtained his Master's Degree in Geotechnical Engineering from the University of Moratuwa, and he obtained Doctoral degree of Engineering from Kyoto University, Japan. His major fields of work are related to Landslide risk reduction, Geotechnical Engineering applications, Resilient constructions, etc. He has engaged in many large-scale infrastructure development projects as a Geotechnical Expert and authored over 10 peer-reviewed technical papers. He is a Chartered Engineer and a member of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE).

As the Director General of the institute, he leads a team of multidisciplinary professionals to reduce the losses due to disasters by integrating disaster risk reduction into the planning and development process in the country to achieve the vision of safer built environment and sustainable development gains.

Synopsis

Landslides are a fatal natural cause in Sri Lanka, which needs to be determined and managed adeptly. Detailed field and laboratory investigations, instrumentation and monitoring were performed to investigate the characteristics and the possible causes of the landslide. As a proactive action to minimise the adverse impacts of landslides, structural mitigation is being carried out using several highly advanced slope stabilisation techniques by assessing the failure mechanism by applying Geotechnical Engineering principals. This includes the use of retaining walls, soil nailing, anchoring, or drainage systems, depending on the specific site conditions.

The construction of expressways in Sri Lanka involved in extensive ground improvement work as many parts of the Expressway traverses through flood plains and marshy ground consisting of very soft peat, organic soils, and clays. Soft ground improvement design had to be carried

out in order to control the settlements and to ensure the stability of the highway embankment. Depending on the ground conditions, various ground improvement methods including remove and replacement, preloading, preloading with vertical drains, dynamic compaction and vacuum consolidation were applied to improve the properties of the natural ground to support infrastructure development and mitigate the risks associated with weak or problematic soils.

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ANALYSIS OF CURVED CREASE ORIGAMI STRUCTURES

K.A.L.H. Kuruppu¹, H.M.Y.C. Mallikarachchi^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Research on origami-based folding patterns has led to major technical developments from nanoscale metamaterial to large-scale deployable space structures. Deployable space structures such as solar sails and reflectors require them to be stored in a small volume while being able to deploy into a large configuration when in operation. The developability of origami facilitates the employment of deployability and self-actuation qualities in making these lightweight structures. In general, these structures are constructed with ultrathin materials and the quality of deployed surface increases the efficiency of the functionality of the structure.

The curved crease origami structures consist of fewer creases than their equivalent straight crease counterparts. Lower number of creases leads to increase in efficiency as well as faster manufacturing rate. At present origami related research is mainly focused on predicting straight crease behaviour and the possible use of curved crease origami folding patterns requires more attention. This research is focused on studying the effect of membrane thickness on the folding behaviour of the curved-crease Miura Ori structures.

Analytical equations for predicting the edge curve motion were first considered after a thorough literature review and an elliptical curved-crease Miura structure with a radii 40 mm and 69 mm made of 80 gsm copier paper was selected as a case study. The proposed numerical scheme for predicting folding and deployment behaviour discretises the curved crease into a series of straight line segments which are then replaced with a series of rotational springs. The equivalent rotational stiffness of a perforated straight crease was measured using a simple experimental setup which measures the force required to open a crease with crease angle opening. Same procedure was repeated for three different specimens and the mean rotational stiffness was used as an input to the rotational spring employed in the numerical model. The selected curved crease pattern was then simulated using the proposed numerical technique to obtain the deformed configuration under predefined loading conditions. The predicted shape was then validated against surface mesh obtained using a LiDAR scan of a physically constructed model under similar loading conditions. The experimentally validated numerical technique was then used to assess the changes in folding behaviour with changing membrane thicknesses. It is shown that the membrane thickness has a clear impact on the folding of the curved crease Miura Ori structure.

Change in edge curve location leads to an overall change in displacement of the folded structure and hence the overall deployability of the structure changes with varying membrane thickness. This change of the edge curve coordinates gets accumulated when the base structure is tessellated to form the final deployable structure.

Keywords: Curved crease, Origami, Miura Ori, Crease stiffness

* Correspondence: yasithem@uom.lk

ANALYSIS OF CURVED CREASE ORIGAMI STRUCTURES



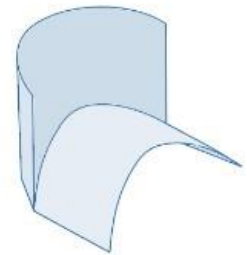
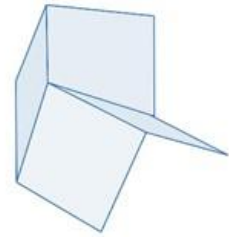
Starshade deployment



Curved beech leaf crease pattern -
Initially wrapped to intermediate stage to final deployment



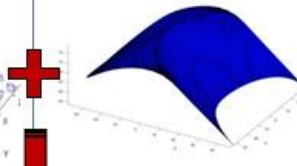
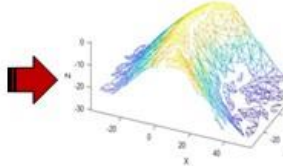
Stages in numerical simulation -
Fully folded to intermediate stage to final deployment



Reduction in number of
creases from straight to
curved crease origami

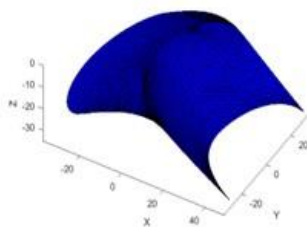


3D Reconstructed Miura Ori curved crease
fold mesh by using LiDAR scanning

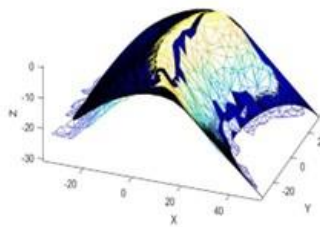


3D Reconstructed numerical folded model
results

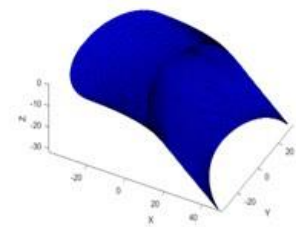
0.5 mm thickness



0.1 mm thickness



1 mm thickness



Comparison of numerical model surfaces of different thicknesses fold at the same dihedral angle

DEVELOPING A MASONRY BLOCK BY USING GLASS WASTE AS AN ALTERNATIVE MATERIAL

O.M. Hasaranga¹, C. Jayasinghe^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The global concern of solid waste management has led to an urgent need for innovative solutions. Among these challenges is the substantial presence of post-consumer glass waste in solid waste streams, causing environmental issues and posing recycling dilemmas. The accumulation of glass waste exacerbates environmental problems, necessitating effective strategies for waste reduction and resource conservation. An intriguing avenue to address waste management challenges while conserving natural resources is the incorporation of waste glass as a substitute for fine aggregate in masonry blocks. To investigate the viability of this solution, a comprehensive experimental study was undertaken. The study primarily focused on utilising industrial waste glass as a replacement for fine aggregate in masonry block production. The experimental setup encompassed an array of tests, including the evaluation of compressive strength, water absorption, moisture content, spray erosion resistance, and the determination of dry, wet, and bulk densities of the masonry blocks. Four distinct concrete mix designs were formulated, with varying proportions of M/sand being replaced by a combination of glass waste and quarry dust. The results revealed that the mix design substituting 25% of M/sand with glass waste exhibited remarkable performance across multiple parameters. This particular mix design demonstrated enhanced compressive strength, improved water absorption characteristics, optimal moisture content levels, and excellent spray erosion resistance. Notably, the performance of this mix surpassed that of the controlled mix, emphasising the potential of waste glass as a sustainable alternative in masonry block production. Additionally, panel testing was conducted to assess the structural integrity of the masonry blocks with the highest compressive strength mix design. This testing confirmed the exceptional performance of the mix designs, showcasing results that exceeded the requirements stipulated in relevant codes.

In conclusion, the incorporation of waste glass as a substitute for fine aggregate in masonry blocks presents a promising avenue for sustainable waste management and resource conservation. The findings from this comprehensive study underscore the viability of this approach, emphasising the potential to mitigate waste accumulation while enhancing the performance of masonry block structures.

Keywords: Waste glass, Masonry blocks, Sustainable construction, Compressive strength, Durability

* Correspondence: chintha@uom.lk

DEVELOPING A MASONRY BLOCK BY USING GLASS WASTE AS AN ALTERNATIVE MATERIAL

AIM & OBJECTIVES

<p>AIM</p> <p>The aim of this study is to develop the concept of Masonry unit technology with the required durability and strength standards by using glass waste as a potential replacement for aggregates used in common concrete masonry units to provide a highly sustainable building walling material for the future of construction</p>	<p>OBJECTIVES</p> <ul style="list-style-type: none"> ➤ Propose suitable mix designs for Masonry blocks with glass waste as an alternative material ➤ Determine the Compressive Strength for the different mix designs ➤ Determine the Water absorption and the durability characteristics of the material ➤ Assess the compressive performance of wall panels
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METHODOLOGY	Collection of the literature and understanding the concepts that followed in similar experiments.
	Gather the resources which are needed for the experimental process such as cement, aggregates, mixing equipment and glass waste by contacting glass company.
	Understand how the experiment should be carried out
	Create masonry blocks by using available resources and conducting the required testing
	Compare the results and arrive at conclusions

TESTING	STANDARDS FOLLOWED
Crushing Strength of Masonry Block	SLS 855
Water Absorption and Moisture Content	SLS 855
Spray Erosion Test	SLS 1382-Part_02
Dimensions of the Block	SLS 855
Service, Dry and Wet Density	ASTM C140
Determination of Compressive Strength of wall panel	BS EN 1052-1: 1999-Part 1

Mix Designs					
Materials	Base	M.D.01	M.D.02	M.D.03	M.D.04
Cement (Kg)	50.00	50.00	50.00	50.00	50.00
Glass (Kg)	0.00	47.50	95.00	157.50	220.00
M/Sand (Kg)	190.00	142.50	95.00	95.00	95.00
Quarry Dust (Kg)	250.00	250.00	250.00	187.50	125.00
(10-05)mm Metal (Kg)	125.00	125.00	125.00	125.00	125.00
Water (Kg)	25.00	25.00	25.00	25.00	25.00



VULNERABILITY OF COLOMBO SUBURBS FOR KELANI RIVER FLOODS

P.G.T.N. Geeshan¹, T.M.N. Wijyaratne^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Floods are globally recognised as a foremost and expensive hazard, cause extensive damage worldwide, affecting lives, property, and crops. Low lying terrain in most of the river basins of Sri Lanka and heavy rainfall in central highlands magnify the susceptibility to these catastrophic events. The study area is lower Kelani basin which is the second largest river in Sri Lanka. It originates from the Central Highlands and flows westwards to the country's western coast. The lower basin of the Kelani River, including the Colombo metropolitan, the business capital of Sri Lanka with a high population, frequently experiences severe inundation due to high discharges of the Kelani River and localised heavy rainfall events.

HEC-RAS 2D model was used in this study to analyse water levels in the Kelani River and assess flood extents with depths and velocities, enabling reliable future predictions despite limited data availability. The model was calibrated and validated by comparing observed and simulated water levels during the May 2008 and June 2016 flood events, demonstrating satisfactory performance with a Root Mean Square Error of 0.134 m, coefficient of correlation of 0.951, Nash-Sutcliffe efficiency of 0.914, and a goodness-of-fit index of 70.1% for inundation extents. Additionally, an ArcGIS model was employed to generate a flood susceptibility map for the lower basin of the Kelani River.

This study involves several steps, including collecting data, setting up the HEC-RAS 2D model, analysing model parameter sensitivity, selecting parameters, calibrating and validating model simulations, generating flood inundation maps, and exploring the effectiveness of the flood bunds during extreme flood events. The study included identifying flood-prone areas in Colombo suburbs, assessing the flood risk through simulation of hypothetical flood bund breaches, estimating the flood extent and related maximum flood depths and maximum velocities. Evaluating the efficiency of existing flood bunds for floods with different return periods and assessing the vulnerability of areas protected by flood bunds on the left bank of Kelani River during 50 and 100-year Kelani floods and a 50-year rainfall in Colombo metropolitan area were the main tasks of the study.

The bund breaching simulation reveals that the total inundated area covers 108 km², with 35% of that area experiencing an inundation depth exceeding 2 m. During a 50-year flood, the total overtopping length at the right bank is 300m, while it increases to 650m during a 100-year flood. This analysis provides valuable insights into the potential advantages of investing in infrastructure improvements to mitigate flood risk in the Colombo Suburbs. The generated flood inundation maps due to the Kelani River flood and the localised rain and flood susceptibility map will serve as a valuable tool for future flood risk planning, formulating implementation strategies aimed at minimising flood damage in Colombo suburbs.

Keywords: HEC-RAS, Kelani River, Flood inundation mapping, 2D model

* Correspondence: nimalw@uom.lk

Vulnerability of Colombo Suburbs for Kelani River Floods

AIM

DISCUSS COLOMBO AT RISK OF FLOODING WITH THE VARIATION OF FLOOD LEVELS, DISCHARGE, DURATION, AND RAINFALL IN COLOMBO SUBURBS.

OBJECTIVES

1. TO CHECK THE ADEQUACY OF THE EXISTING FLOOD BUND HEIGHTS AND DESIGNING NEW FLOOD BUND HEIGHTS FOR THE PRESENT CONDITIONS
2. TO IDENTIFY THE CRITICAL LOCATIONS, SIMULATING POSSIBLE HYPOTHETICAL BUND BREACH/GATE FAILURE SCENARIOS, AND ESTIMATING THE FLOOD EXTENT
3. TO DEVELOP A SUITABLE MODEL FOR THE COLOMBO CATCHMENT AREA USING HEC-RAS
4. TO FIND OUT HOW EXTREME RAINFALL AFFECTS THE VULNERABILITY OF COLOMBO AND ITS SUBURBS DURING THE KELANI FLOODS

METHODOLOGY

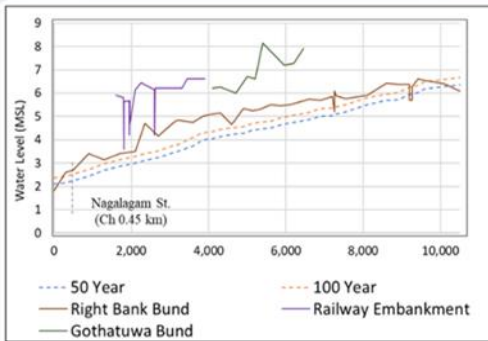
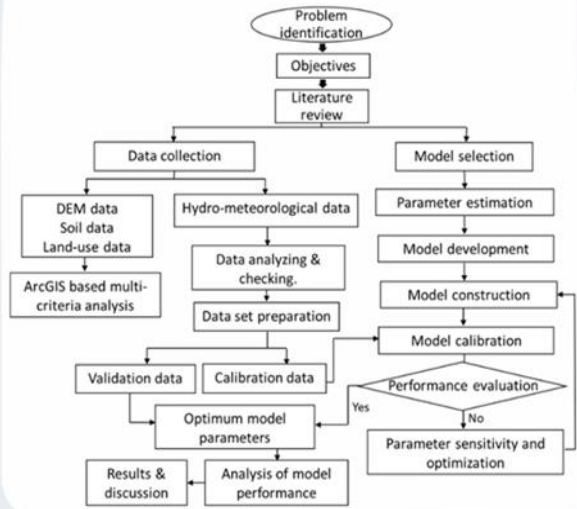


FIGURE 1. EXISTING FLOOD BUNS LEVELS AND DESIGN FLOOD LEVELS

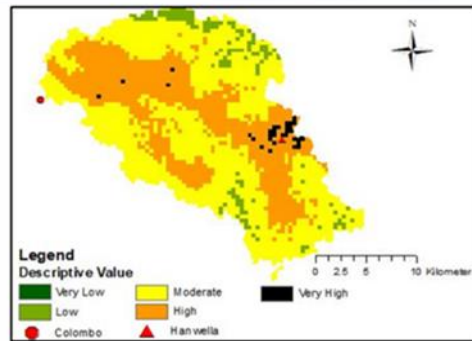


FIGURE 2. FLOOD SUSCEPTIBILITY MAP

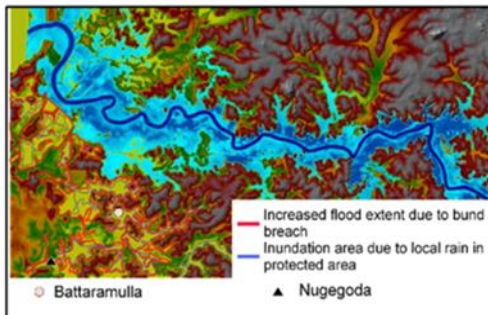


FIGURE 3. INCREMENT OF FLOOD EXTENT DUE TO BUND BREACH AND LOCAL RAINFALL

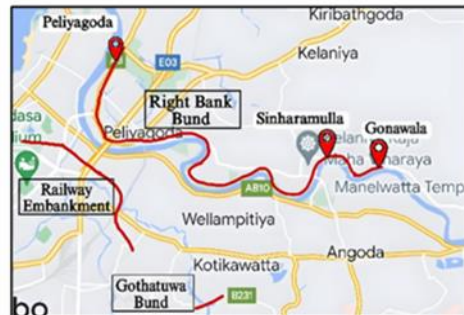


FIGURE 4. EXISTING FLOOD BUNDS AND IDENTIFIED VULNERABLE LOCATIONS

DEVELOPMENT OF AN ECONOMICAL LEVEL OF SERVICE ESTIMATION MODEL USING GPS DATA IN A MIXED TRAFFIC CONDITION

S.S. Jayawardhana ¹, H.L.K. Perera ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

This research presents the development of an economical Level-of-Service (LOS) estimation model using GPS data in a mixed traffic condition, with a specific focus on defining clusters based on the categories within the existing Highway Capacity Manual (HCM) definitions of motorised LOS, for practical application. The study aims to enhance the representation of Sri Lankan traffic conditions, predominantly observed on 2-lane roads, particularly within the LOS D and E categories where the majority of typical Sri Lankan traffic situations occur. The data collection scope encompasses the entirety of Sri Lanka to ensure the generation of more representative values for the defined clusters. As clusterisation parameters, Average Travel Speed which is a reflection of mobility, Percentage Time Spent Following another vehicle and the Percentage Free Flow Speed which is a ratio of current speed to the posted speed limit were used in the same manner as HCM 2016 - 15-2.

It showcases the utilisation of two CNN based image processing models developed, one for assessing the ‘following’ and ‘non-following’ states and the other to assess the types of road (road classes), using the Google Colaboratory platform, for the analysis of geo-tagged video collected through the Transcend DrivePro 250 and their combination with 1 Hz GPS data collected by the Qtravel GPS device, which includes parameters such as speed, heading local date and time. Additionally, application of unsupervised K means clustering, which finds k centroids and then assigns each data point to the closest cluster while minimising the size of the centroids, to define clusters corresponding to the HCM definitions. The proposed methodology and model aim to provide an improved representation of LOS in Sri Lanka's traffic conditions, considering the unique characteristics of the road network and the predominant traffic scenarios observed in the country. The research findings, produce a table containing parameters similar to HCM 15-2 (Motorised LOS parameters for 2 lane roads) but in a practical sense instead of a planning tool.

Cluster	Road Class			
	Class 01		Class 02	Class 03
	ATS (mi/h)	PTSF (%)	PTSF (%)	PFFS (%)
01	> 44	< 33	< 50	>100
02	34 – 44	33 – 55	50 – 70	76 – 100
03	24 – 34	55 – 72	70 – 84	48 – 76
04	11 – 24	72 – 88	84 – 94	18 – 48
05	< 11	> 88	> 94	< 18

PFFS exceeded 100% due to speed limit choice (50 km/h) for class 03 roads and FCD non-compliance. Cluster 5 needs to be checked against road capacity levels. Adjusting limits in the clustering model can eliminate any potential issues. However, the primary objective has been achieved for representative LOS clusterisation from GPS and geo-tagged video data.

Keywords: Level of Service (LOS), GPS data, CNN, KMeans Clustering, Highway Capacity Manual (HCM)

* Correspondence: loshakup@uom.lk



Development of an Economical Level of Service Estimation Model Using GPS Data in a Mixed Traffic Condition

Dr. H.L.K. Perera*, S.S. Jayawardhana

LOS?

A system of grading for quality of operations of,

- Road segments
- Surrounding infrastructure

provided to its users

Comprehensible for both experts and non-experts
Driven by the standards within Highway Capacity Manual (Transport Research Board, USA)

Why GPS?

Economical | Accurate | Readily available
Spatial and Temporal data → Real-time traffic management

Conventional methods of LOS definition doesn't fit Sri Lankan road conditions
HCM definitions will not comply

Problem Statement

Why?
Mixed traffic conditions that exist within Sri Lankan roads
Majority Motor Cars, Bicycles and 3 Wheelers

What is required? (Objective)
An **economical** approach to define and categorize LOS

Re-categorization of existing HCM levels will be done
HCM 2016 - Chapter 15-2 (2 lane highways)

LOS	Class I Highways		Class II Highways		Class III Highways	
	ATS (mi/h)	PTSF (%)	PTSF (%)	PTSF (%)	PFFS (%)	PFFS (%)
A	>55	<25	<40	>81.7	>81.7	>81.7
B	>50-55	>35-50	>40-55	>83.3-91.7	>83.3-91.7	>83.3-91.7
C	>45-50	>30-35	>50-70	>75.0-83.3	>75.0-83.3	>75.0-83.3
D	>40-45	>25-30	>70-85	>66.7-75.0	>66.7-75.0	>66.7-75.0
E	>35-40	>20-25	>85	>66.7	>66.7	>66.7
F	>30-35	>15-20	>85	>66.7	>66.7	>66.7

Note: For Class I Highways, LOS is determined by the worse of ATS-based LOS and PTSF-based LOS.

LOS will be defined for motorized vehicles based on 2-lane roads only
Expressways not considered

2-LANE HIGHWAY CATEGORIZATION

CLASS 01

Motorists traveling at high speeds
Majority of routes
Primary connectors of major traffic generators
Daily commuter routes
Major links in state or national highways

CLASS 02

Motorists not expecting to travel at high speeds
Access routes to class 1 facilities
Scenic and recreational routes (Not as primary arteries)
Roads that pass through rugged terrain (Serves relatively short trips)

CLASS 03

Serve moderately developed areas
They may be portions of a Class 1 or Class 2 highways that pass through small towns or developed recreational areas
Local traffic often mixes with through traffic on these segments, and the number of ungridded driveways and cross streets is noticeably higher than in a purely rural area

PARAMETER APPLICABILITY

ATS

Average Travel Speed
For this study, the GPS speed recordings with 1Hz frequency are directly clustered to get reflective average values.

PTSF

Percentage Time Spent Following
average percentage of time that vehicles must travel in platoons behind slower vehicles due to the inability to pass. Obtained by analysis of the geo-tagged video.

PFFS

Percentage Free Flow Speed
Essentially this is the ratio of ATS to PFFS. The PFFS for Class 3 road segments will be considered as 50 km/h. The final result can be easily manipulated to reflect more suited PFFS values.

Methodology

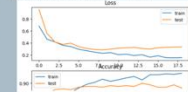
Data Collection

Initial Data Filtering and Arrangement

PROCESSING OF VIDEO DATA

Model Training
Uses ResNet-50 (50 layers deep) CNN
Pre-trained versions of the neural network on more than a million images from the ImageNet database can be loaded - Reduces the required training data

FNF Model - Assess Following and Non-following status
Input - 1652 images manually assessed as 'Following' or 'Non-following' were input.
Training data - 1322 images selected by the model
Validation data - 330 images selected by the model
Plot loss during training - 0.3048
Plot accuracy during training - 0.8999

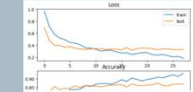


Representative sample of data captured via QTravel GPS device

Time	Lat	Long	Alt	Speed	Heading	Acc	Mag	Roll	Pitch	Yaw
1	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
9	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
10	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

RC Model - Assess Type of Road (Road Classes)

Input - 2320 images manually assessed as 'Class 1', 'Class 2' & 'Class 3' were input.
Training data - 1856 images selected by the model
Validation data - 464 images selected by the model
Plot loss during training - 0.3223
Plot accuracy during training - 0.875



Representative sample of data processed through the image processing model as well as the secondary python program

Time	Lat	Long	Alt	Speed	Heading	Acc	Mag	Roll	Pitch	Yaw
1	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
9	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
10	6.900000	79.850000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Clusterization

Why KMeans?
KMeans clustering is one of the **unsupervised** Machine Learning algorithms that is used to **cluster categorical variables**

Requirement → **Clustering**

No. of clusters (k) required must be determined
k = 5
denotes the quantity of centroids required in the dataset

0.5 MILLION

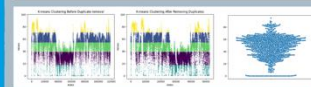
data points in final .csv file (Filtered) from all 3 road classes

Developed using visual studio code
Relevant HCM parameters were clustered separately from each road class
Cluster ranges obtained as output
• Scatter Plots (with and without duplicates)
• Swarm Plots (for random 1000 points)

Results

KMeans Clustering Model Ranges

Cluster	Class 01		Class 02		Class 03	
	ATS (mi/h)	PTSF (%)	PTSF (%)	PTSF (%)	PFFS (%)	PFFS (%)
01	> 44	< 33	< 50	> 100	> 100	> 100
02	34 - 44	33 - 55	50 - 70	70 - 100	70 - 100	70 - 100
03	24 - 34	55 - 72	70 - 84	48 - 76	48 - 76	48 - 76
04	11 - 24	72 - 88	84 - 94	18 - 48	18 - 48	18 - 48
05	< 11	> 88	> 94	< 18	< 18	< 18



Eg: Visualization - Class 01 ATS

Potential Improvements

BIGGER DATA POOL
An optimal data pool would be in excess of 3 million data points with corresponding video frames.
FNF & RC MODEL ACCURACY
The obtained accuracy is close to 90%. This can be further optimized in order to reach around 95% through provision of additional, distinct training images relevant to each parameter.

BETTER CLUSTERIZATION
A research question should be raised towards the possibility of another parameter that fits all the parameters within the study and allows for multi-vector clustering to get a far superior classification.

FINITE ELEMENT ANALYSIS OF A DEEP EXCAVATION SUPPORTED USING A SECANT PILE WALL: A CASE STUDY

V.S.S.D. Silva¹, L.I.N. de Silva^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Coulomb (1776) introduced the first method to calculate the lateral earth pressure acting on retaining walls. Rankine theory was introduced as a result of improving the previous work (Rankine, 1857). Many methods are currently used to evaluate the earth pressure distributions of the retaining wall and the prop forces of the support system used in deep excavations. The Apparent earth Pressure Diagram (APD) and Distributed Prop Load method (DPL) introduced by Terzaghi, K. & Peck (1967) and Twine and Roscoe (1999) are the most widely used empirical methods to calculate the earth pressure distributions and prop forces acting on multi-propped retaining walls.

Finite element modelling has become the most widely used feature with rapid technological advancement. Studies have found that soil stiffness is the parameter that has the dominant control over ground movement induced by deep excavation. Elastic modulus (E_{50}), unloading-reloading modulus (E_{ur}), and tangent modulus (E_0) are the most widely used soil stiffness parameters in design work.

This study suggests recommendations for selecting appropriate parameters and correct modelling procedures in the FEM of deep excavations using measured field data using two-dimensional analysis. Previous studies indicate that the elastic modulus (E_{50}) of the soil can be increased several times to obtain the unloading-reloading stiffness (E_{ur}) of the soil during deep excavation. The back analysis technique is commonly used in studies to calibrate the critical parameters to minimize the deviation between numerically computed results and field observation results. Back analysis was used to calibrate the elastic modulus of the soil by comparing the lateral wall deformation profile obtained from the FEM software with inclinometer readings acquired from the excavation site. Prop force and earth pressure distribution results obtained from FE analysis were compared with Peck and DPL methods considering sandy and clayey soil.

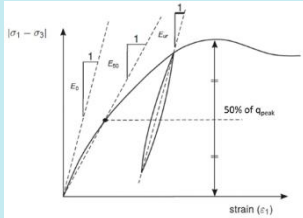
Prop forces from the numerical model were compared with those from different empirical methods commonly used to estimate prop forces on multi-propped retaining structures. The study highlights that the elastic modulus (E_{50}) values derived from the SPT N data can be multiplied by 2 to 4 times to obtain the unloading-reloading modulus (E_{ur}) value that would reasonably predict the wall movement in the FE analysis. As the depth of excavation increases, the lateral deformation was underestimated mainly due to the impact of the corner effects. Considering sandy soil, both Peck and DPL methods produced higher prop force values for the first prop level, while the second and third prop levels had lower values compared to the results of the numerical analysis. The lower earth pressure distribution obtained from the DPL and Peck methods compared to the earth pressure distribution of the FE analysis caused this result.

Keywords: Deep Excavation, Finite Element Analysis, Elastic Modulus, Back Analysis, Apparent Pressure Diagrams

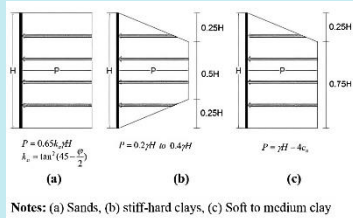
* Correspondence: nalinds@uom.lk

FINITE ELEMENT ANALYSIS OF A DEEP EXCAVATION SUPPORTED USING A SECANT PILE WALL: A CASE STUDY

BACKGROUND



Triaxial compression test results

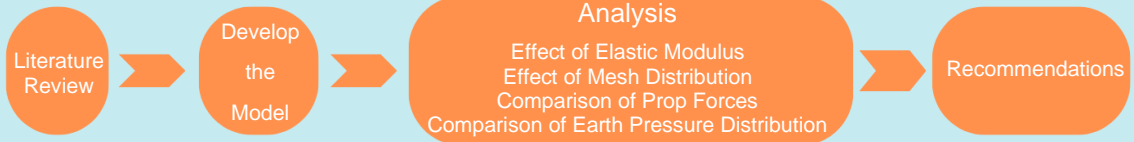


Apparent earth pressure diagrams presented by Terzaghi & Peck (1967)

Class	Soil	Over retained height	DPL
AS	Same as AF for medium strength clay	Top 20%	0.2 yH
		Bottom 80%	0.3 yH
AF	Medium strength clay	Top 20%	0.5 yH
		Bottom 80%	0.65 yH
	Low strength clay with stable base	Top 20%	0.65 yH
		Bottom 80%	1.15 yH
BS	High to very high strength clay	All	0.5 yH
		All	0.3 yH
BF	High to very high strength clay	All	0.2 (γ-y)H
		All	0.2 yH
C	Granular soil, submerged	Above water	0.2 (γ-y)H + γs(z-d)
		Below water	

Triaxial compression test results

METHODOLOGY



FINITE ELEMENT MODEL

PLAXIS 2D

Plan Strain Idealization

Mohr Coulomb Model

Drainage Type – Drained

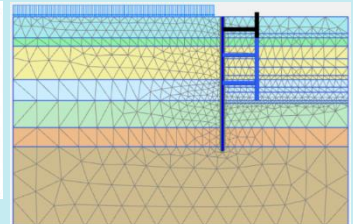
Strut and Waler Material Type – Elastic

Retaining Wall Behaviour – Elastic

$\phi = 0.45 N_{70} + 20^{\circ}$

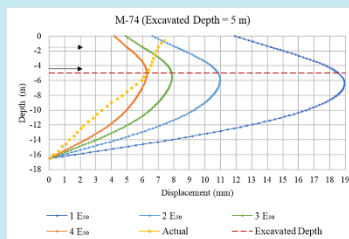
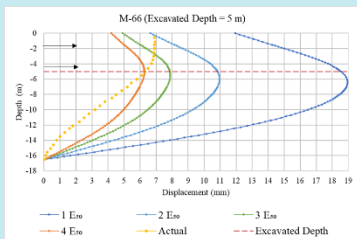
Elastic Modulus = 7 N (Yoshida & Yoshinaka, 1972)

Soil	1 Clayey sand (SPT N = 6)	2 Clayey Sand (SPT N = 26)	3 Silty clayey sand (SPT N = 7.5)	4 Clayey sand (SPT N = 50)	5 Fine sand (SPT N = 15)	6 HRW (SPT N = 8)
Depth (m)	0.0 to -2.5	-2.5 to -3.5	-3.5 to -7.5	-7.5 to -10.0	-10.0 to -13.2	-13.2 to -15.5
Material Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
γ_{sat} [kN/m ³]	16.00	20.00	20.00	21.00	17.00	16.00
γ_{dry} [kN/m ³]	17.00	21.00	21.00	22.00	18.00	17.00
k_v [m/s]	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸
k_h [m/s]	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸	10 ⁻⁸
E_{ur} [kN/m ²]	12000	40000	50000	70000	22000	14000
ν [-]	0.350	0.300	0.300	0.250	0.300	0.350
c_{int} [kN/m ²]	8.00	8.00	8.00	10.00	0.00	3.00
ϕ [°]	24.00	30.00	32.00	38.00	28.00	25.00
ψ [°]	0.00	0.00	2.90	8.00	0.00	0.00
R_{int}	-	0.67	0.67	0.67	0.67	0.67

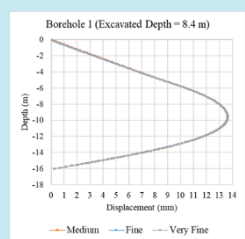


ANALYSIS

Effect of Elastic Modulus



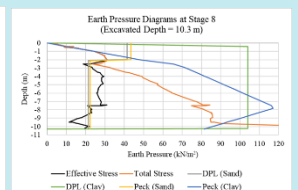
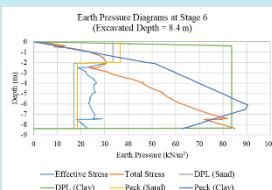
Effect of Mesh Distribution



Prop Force Comparison

Stage	Strut Level	Strut Dimensions (mm)	Finite Element Analysis (kN/m)	Peck Method (Sand) (kN)	Peck Method (Clay) (kN)	DPL Method (Sand) (kN)	DPL Method (Clay) (kN)
Stage 5	At - 1.5 m	200x200x49	101.77	118.15	119.73	88.16	220.4
	At - 4.575 m	300x300x94	325.79	215.54	318.07	233.96	386.61
Stage 6	At - 1.5 m	200x200x49	58.05	148.75	150.8	132.15	330.32
	At - 4.575 m	300x300x94	360.89	205.55	330.38	241.63	412.58
Stage 8	At - 1.5 m	200x200x49	33.74	164.01	162.04	156.77	391.95
	At - 4.575 m	300x300x94	360.89	205.55	330.38	241.63	412.58
Stage 8	At - 7.9 m	300x300x94	308.84	268.73	430.22	260.96	384.21

Earth Pressure Distribution Comparison



PREDICTION AND UNCERTAINTY QUANTIFICATION OF MECHANICAL PROPERTIES OF HOMOGENISED WOVEN COMPOSITES

G.N.C. Ariyasinghe¹, H.M.S.T. Herath^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Woven composites are widely used among many industrial applications due to their unique properties and understanding how these woven composites behave under certain conditions enables us to predict their responses and design efficient solutions. This prior knowledge can be acquired through experimentation and computer simulations. In instances such as in aerospace applications, where experimental investigations are challenging due to the difficulties and constraints present in providing microgravity conditions, computer simulations are the preferred approach. These simulations assume ideal conditions but whenever these models are brought into the physical world, they tend to exhibit unexpected behaviour and the main reason for this deviation is the uncertainty introduced at many stages of the application.

The research provides a framework for providing predictions and to quantify the uncertainty of the mechanical response when a two-ply carbon fibre woven composite laminate composed of T300-1k fibres and Hexply 913 epoxy resin are subjected to material uncertainty. The mechanical properties of the homogenised woven composite are expressed through the ABD stiffness matrix and obtained using a computer-simulated Representative Unit Cell (RUC).

The predictions and uncertainty quantification are carried out by using Supervised Machine Learning (ML) techniques employing Gaussian Process Regression (GPR). In GPR, the input variables are assumed to be correlated, and the output variables are modelled as a distribution over functions, rather than a single function. The mean and covariance of the output distribution are then computed using Bayesian inference, which allows for the predictions and quantification of uncertainty in the output space.

The input space introduces uncertainties to the model through the Latin Hypercube Sampling technique which was propagated through the RUC to obtain the outputs to create the sample database. Model training and testing were carried out on the created database. The evaluation of the fit was carried out based on the Normalised Root Mean Squared Error (NRMSE) values and model validation was carried out using the repeated k-fold cross-validation technique.

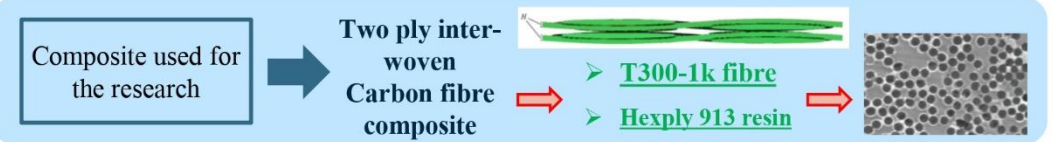
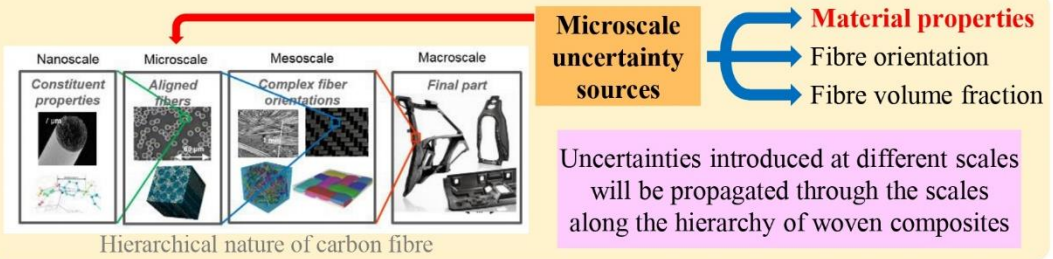
The evaluation of different kernel functions revealed that some covariance functions exhibited superior performance compared to others. The NRMSE values obtained during model training reflect the sensitivity of mechanical properties to constituent material properties. Notably, A12 and A66 of the ABD stiffness matrix exhibited higher errors and lower sensitivity in comparison to other stiffnesses. Comparing various ML techniques based on previous research, GPR models consistently outperformed Artificial Neural Networks (ANNs) and Linear Regression, particularly for specific stiffnesses. The GPR model showcased robust extrapolation capabilities, offering accurate predictions within 10% variations despite being trained for 5% uncertainty. This study also concluded that the model's predictions remained within narrow variation ranges for different uncertainty levels in constituent material properties.

Keywords: Woven Composites, Gaussian Process Regression, Machine Learning, Prediction, Uncertainty Quantification

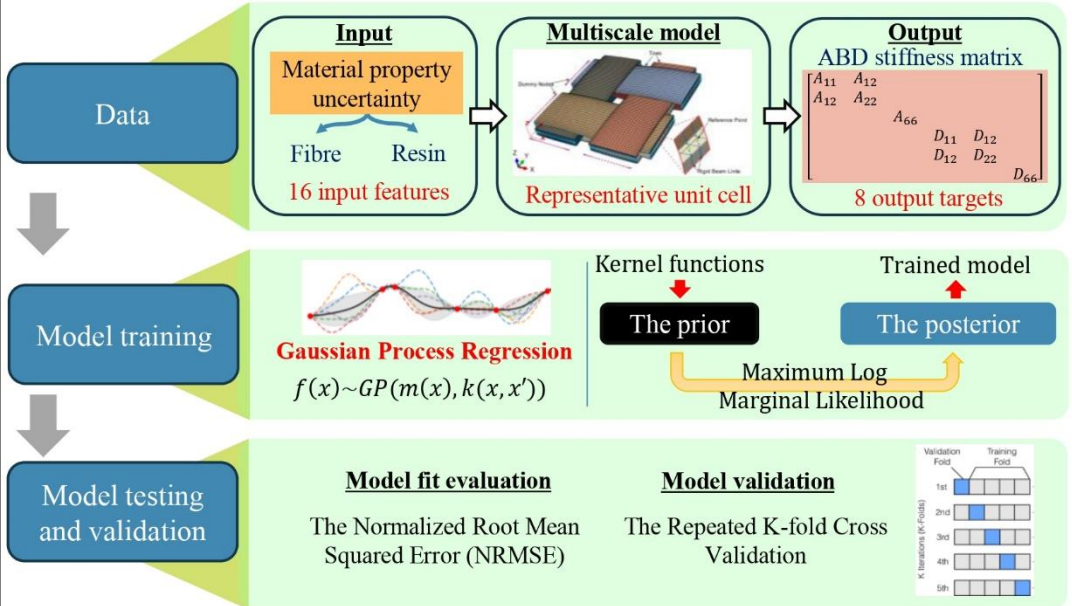
* Correspondence: sumuduh@uom.lk

PREDICTION AND UNCERTAINTY QUANTIFICATION OF MECHANICAL PROPERTIES OF HOMOGENIZED WOVEN COMPOSITES

1. Background

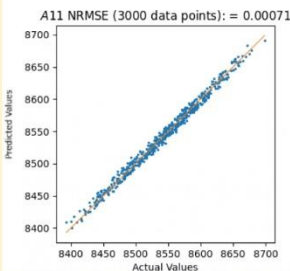


2. Research Methodology

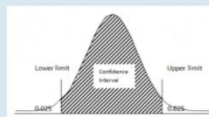


3. Results

Prediction



Uncertainty quantification



	Error percentage for 5% material property variance	
	Lower bound	Upper bound
A11	-1.8	1.9
A12	-0.6	1.0
A22	-2.0	1.7
A66	-0.5	0.6
D11	-2.3	2.2
D12	-0.7	0.5
D22	-2.3	2.3
D66	-0.4	0.6

ASSESSING THE READINESS FOR DIGITAL TECHNOLOGIES ADOPTION FOR ENHANCING PRODUCTIVITY IN THE SRI LANKAN CONSTRUCTION INDUSTRY

I.H.N. Chathuranga¹, C.S.A. Siriwardana^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The Construction Industry (CI) is a vital sector that continually seeks to enhance productivity and profitability, facing distinct challenges compared to other industries. Amidst global trends emphasising the integration of digital technologies for improved productivity, the CI's adoption of such innovation technologies lags in a global perspective. The study recognises that digital transformation is vital to significant productivity gains in the construction industry. However, in the Sri Lankan context, a comprehensive study has not yet been done to develop a tool to assess the Sri Lankan construction industry's readiness towards digitalisation. This research paper addresses this gap by developing a readiness model and a self-assessment tool to measure the organisational readiness of Sri Lankan construction industry to adopt digital technologies in a holistic approach. This study employs a multi-dimensional approach by amalgamating the Technology-Organisation-Environment framework and the Readiness for Workforce Strategic Change Management framework, effectively addressing the complexities of digital technology adoption within organisations. A rigorous literature survey identified 15 readiness indicators spanning Environment, Technology, Organisation, Leadership, and Workforce dimensions to evaluate the construction industry's readiness. The research employs a mixed-methods approach involving a literature survey, pilot questionnaire, comprehensive questionnaire, and robust data analysis techniques, including descriptive, factor, and Fuzzy Synthetic Evaluation analyses. The outcomes reveal a nuanced understanding of critical indicators, categorised into two groups named ELPA (Environment, Leadership, Workforce Attitude, and Organisational Performance) and TOK (Technology, Organisation, and Technical Knowledge). The study's primary contributions include the development of an organisational readiness model and a self-assessment tool, facilitating self-evaluation by construction organisations. The developed readiness model integrates these dimensions through weighted indicators, providing a holistic assessment of readiness.

The self-assessment tool operationalises the model, enabling practitioners to gauge readiness by assessing each indicator's relevance towards digitalisation. The model is underpinned by Fuzzy Synthetic Evaluation, ensuring objectivity and addressing subjective judgments. The assessment tool is precious for its practical applicability, offering a user-friendly approach for organisations to identify their strengths and weaknesses towards digital technology adoption at the organisational level. Ultimately, this research sheds light on the readiness landscape of the Sri Lankan construction industry, paving the way for strategic interventions and informed decision-making towards digitalisation. By aligning strategic plans based on the results obtained from the developed readiness model, organisations can drive their digital transformation journey, harnessing the potential of digital technologies to boost construction industry performance, bridge productivity gaps, and contribute to the economic growth of Sri Lanka.

Keywords: Digital Technologies, Construction Industry Readiness, Readiness Assessment, Digital Construction, Construction Productivity

* Correspondence: chaasi@uom.lk

SELF-READINESS TOOL FOR ASSESSING SRI LANKAN CONSTRUCTION INDUSTRY READINESS TOWARDS DIGITALIZATION

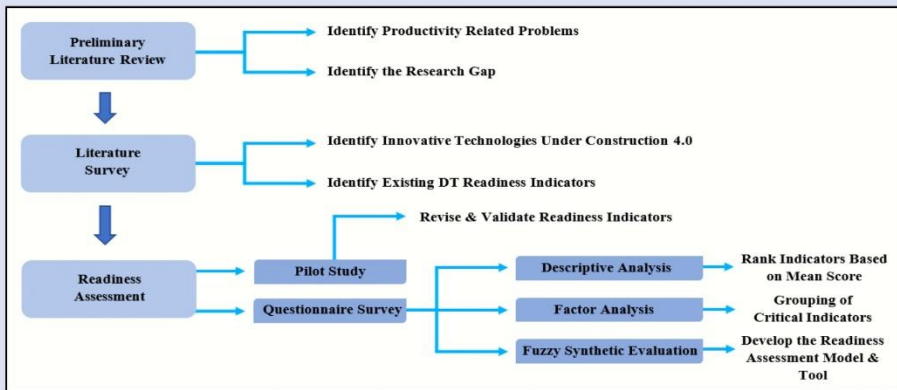
Aim

Assessing the Sri Lankan construction industry readiness towards digitalization

Objectives

- Identify existing readiness indicators that can be used to assess construction industry readiness
- Develop an organizational readiness model
- Develop a simplified tool to assess the organizational readiness

Methodology



$$\text{ORGANIZATIONAL READINESS} = 0.496 \times \text{TOK} + 0.504 \times \text{ELPA}$$

Self Assessment Tool

Ind.	Statement	Score (1-7)	Weight	Weighted Score	Final Score
TOK Group					
1	We are familiarized with novel DT and application areas	y	0.132	0.132 × y	
2	We provide employee education and training to ensure technology proficiency	y	0.131	0.131 × y	
3	We have the infrastructure of equipment and software systems for implementing DT.	y	0.128	0.128 × y	
4	We have a Strategy or implementation plan for DT implementation	y	0.127	0.127 × y	
5	We Exchange DT-related expertise and information between organizations	y	0.126	0.126 × y	
6	We have Coordination between functional units to utilize and introduce new DT.	y	0.125	0.125 × y	
7	We have a Budget for developing or implementing DT or Research & Development	y	0.122	0.122 × y	
8	Our Talent pool for utilizing cutting-edge DT is sufficient	y	0.108	0.108 × y	
TOK Total Score					X
ELPA Group					
9	We have KPIs regarding implementing digital technology	y	0.151	0.151 × y	
10	Our financial capability is high to manage the risk associated with DT adoption	y	0.148	0.148 × y	
11	Our organizational culture values/welcomes digital technology implementation and adoption	y	0.146	0.146 × y	
12	We have a well understanding of the legal & ethical regulations regarding DT adoption	y	0.144	0.144 × y	
13	Our top management understands the importance of integrating emerging technologies	y	0.141	0.141 × y	
14	Our Leadership/executive authority promotes the adoption of digital technology	y	0.139	0.139 × y	
15	The attitudes and beliefs of our employees are toward the adoption of digital technologies	y	0.132	0.132 × y	
ELPA Total Score					Y
Total Score Possible					7
Organizational Readiness Score (0.496 × X + 0.504 × Y)					Z
Organizational Readiness Towards DT Adoption = (Z/7)×100%					

EVALUATION OF ENVIRONMENTAL IMPACTS OF SOLAR PV SYSTEMS WITH CONCEPTUAL LIFE CYCLE ASSESSMENT AND RECYCLING OF END-OF-LIFE PV PANELS

A.R.I. De Alwis ¹, Jagath Manatunge ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Although numerous dialogues on the recycling processes of PV panels have been in the limelight, their progress has been slow due to the lack of institutional support and the lack of robust legislation within countries. Given the slow progress in PV recycling, this thesis attempts to analyse the evaluation of the environmental impacts of solar PV systems with conceptual life cycle assessment and recycling of end-of-life PV panels. This thesis will be based on the reflective analysis of information mainly gathered through a comparison study of secondary journal articles and an inventory of carbon and energy.

This analysis focuses on the carbon emissions associated with various phases of a solar PV system, including manufacturing, transportation, installation, and operation. By using embodied carbon coefficients, the study quantifies the CO₂ intensity (kgCO₂/kWh) for each phase and reveals valuable insights into their environmental impact. The findings highlight the significance of optimising the installation process and exploring greener transportation alternatives to reduce the system's carbon footprint.

The study also emphasises the importance of implementing effective end-of-life management strategies, promoting material recovery, and reducing demand for new materials to achieve overall embodied carbon emission reductions. To address the growing concern of solar PV panel waste, the establishment of a comprehensive framework for PV end-of-life management in Sri Lanka is essential. Creating accountability through collective responsibility, government support, and producer involvement is crucial to promoting recycling and ensuring sustainable practices. Financial support from the government is vital to encourage recycling initiatives, and establishing provincial collection points can further facilitate the recycling process.

Keywords: End-of-Life, PV, Solar, PV waste, Solar Energy, Environmental impacts, Recycling of PV, Framework, Conceptual Life Cycle Assessment

* Correspondence: manatunge@uom.lk

Evaluation of Environmental Impacts of Solar PV Systems with Life Cycle Assessment and Recycling of End-of-Life PV Panels

This research will assess the environmental impact of PV panels, using a method called Conceptual Life Cycle Assessment and Recycling of End-of-Life PV panels. It will address the absence of a regulatory framework for the disposal and recycling of solar PV panels on the new solar parks in Sri Lanka by creating a policy framework for the disposal and recycling of solar panels.

1. Objectives

-  A Conceptual LCA (Embodied Carbon) on PV panels will be provided
-  Development of more efficient and sustainable recycling technologies for end-of-life PV panels
-  Propose a policy framework for recycling PV panels in Sri Lanka

3. Resources



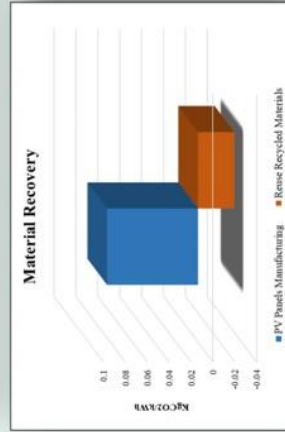
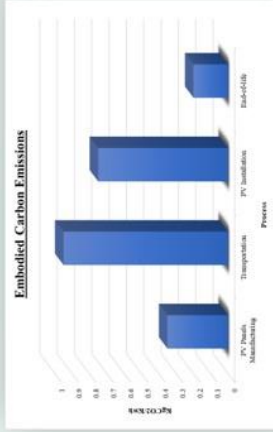
2. Methodology



Conclusion

- A study analyzing the carbon emissions of solar PV systems highlighted the significant impact of installation and transportation phases on overall emissions.
- The research emphasized the efficiency and feasibility of recycling methods that can be applied in the Sri Lankan context when it comes to general practices in the world.
- The study also addresses the importance of effective end-of-life management, particularly in developing countries like Sri Lanka.

4. Analysis



DEVELOPMENT OF FIBRE REINFORCED PAVING BLOCK FOR OUTDOOR SPORTS SURFACES

G.K.B.M. Gannoruwa ^{1,*}, S.S.K. Muthurathne ², S.M.A. Nanayakkara ³

¹ Building Materials Research & Testing Division, NBRO, Sri Lanka

² Building Materials Research & Testing Division, NBRO, Sri Lanka

³ Department of Civil Engineering, University of Moratuwa, Moratuwa

Synthetic fibre blended fabric offcuts generated from textile industry are considered as waste and currently incinerated in cement kilns. Utilisation of textile waste in development of cement based product was focused in this study. Behaviour of fabric pieces in cement matrix indicates its reinforcing effect with proper bonding characteristics while changing its failure pattern from brittle mode to more ductile pattern. Experimental investigation was carried out to identify the optimum size of shredded fabric pieces and its content which can be incorporated into cement matrix to achieve the highest flexural strength of the fabric-cement composite. Optimum fabric content was found to be 26% by volume and most suitable size range of shredded fabric pieces was identified as 0 to 10 mm. Superplasticiser was used to improve the workability of mixture at low w/c ratios and viscosity modifier was used to improve the homogeneity. Paving block was developed with the use of shredded form of polyester spandex fabric, manufactured sand, cement and admixtures. Developed block complies with the requirements specified for paving blocks in SLS 1425 and BS EN 1338 standards. Fiber reinforced paving block has a compressive strength of 18 MPa and tensile splitting strength of 5.4 MPa. Under compression type load, the block is initially subjected to elastic deformation and then plastic deformation. Failure pattern changing point from elastic deformation region to plastic deformation region was considered as failure point of that block to estimate its compressive strength. The developed paving block has an abrasion resistance of 17 mm and a skid resistance of 80 USRV. Elasticity effect of polyester spandex fabric leads to improve the shock absorption characteristics of fibre reinforced paving block. The shock absorption capability of this paving block was measured using a test apparatus that was fabricated in accordance with the BS EN 14808 standard, which specifies the determination of shock absorption characteristics of sports surfaces. The shock absorption capability of this block is 21%, which meets the requirement specified in the BS EN 15330-1 standard for tennis court surfaces. Incorporation of fabric pieces into cement matrix leads to create a porous structure while improving water infiltration capability. Permeability of the paving block was measured in terms of its infiltrated water volume at constant time intervals under constant pressure head. This paving block has a water percolation capability of 200 litres/m² per hour, which means it can absorb up to 100 litres of water per square meter in 30 minutes under a pressure head of 1.1 bar. This helps to reduce surface runoff of rainwater. Deterioration of fabric fibres in an alkaline environment was evaluated as per ISO 8336 standard while subjecting fibre reinforced paving blocks to 50 numbers of soak-dry cycles and soak-dry performance criteria was estimated as 0.8 which satisfies the ISO 8336 standard requirement. Developed paving block satisfies the requirements specified for paving blocks in SLS and BS EN standards. The novel paving block has improved shock absorption and water infiltration characteristics, as well as satisfactory durability. It is suitable for outdoor sports surfaces, as it provides better foot comfort and slip resistance.

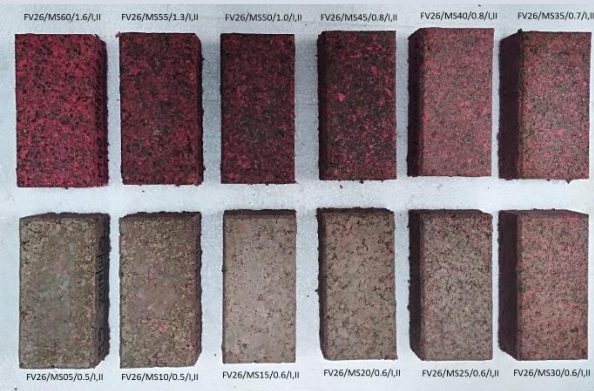
Keywords: Paving block, Polyester spandex, Shock absorption, Permeability, Sports surfaces

* Correspondence: bhagyagannoruwa@gmail.com

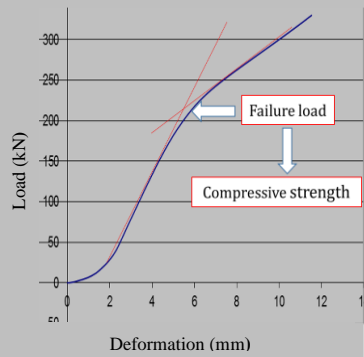
DEVELOPMENT OF FIBRE REINFORCED PAVING BLOCK FOR OUTDOOR SPORTS SURFACES

G.K.B.M. Gannoruwa, S.S.K. Muthurathne, S.M.A. Nanayakkara

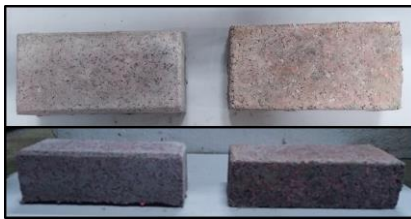
Surface Texture of Fabric Embedded Paving Blocks



Load vs. Deformation pattern under Compression Test



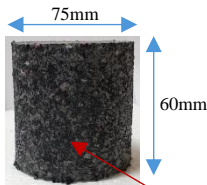
Failure Pattern under Compression Test



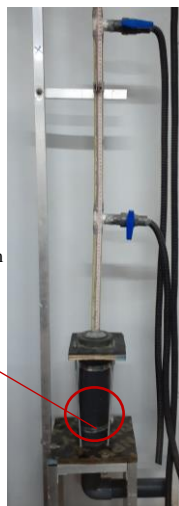
Failure Pattern of Specimen under Tensile Splitting Strength Test



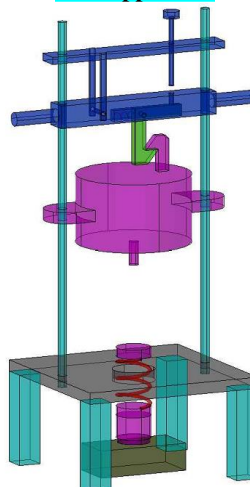
Constant Head Permeability Test



Test Specimen



Shock Absorption Test Apparatus



Fibre Reinforced Paving Blocks Laid Jogging Track at SLLI Panagoda



Product Performance

Property	Test Result	Specified Standard Requirement
Compressive Strength	18 N/mm ²	≥ 15 N/mm ² (SLS 1425)
Tensile Splitting Strength	5.4 N/mm ²	≥ 3.6 N/mm ² (BS EN 1338)
Abrasion Resistance	17 mm	≤ 20 mm
Skid Resistance	80 USRV	≥ 55 USRV
Permeability	100 litres/mm ² (30 mins)	-
Shock Absorption	21%	15% - 24% (BS EN 15330-1)
Durability	0.80	≥ 0.75 (ISO 10904)

DEVELOPMENT OF ISO STANDARD SAND FROM LOCAL SILICA SAND DEPOSITS FOR CEMENT TESTING

E.G.H.D.B. Ellegama ^{1, *}, S.S.K.Muthurathne ², S.M.A.Nanayakkara ³

¹ Building Materials Research & Testing Division, NBRO, Sri Lanka

² Building Materials Research & Testing Division, NBRO, Sri Lanka

³ Department of Civil Engineering, University of Moratuwa, Moratuwa

ISO standard sand is a siliceous natural sand used in the testing of cement for the SLSI certification process, material approval in construction projects, and material clearance in importing cement. Testing laboratories in government institutes and cement manufacturers import standard sand as it is not produced in Sri Lanka. According to the market survey carried out among the cement manufacturers and testing agencies, standard sand is imported mainly from China, France and Germany. Under the current economic situation in Sri Lanka, the government has imposed restrictions on importing standard sand required for the testing of cement. Hence, this research is mainly focused on developing ISO standard sand using locally available materials. There are several requirements for standard sand specified in SLS ISO 679 – Methods of testing cements – Determination of Strength, such as particle size distribution, and moisture content, and it must be verified with reference sand. The main mineral phase in standard sand and reference sand is Quartz. Hence, locally available vein quartz and silica sand were selected for this study due to their high silica content. Silica sand was obtained from the Marawila area in the Puttalam district, and Quartz powder from Naula in the Matale district. The sieve analysis was conducted for both washed silica sand and Quartz powder using the relevant sieves to separate each size fraction. It was observed that the percentage of particles less than 150 microns in silica sand from Marawila was very small. Therefore, Quartz powder was used to meet the particle size fraction less than 150 microns requirement. Standard sand was prepared by combining both silica sources to satisfy the requirements specified in SLS ISO 679.

The compressive strength of cement mortar samples prepared with imported ISO standard sand and standard sand prepared with local sand were determined as per the procedure given in SLS ISO 679 standard. It was observed that the particle size distribution of ISO Standard sand has a considerable effect on the compressive strength of cement mortar, even when it is within the recommended band limits as specified in SLS ISO 679. It was also observed that, even with the same particle size distribution, there was a variation of strength between different sand sources. These results indicate the importance of controlling not only particle size distribution but also characteristics of sand particles, such as particle shape and surface texture, when developing standard sand in order to obtain consistent results when testing cement for strength. Inter-laboratory test results of different cement types with the developed local standard sand indicate that the repeatability and reproducibility of the compressive strength test results are at a satisfactory level.

Keywords: ISO standards sand, Silica sand, Cement testing, Compressive strength

* Correspondence: heshandbandara@gmail.com

Development of ISO Standard Sand from Local Silica sand Deposits for Cement Testing

E.G.H.D.B.Ellegama, S.S.K.Muthurathne, S.M.A.Nanayakkara

ISO standard sand is a naturally occurring siliceous sand used to test cement. In Sri Lanka, standard sand is imported from countries like China, Germany, and France. Due to the ongoing economic crisis and stringent regulations on the importation of essential items, accredited laboratories and cement manufacturers are facing difficulties in obtaining the standard sand for testing cement. In response to a request from the Sri Lanka Standards Institute (SLSI), the National Building Research Organization (NBRO) investigated the possibility of producing standard sand from suitable local sources to meet the demand for standard sand in the Sri Lankan construction industry.

The SLS ISO 679 standard specifies the requirements for standard sand and the procedures for testing it. The standard sand must meet several requirements, including a specific particle size distribution and moisture content. It must also be verified with reference sand.

Methodology

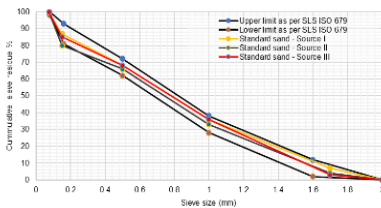
Preliminary Study

Investigation Local Source

Local Standard Sand Preparation

Test results on standard sand

Particle size distribution-



Silica sand

From Marawila area



Quartz silica powder

From Naula area



(0.150mm ≤ Particle size < 2.0mm) 0.080mm ≤ Particle size < 0.150mm

Silica sand

Quartz silica powder



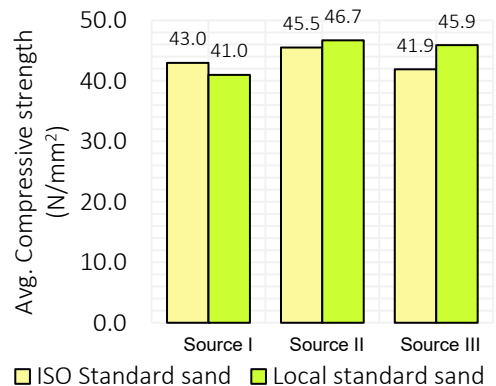
	Relative Density	Uncompacted Void Content (%)
Source I	2.57	38.72
Source II	2.61	37.25
Source III	2.57	39.13

Quartz percentage is more than 94 % in both sources

Conclusion

- Particle size distribution of ISO Standard sand has considerable impact on the compressive strength of cement mortar even though the particle size distribution is within the recommended band limits as specified in SLS ISO 679.
- Even with the same particle size distribution, there was a variation of strength between different standard sand sources.
- These results indicate the importance of controlling not only particle size distribution but also characteristics of sand particles such as particle shape and surface texture when developing standard sand in order to obtain consistent results when testing cement for strength.

Test results



ROADSIDE SLOPE RISK ASSESSMENT IN SRI LANKA

V.G.D. Gangani^{1,*}, S.A.S. Kulathilaka²

¹ Geotechnical Engineering Division, NBRO, Sri Lanka

² Department of Civil Engineering, University of Moratuwa, Moratuwa

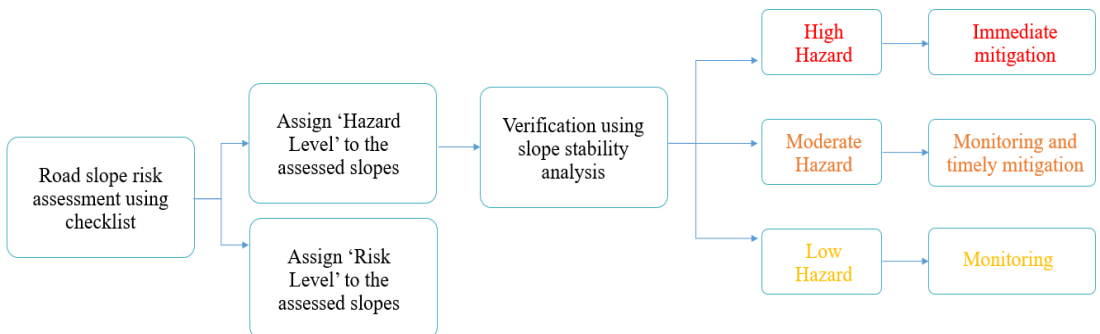
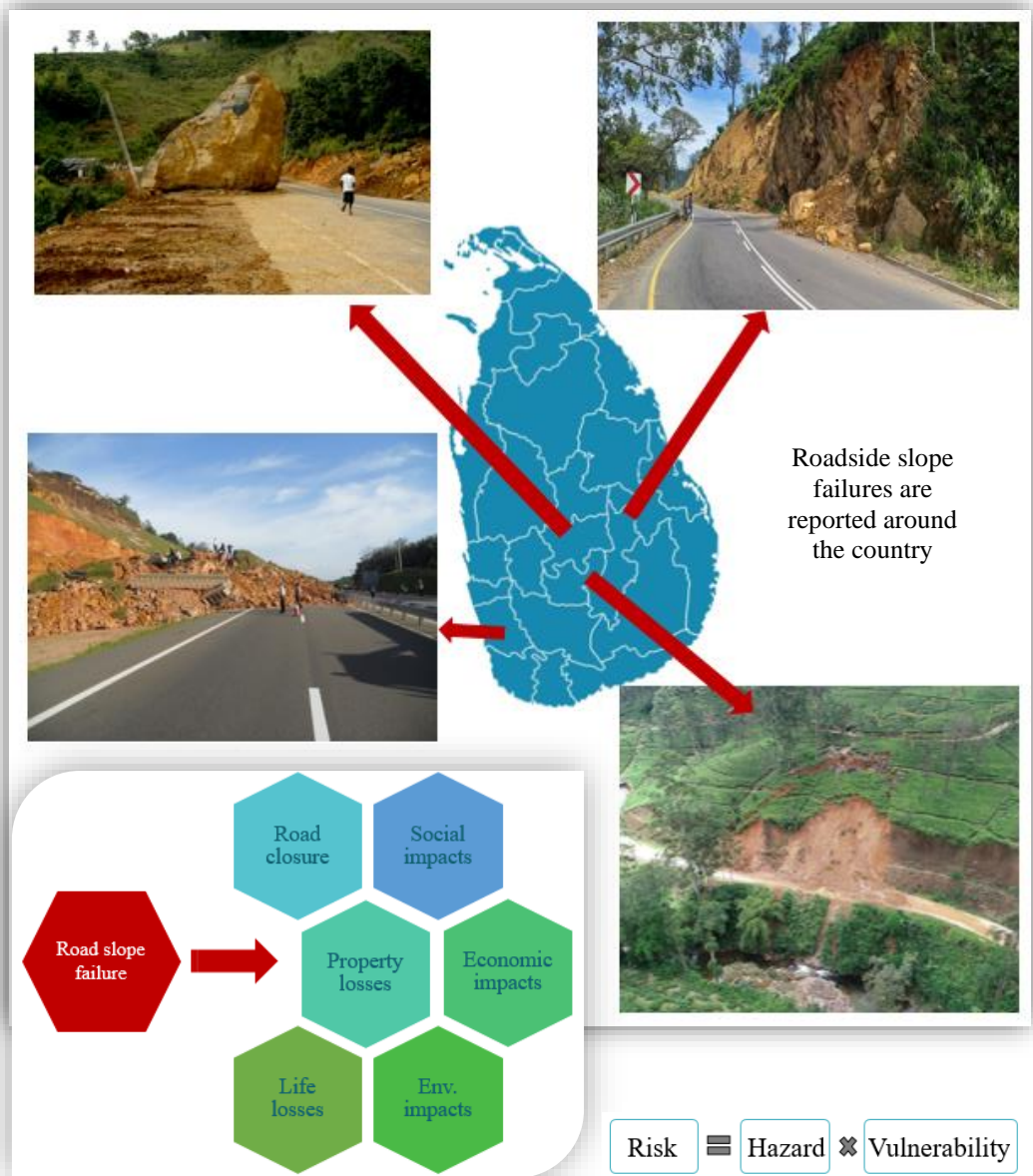
Sri Lanka is experiencing frequent events of slope failures, cutting failures and landslides along the road network throughout the island. Considerably high number of events occurred recently, with the growth in the road sector through expanding the highway network, widening the existing road system and constructing an expressway network in the country. All these failures are triggered by rainy weather. Road closures, property damages and loss of human lives in some instances are reported due to these failures triggered by monsoonal rains. Usually, slope risk assessments are carried out after such failures or with the appearance of early signs of failure. Consequent risk mitigation design and construction are carried out considering only the area subjected to failure or susceptible to failure. Although a considerable region along a particular road may have the same geological and geomorphological conditions with a possibility of failure, currently, there is no proper methodology to assess the overall risk along the road. In the absence of that failures along the road network are repeatedly reported periodically.

The necessity to streamline the process of roadside slope risk assessment is addressed in this research, to ensure the minimisation of the probability of further failures along a mitigated road. A nationally applicable procedure should be implemented to assess the level of risk associated with slopes along the road network and to develop a proper mitigation plan, based on the identified risk levels. One of the most preferred methods for a proper assessment is to maintain a checklist as a tool that can be used by a professional with knowledge and experience regarding road slope failures. The checklist assesses the hazard and vulnerability of a road slope based on slope geometry, soil/rock properties, drainage condition, elements at risk, etc. 'Assessed risk factor' is calculated for each slope and categorised as High, Medium or Low risk. Verification of the outcome from checklist is done by slope stability analysis along with modelling of infiltration. This research focuses on the development of the checklist, application of the developed checklist, and verification of the results obtained from the assessment done through the checklist.

Keywords: Road slope failure, Hazard, Vulnerability, Risk Assessment

* Correspondence: gangani.nbro@gmail.com

ROADSIDE SLOPE RISK ASSESSMENT IN SRI LANKA



VALIDATION OF RAIN-INDUCED FAILURE OF UNSATURATED COLLUVIUM SLOPES: A CASE STUDY

M.P. Amarasinghe^{1,2,*}, S.A.S. Kulathilaka¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

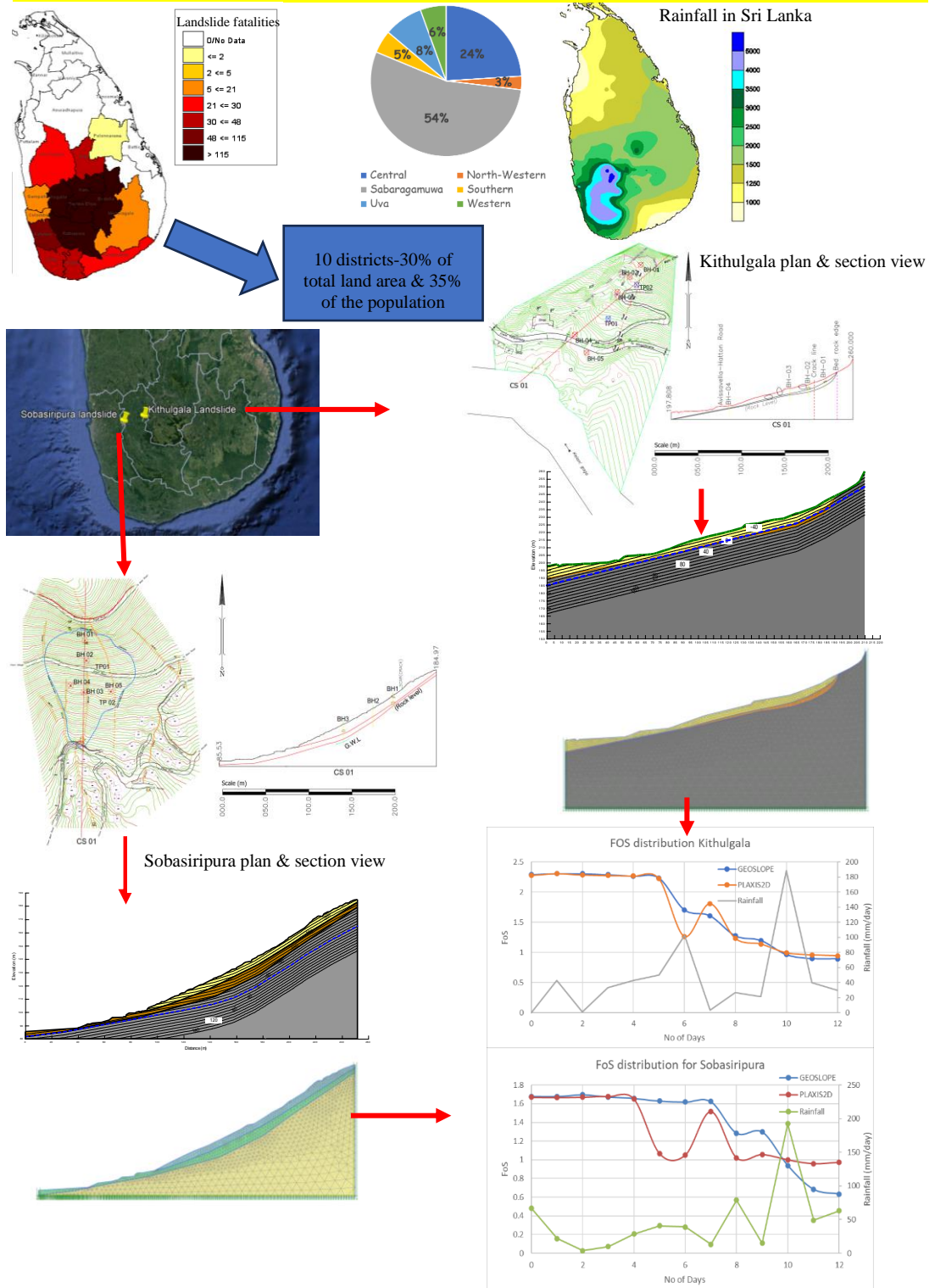
² Landslide Research and Risk Management Division, NBRO, Sri Lanka

Landslides are a major global hazard that affects human and economic losses every year. The spatial and temporal distribution of landslides is one of the fundamental tools for landslide susceptibility, hazard and risk assessment to establish land use policies and mitigation measures. Sri Lanka has been identified as a hotspot for rainfall-induced landslides, considering the heavy and prolonged rainfalls received during tropical monsoon seasons. Further, favourable preparatory factors for landslides such as ground conditions, geomorphology and anthropogenic activities prevails in the country. The significant weathering in the tropical region due to temperature and humidity can form thick soil layers and geological structures of high variability. The ground conditions in the central hill country in Sri Lanka is highly complex due to the weathering of the crystalline metamorphic rock of Precambrian age which exists in this region. Colluvium soils are a heterogeneous mixture of soil and rock particles accumulated at the toe area of the slope due to previous downslope movements under gravity. Movements within these layers can get easily reactivated due to porewater pressure variations or human interventions. Currently, landslide susceptibility in the mountainous regions of Sri Lanka has been identified and mapped based on a model considering six terrain factors and factor classes on the scale of 1:10,000 and 1:50,000. Landslide early warnings are issued for the high susceptible areas based on the empirical thresholds identified for the whole nation and these can lead to false alarms. Hence it is vital to implement early warning based on rainfall thresholds identified using process-based methods, which is more accurate and reliable. In this study, the suitability of limit equilibrium (LE) and finite element (FE) methods to assess slope stability with rainfall infiltration was evaluated using two case studies. The first case study was conducted on the Kithulgala landslide which occurred on 15th May 2016 in Kithulgala area along the Avissawella-Haton main road. Sobasiripura landslide which occurred on the same day in Hanwella North was selected as the second case study. For the LE study SLOPE/W software was utilised along with the SEEP/W software for FE seepage analysis. Alternatively, PLAXIS 2D software was used to conduct a FE based coupled hydro-mechanical stability analysis. Rainfall for 10 days prior to the failure was considered for the analysis to allow the antecedent rainfall conditions and the equilibrium of the groundwater table. From the results of the study, it was evident that both methods can be used to effectively verify the failure and triggering rainfall that closely resemble the failure surface identified at the site. The failure occurred along the colluvium-weathered rock interface in both cases and the matric suction loss in the colluvium layer was the main reason for the failure rather than the rise of the groundwater table.

Keywords: Finite element analysis, Limit equilibrium, Landslide, Rainfall, Slope stability

* Correspondence: amarasinghemp.21@uom.lk

VALIDATION OF RAIN-INDUCED FAILURE OF UNSATURATED COLLUVIUM SLOPES: A CASE STUDY



OUT-OF-PLANE DEFORMATION MEASUREMENTS USING DIGITAL IMAGE CORRELATION

V.G.E.S. Gamage, H.M.Y.C. Mallikarachchi ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Accurate measurement of 3D full-field deformation is paramount for the development of modern applications in structural engineering. Over the past decade, digital image correlation commonly referred to as DIC has emerged as a promising optical-based displacement measurement technique. Its usage in experimental science has gained popularity due to its advantages, including ease of use, high spatial resolution, non-contact nature, and reusability. While advanced DIC measurement systems exist, their high capital costs have limited their widespread adoption. Furthermore, most of the open-source DIC software systems are primarily designed for 2D measurements. Consequently, previous research efforts in DIC have predominantly focused on assessing materials with 2D deformations, with fewer studies addressing materials undergoing significant out-of-plane deformation.

This study introduces an innovative measuring tool based on DIC for the precise capture of 3D full-field out-of-plane deformation data. The proposed system utilises commercially available digital cameras and employs MATLAB-based algorithms for data processing and analysis. Uniaxial buckling tests were conducted on thin steel plate elements, considering their ability to induce significant out-of-plane deformations to validate the efficacy of this approach. A random speckle pattern was applied on the specimen surface to aid in feature detection and tracking. Simultaneous stereo images of the specimen were captured using two digital cameras at predefined loading intervals. Subsequently, the acquired images were subjected to disparity removal and rectification procedures.

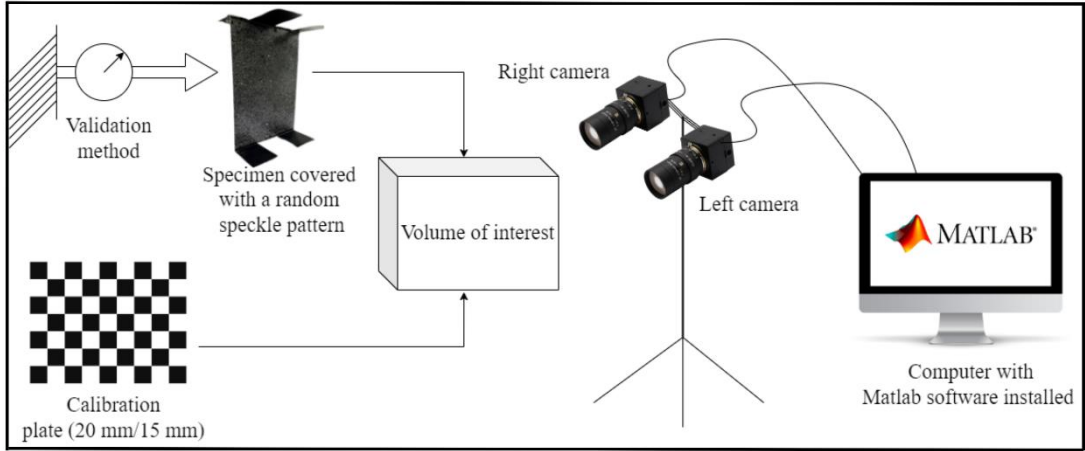
From the generated disparity map, a 3D point cloud of the specimen was constructed, resulting in a 3D array of surface coordinates. Surface features of the specimen at each deformed stage were detected and extracted using the KAZE feature detection algorithm, leading to the generation of a 2D geometric transformation matrix for consecutive image pairs. By utilising this matrix in conjunction with the generated 3D point clouds, the displacement value of each pixel on the specimen's images was computed. Notably, an incremental correlation method was employed between successive images, as opposed to the conventional direct correlation method, to accurately capture significant out-of-plane deformations.

The displacement values obtained from the DIC system were subsequently validated against dial gauge readings. A comprehensive comparative analysis of the results demonstrates the capability of the proposed system to generate precise full-field displacement and strain maps in all three dimensions. The reliability and accuracy of the system in capturing substantial 3D deformations are underscored by the fact that the measurements obtained from the proposed system closely align, with a similarity exceeding 95%, further affirming its effectiveness.

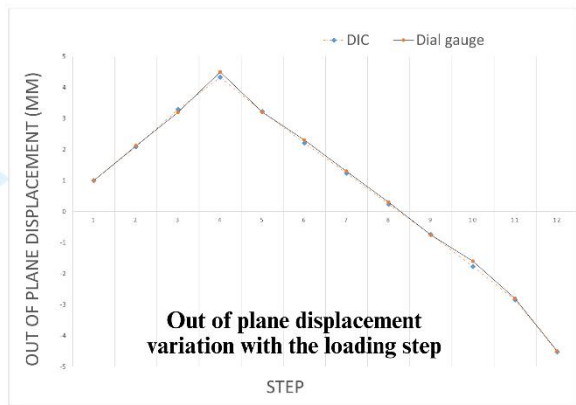
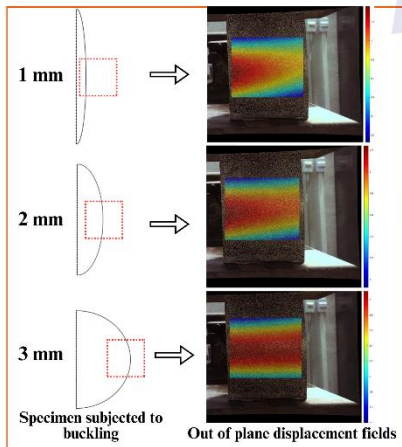
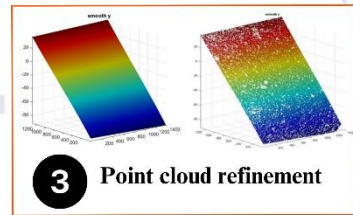
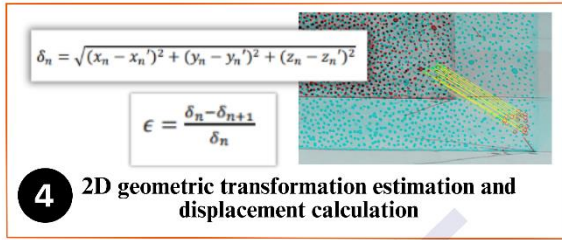
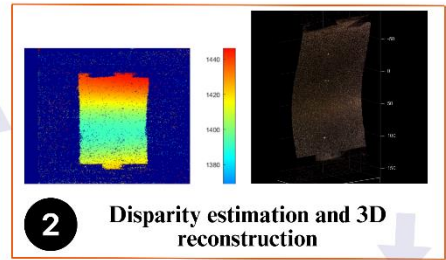
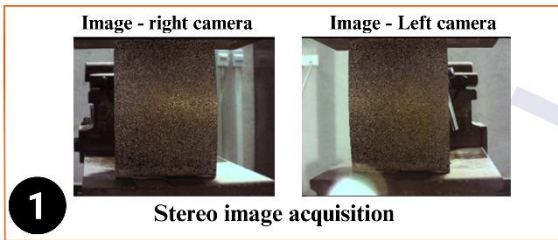
Keywords: Digital Image Correlation, 3D point cloud, Out-of-plane deformations

* Correspondence: yasithcm@uom.lk

OUT-OF-PLANE DEFORMATION MEASUREMENTS USING DIGITAL IMAGE CORRELATION



Experimental setup



STRUCTURAL ANALYSIS OF ANCIENT STUPA IN SRI LANKA

S.G.I.M. Premarathne¹, H.M.Y.C. Mallikarachchi^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Ancient stupas in Sri Lanka hold immense historical, archaeological, and religious significance. These monumental structures, dating back to ancient times, serve as tangible links to the country's rich cultural heritage. Therefore, it is imperative to restore and conserve these structures with great care so that future generations can witness the remarkable engineering technology of the past. However, it is essential to acknowledge that some restoration attempts in the past have resulted in catastrophic failures. These failures were mainly due to the complex structural behaviour of these massive structures due to complex geometries and different loading conditions. Consequently, these misguided restoration efforts have not only failed to preserve the historical value of the stupas but have also led to their degradation. The purpose of this research is to tackle the limitations found in current finite models and understand how they affect the restoration work. To achieve this aim, the study has two main objectives. Firstly, it investigates whether shifting from a 2D axisymmetric analysis to a more detailed 3D analysis is necessary. This change could significantly impact how successful restoration efforts are. Secondly, the research examines the lasting effects on stupas caused by moisture-induced expansion and the impact of temperature changes. Both of these factors play a crucial role in the restoration of stupas.

Deegawapi stupa was taken as the case study to achieve the objectives of the research. Then, 2D axisymmetric and 3D non-axisymmetric models of Deegawapi stupa were analysed under self-weight using the finite element package ABAQUS. Results indicated minimal divergence in maximum stress values between the two models. Notably, comparing full 3D analysis to partial (half and quarter) stupa analyses reveals negligible differences in outcomes, accompanied by significantly reduced computational time in wedge analyses. Accounting for material non-homogeneity between the original and new components of the stupa, there was stress variation in the structure compared to the homogeneous model. Notably, there was a high stress concentration between the interface of new and old material. However, stress concentrations at this interface were within material strength limits. Given that ancient stupas are predominantly constructed from clay bricks and a butter-like plaster, both of which are highly susceptible to moisture-induced expansion, this study conducted an analysis to assess the implications of this phenomenon. The analysis outcomes revealed a notable concentration of high stress at the interface between the new and old components, which exceeded the strength of both the new and old materials. Considering that these ancient structures are primarily situated in arid regions, they are subject to elevated thermal loads arising from intense solar radiation. To replicate the impact of such conditions, a thermal load ranging from 35°C to 65°C was applied to the stupa's exposed surface. The subsequent analysis of stress distribution revealed that the recorded stresses remained within the material strength.

Based on the findings of this research, it can be recommended to consider the non-linear properties of the stupa's materials for future studies in this field.

Keywords: Axisymmetric, 3D analysis, Material Non-homogeneity, Moisture expansion, Thermal effect

* Correspondence: yasithcm@uom.lk

STRUCTURAL ANALYSIS OF ANCIENT STUPA IN SRI LANKA

PAST FAILURES

TISSAMAHARAMA STUPA



Cracks on the dome



Post stressing the dome using stainless steel cables



Post-tensioned dome

Present conservation guidelines, which prioritise minimal intervention and preservation of structures' historical and cultural value (Ranaweera 2001), conducting a highly accurate structural analysis is essential before undertaking any restoration process

ISSUES AND DRAWBACKS RELATED TO CURRENT FE MODELS

Material non-homogeneity

Old brick vs new brick

Non-axisymmetric nature of the stupa

2D vs 3D finite element analysis

Long term effects on the stupa

Shrinkage and expansion

Thermal effects

Primary Aim: Analysing how to restore stupas in Sri Lanka that ensures a successful restoration process without any failures while preserving their archaeological and architectural value.

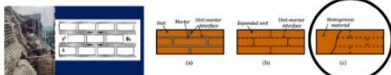
The aim of this research will be achieved based on the following research objectives

- 1) Quantifying the effect of 2D and 3D analysis of stupa for restoration purpose
- 2) Analysing long-term effects on stupas
 - Moisture expansion of old stupa
 - Thermal effects

FINITE ELEMENT MODELLING OF STUPA

Main assumptions

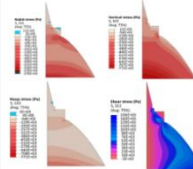
- Modelling technique of Masonry Stupa : **Macro modelling**



- Material model for Masonry Stupa : **Elastic model**
- Material and geometric non-linearity not considered

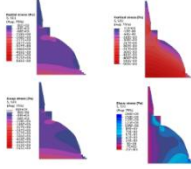
2D FEM ANALYSIS

ABHAYAGIRI STUPA



Abhayagiri Stupa	2D ABAQUS Model
Vertical Stress	
Maximum compression	-772 kPa (Bottom center)
Hoop stress	
Maximum compression	-253 kPa
Maximum tension	0 kPa
Radial stress	All compressive

DEEGAWAPI STUPA



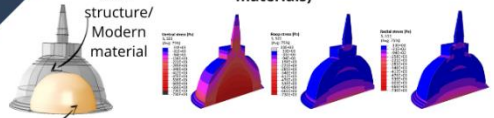
Deegawapi Stupa	2D ABAQUS Model
Vertical Stress	
Maximum compression	565 kPa (Bottom center)
Hoop stress	
Maximum compression	12 kPa (Dome)
Maximum tension	28 kPa (Spire)
Radial stress	
Maximum tension	Negligible tension (Dome)

24 kPa (Spire)

3D ANALYSIS OF STUPA

NON-HOMOGENEOUS MODEL

(Material non-homogeneity between old and new materials)



Old structure/Ancient material (Assume symmetric)

Continuous connection between the two surfaces was considered

MOISTURE EXPANSION OF THE OLD STRUCTURE OF THE STUPA

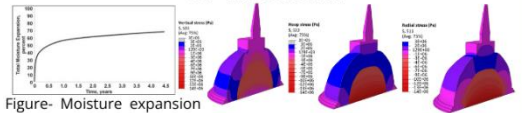
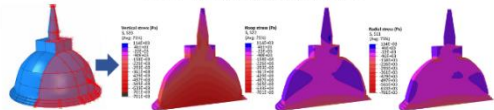


Figure- Moisture expansion of clay brickwork over time

THERMAL ANALYSIS



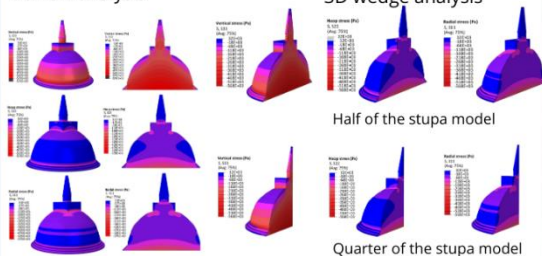
Considering the most critical temperature load of 65°C on exposed surface of stupa to direct solar radiation

3D ANALYSIS OF STUPA - HOMOGENEOUS MODEL

DEEGAWAPI STUPA

Full 3D analysis

3D wedge analysis



CONCLUSION

- When analysing a stupa solely under its self-weight, 3D geometry modelling will not be essential
- Under the same conditions where a more detailed stress distribution of the structure is necessary, it is feasible to model a wedge of 3D geometry because there is no significant variation between full and wedge analysis

Model	Computational time
Half	0.35×Full 3D Model
Quarter	0.06×Full 3D Model (0.16×Half 3D Model)

- Other than self-weight, loading due to external environmental factors has a high effect on stress distribution of the structure. Therefore, if there is a chance of moisture leaking to the stupa core and high thermal loading on the stupa surface, it should be incorporated to the analysis

MULTISCALE MODELING OF LATTICE STRUCTURES UNDER LARGE DEFORMATIONS

P.N. Ahangamage¹, H.M.S.T. Herath^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The rapid advancement of additive manufacturing (AM) enables the fabrication of strong, lightweight structures with a topology that is unreachable using conventional manufacturing processes, such as complex lattice structures. Among these lattice structures, soft lattice structures can undergo large elastic deformations, absorb energy and dampen vibrations in a reversible manner, exploit mechanical instabilities and buckling, exhibit auxetic behaviour, possess negative thermal expansion, and have shape-memory and shape-morphing capabilities. These unique characteristics of soft lattices open up new pathways to a wide range of multifunctional applications, including soft robotics, biomedical devices, energy harvesting, and storage. Hence, the modelling of soft lattice structures has become very important thing.

This research study introduces a computational modelling framework for characterising the effective nonlinear micromechanical behaviour of soft lattice structures under uniaxial loading conditions with large deformations. It also explores the impact and necessity of joint stiffening in modelling soft lattices. Furthermore, it investigates the effects of parameter variations on the overall micromechanical behaviour of unit cells.

Under uniaxial loading, certain soft lattice structures present buckling-dominated behaviour, while others present bending-dominated characteristics. In developing and validating the computational modelling framework, Body Centred Cubic (BCC) structures were used to represent buckling behaviour, and Body Centred (BC) structures were used to represent bending behaviour. Numerical simulations were performed using Abaqus FEA software. For micromechanical analysis, Periodic boundary conditions were applied to simulate unit cell behaviour, facilitating the extraction of effective homogenised responses.

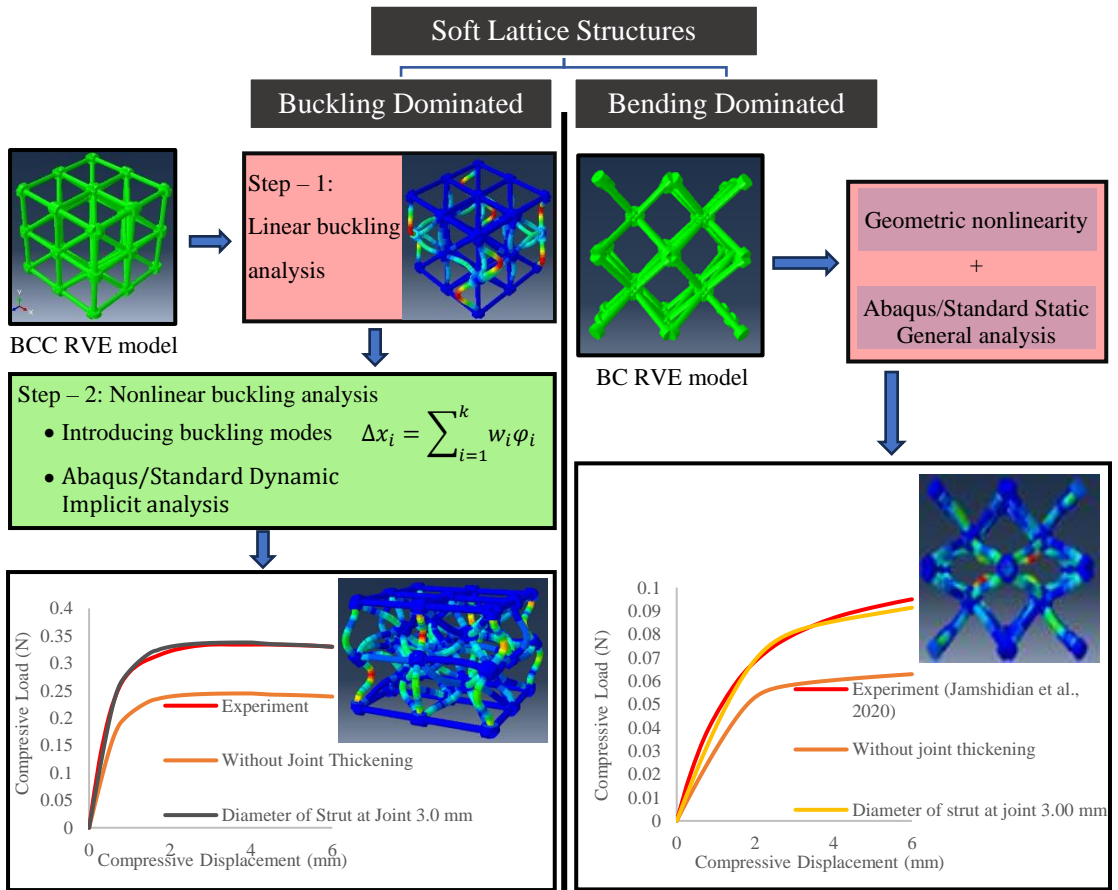
To achieve the required joint stiffness in soft lattices, it is necessary to increase the joint thickness by 100% of the strut diameter for a length equal to the diameter. During uniaxial testing, lattice structures dominated by bending and stretching can be modelled using the ABAQUS/Standard Static General solver, avoiding the introduction of buckling mode shapes. Conversely, lattice structures exhibiting buckling behaviour can be modelled employing the ABAQUS/Standard Dynamic Implicit solver, incorporating proper scaling factors to simulate buckling mode shapes within ideal lattice structures.

The developed effective stress-strain responses of unit cells under uniaxial loading can be used to develop a material model for soft lattice structures. Curve fitting techniques and artificial neural networks are recommended methods for material model development in further studies.

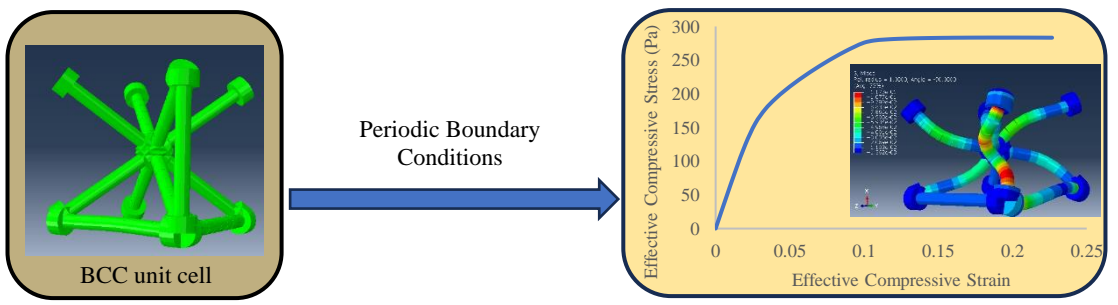
Keywords: Multiscale modelling, Soft Lattice structures, Nonlinear buckling analysis, Computational framework

* Correspondence: sumuduh@uom.lk

MULTISCALE MODELLING OF LATTICE STRUCTURES
UNDER LARGE DEFORMATIONS



Micromechanical Modelling



FLEXURE BEHAVIOUR OF DAMAGED REINFORCED RUBBERISED CONCRETE BEAMS STRENGTHENED WITH CARBON FIBRE REINFORCED POLYMERS

R.K.S. Maleesha¹, J.C.P.H. Gamage^{1,*}, E.R.K. Chandrathilaka¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

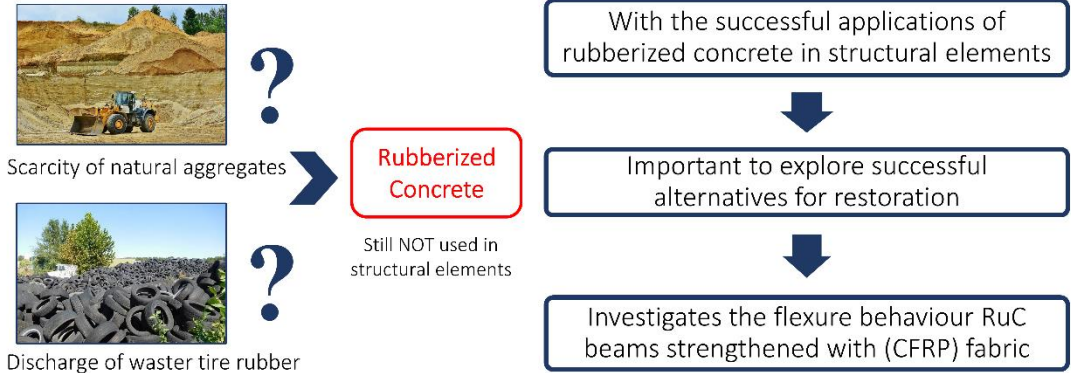
Developing rubberised concrete (RuC) for structural applications is an excellent solution for the scarcity of natural aggregates and the discharge of rubber waste in bulk volumes into the natural environment. With the successful applications of rubberised concrete in structural elements, it is important to explore successful alternatives for restoration in case of deficiencies met in their service life. This study investigates the flexure behaviour of damaged reinforced rubberised concrete beams strengthened with Carbon Fibre Reinforced Polymer (CFRP) fabric which is one of the best solutions that can be implemented to strengthen cracked reinforced rubberised concrete beams. To prepare RuC, rubber particles having three different size ranges, were obtained from outdated vehicular tires through the process of mechanical shredding. The first range, consisting of fine rubber particles ranging from 0-5 mm, was used to replace fine aggregate. The second and third ranges, consisting of coarse rubber particles ranging from 5-10 mm and 10-20 mm, respectively were utilised to replace gravel. The average measured 28 days compressive strength of rubberised and normal concrete was 40.54 MPa and 51.7 MPa, respectively. A total of four medium-scale non-strengthened reinforced RuC beams, and a normal concrete beam were preloaded until a 0.3 mm crack occurs. All beams had the same dimensions with 1650 mm×180 mm×130 mm for length, depth, and width, respectively. Then the damaged beams were strengthened using CFRP with and without polymer anchors at the ends of bonded fabric. Four-point bending test was conducted subsequent application of cyclic load with the amplitude of 50% and 75% of the ultimate load. The beams were considered as simply supported with a clear span of 1500 mm.

CFRP-strengthened reinforced rubberised concrete beams could reach a 53% higher load with 61% less displacement until a 0.3 mm crack occurs than non-strengthened reinforced RuC beams. It was found that the U-wrap end anchorage system increased the ultimate load by 5% than without end anchorage, delaying the debonding of CFRP fabric. CFRP-strengthened reinforced RuC also exhibited a similar load-deflection curve as strengthened normal concrete beams. When considering the crack patterns, vertical flexural cracks first formed when the load is 20 kN-40 kN in the middle third of the beam, between two-point loads, and then propagated towards the compression zone when the load increased. Additionally, flexural-shear cracks originated near the supports and subsequently propagated at an incline throughout the compression zone. Beams failed in two failure modes, which are debonding of the CFRP fabric near the support region and cover delamination. The strengthened RuC beams using CFRP could reach the required strength enhancement similar to reinforced concrete beams. Overall, the experimental results exhibited the feasibility of strengthening rubberised concrete beams in structural applications with CFRP fabric. However, further investigations are required to evaluate fire and durability performance.

Keywords: Rubberised concrete, Damaged concrete beams, Flexural strength, CFRP

* Correspondence: kgame@uom.lk

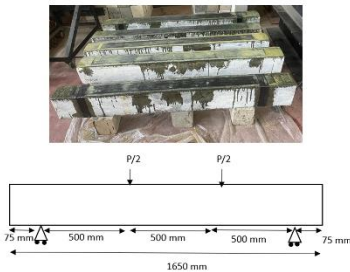
Flexure behavior of damaged reinforced rubberized concrete beams strengthen with Carbon Fiber Reinforced Polymers



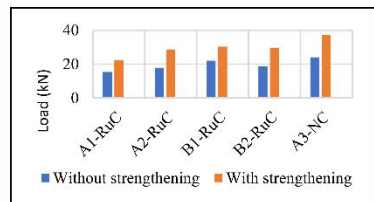
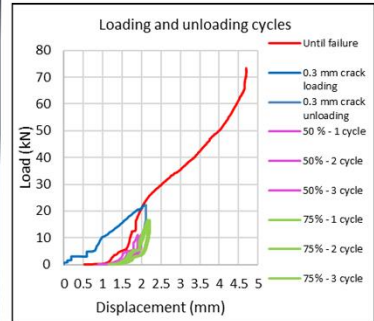
Experimental Program

Material	Quantity (kg/m ³)
Cement	340
Silica fume	42.5
Fly ash	42.5
Fine aggregate (0-5 mm)	820
Coarse aggregate (5-10 mm)	364
Coarse aggregate (10-20 mm)	637
Water	150
Superplasticizer	7.66

Rubberized concrete by replacing both fine and coarse aggregate by 10% of the volume



Results and Analysis



Debonding & Cover delamination

Conclusion

U-wrap end anchorage system increase the ultimate load by 5% than without end anchorage successfully

It is feasible to strengthen rubberized concrete beams in structural applications with CFRP fabric.

APPLICABILITY OF RCPT FOR PERFORMANCE-BASED DURABILITY DESIGN OF REINFORCED CONCRETE STRUCTURES

H.M. Abeywickrama¹, S.M.A. Nanayakkara^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

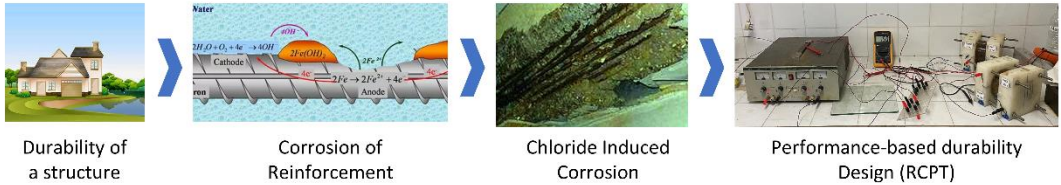
Concrete is an extensively used composite material in the construction industry, known for its heterogeneous nature. In the context of structural service life predictions, the durability of concrete plays a vital role, especially with the advancement of new constituent materials. Among various factors contributing to concrete deterioration, corrosion of reinforcement poses a significant challenge to durability. Chloride ingress is one of the primary factors that cause corrosion of reinforcements. Therefore, this research paper focuses mainly on the impact of chloride-induced corrosion which is the major cause of corrosion of reinforcement. There are several tests that are still available to evaluate that kind of corrosion. The Rapid Chloride Penetration Test (RCPT) serves as a quick measure of chloride ion penetration resistance, which relies on the characteristics of pore structure and pore solution. The standard RCPT (ASTM C1202) is done under certain conditions. But there are limitations and drawbacks of RCPT due to certain conditions. In that way, the significant effect of RCPT results can be evaluated by changing the voltage, cathodic solution, and time. Therefore, this study investigates the influence of the cathodic solution changing with natural seawater to represent more actual conditions. The chloride content of that seawater was 10% w/w.

The standard RCPT gave 2401 C while the modified method gave 3122 C as the charge pass. Once the RCPT procedure concludes, concrete powder samples were collected at various depths to determine the chloride profile. These obtained profiles were then subjected to nonlinear regression analysis to calculate chloride penetration depths. By applying Fick's second law to the chloride profile and penetration depth, the chloride diffusion coefficient was determined. Finally, a performance-based design approach was proposed, linking RCPT values with the Fib Model Code 2010, to predict the service life of uncracked concrete affected by corrosion. Then results were compared with the results which were obtained by a standard method for chloride diffusion coefficient. That standard method used for this study was RCMT (according to NT BUILD 492). Then the obtained diffusion coefficient values were 21.43 mm²/year, 20.97 mm²/year, and 21.02 mm²/year for the standard RCPT, the modified method and the RCMT, respectively. The errors were 0.2% and 1.9%, for the modified method and standard RCPT when compared with RCMT result. On the other hand, the predicted service lives for standard RCPT and modified methods were 44.32 years and 42.84 years, respectively. The RCMT gave the service life as 40 years. So, the percentage in errors were 10.8% and 7.1% for standard RCPT and modified methods when compared with RCMT result. In conclusion, standard RCPT should be modified by using sea water from actual environment instead of 3% NaCl solution if the structure is contact with sea water. RCPT can be used for performance-based durability designs. However, further investigations are required to establish the correlation between RCPT values and chloride diffusion coefficient for different grades of concrete.

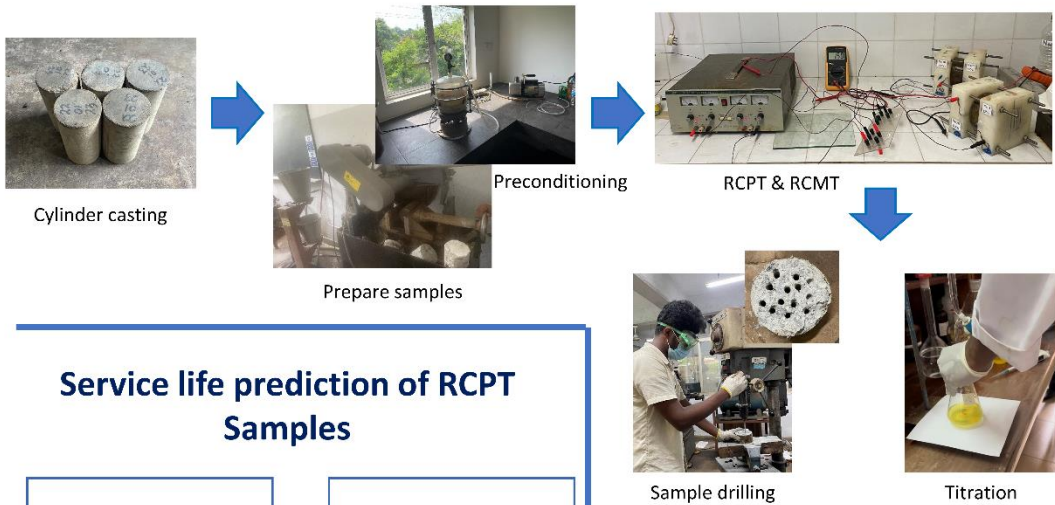
Keywords: Concrete Durability, Chloride Penetration, RCPT, Service Life Prediction, Modifications for RCPT

* Correspondence: sman@uom.lk

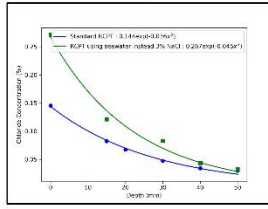
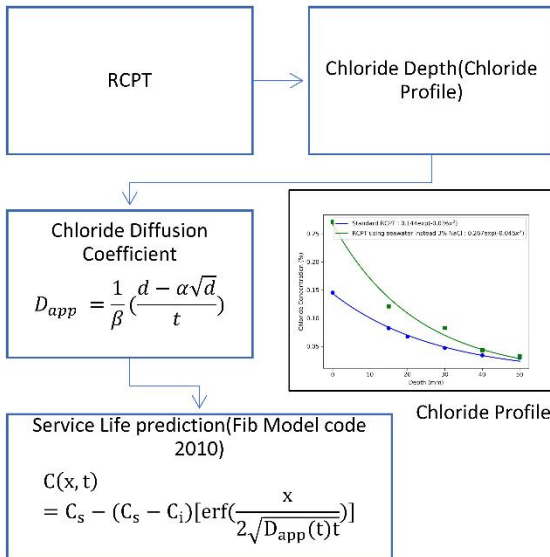
Applicability of RCPT for performance-based durability design of reinforced concrete structures



Experimental program



Service life prediction of RCPT Samples



Results & Analysis

Sample Condition	Charge Passed (C)	D_{app} ($\frac{mm^2}{years}$)	Variation	Service Life Years	Variation
Standard Method (RCMT)	-	21.02	-	40.009	-
Standard Method	2401.1	21.43	1.9%	44.32	10.8%
Sea water instead of NaCl	3121.5	20.97	0.2%	42.84	7.1%

Conclusion

- RCPT can be used for performance-based durability designs
- Standard RCPT should be modified by seawater instead of 3% NaCl

A GENERAL NUMERICAL MODELLING APPROACH FOR BLAST LOADS ON A BUILDING

K.L.L. Shamiranga¹, P.L.N. Fernando^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

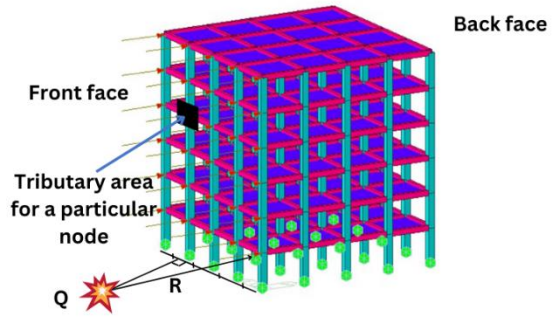
A blast load acting on a structure can be considered as an amalgamation of overpressure and impulse over an extremely short duration, which can cause catastrophic exterior and internal damage. Such blast loads can be generated due to either intentional or accidental actions. Due to growing threats, over the years, researchers have given special attention to studying the behaviour of structures when subjected to blast loads, and numerical modelling is a common approach used for such studies due to its practicality. However, existing modelling methods using advanced Finite Element Modelling (FEM) software can be complicated and computationally expensive and, in most cases, aims at studying the localised behaviour due to blast loads. On the other hand, Advanced FEM tools may require specialised expertise, limiting their accessibility for day-to-day structural design activities. This study aims to develop a general yet accurate model to simulate the complex behaviour of blast loads on a multi-storey building. To achieve this aim, two objectives are defined as identifying the applicable blast load parameters to represent the blast event accurately and simulating the behaviour of a building under positive overpressure due to blast loads. The approach approximates the blast load as a force at each node in the front face by multiplying the pressure by the tributary area and is implemented using finite element analysis. The approach is validated against data from open literature shown to be effective in predicting the response of structures to blast loads at a conservative level (49% difference for near-field explosions while 23% difference for far-field explosions). In this study, reinforced concrete buildings with three, six, and twelve storeys were modelled with blast loads of 1000 kg TNT at standoff distances of 5 m, 10 m, and 30 m from the building. Here, when the standoff distance is 5 m, it represents a near-field explosion, whereas when the standoff distance is 30 m, it represents a far-field explosion. The top-storey displacement due to the blast load was obtained as the main result, and a comparison was made to analyse the effect of blast load when there are shear walls and see the effect of slabs in resisting blast loads. The analysis was carried out using the commercially available finite element package, Midas Gen. The results demonstrate the potential of the proposed modelling technique to model the effects of the blast event with reasonable accuracy. However, it must be noted that the scope of this proposed approach is limited to structures that only need an initial blast load analysis and are not categorised as being vulnerable to blast loads. The results indicated that this method is more accurate for far-field explosions than for near-field explosions, where the expected behaviour of the structure is global and local, respectively. The top floor displacement is less than the no-shear wall scenario when there are shear walls. Also, the top floor displacement is less when there are slabs than in the no-slab scenario. In both situations, the rigidity of the structure due to laterally applied blast loads is high with shear walls and slabs. When the standoff distance is higher from the structure, it results in a uniform blast load on the front face, and at the same time, when the height of the buildings increases, they behave as cantilevers, and hence the top floor displacement is high. When the standoff distance is lesser from the structure, the blast load is localised, and the variation of top floor displacement is opposite to that in the far-field explosion.

Keywords: Blast load, Finite Element Modelling, Midas Gen, Far-field blast

* Correspondence: lakshithaf@uom.lk

Blast load is applied as a dynamic nodal load at each beam column joint at front face

- Following Cases are considered By varying the Standoff distance
- Case1: 1000 kg TNT at 5 m
 - Case2: 1000 kg TNT at 10 m
 - Case3: 1000 kg TNT at 30 m



Methodology



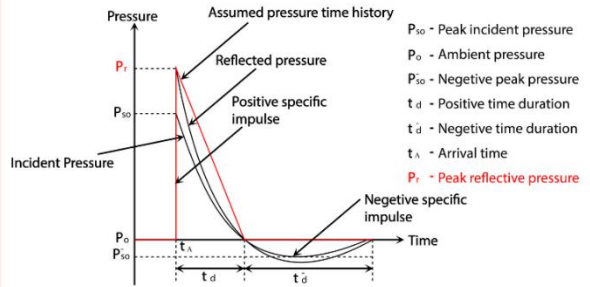
Modelling techniques used to model the blast loads

Identifying the blast wave behaviour

Develop the FE model and validation

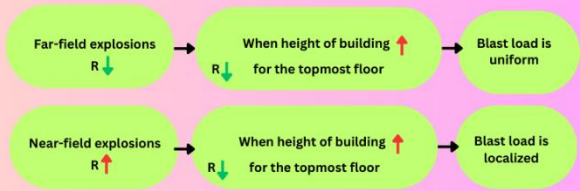
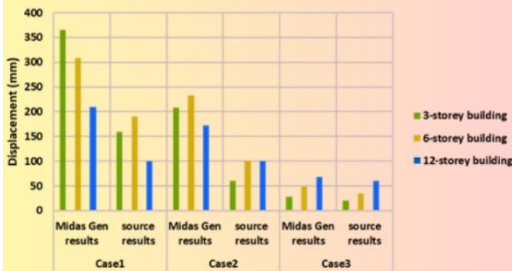
Analysis of results

Identifying the method of improving the blast resistance

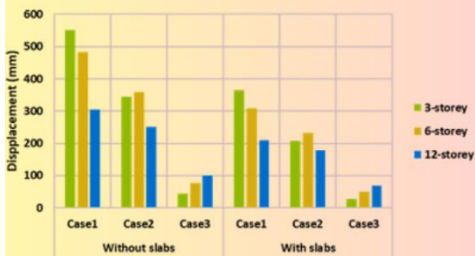


Results

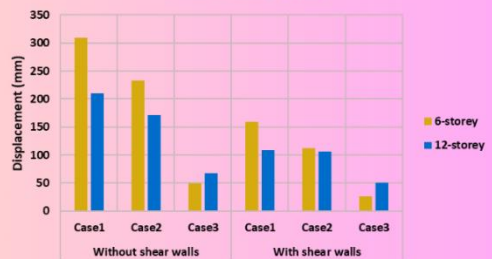
Comparison of Displacement at the top floor



Effect of rigidity of slabs



Effect of shear walls



The effect of rigidity coming from the slabs has an effect on the deflection of the structure for the laterally applied blast loads.

The presence of shear walls significantly reduces the deflection of the structure due to the laterally applied blast loads

FLEXURAL BEHAVIOUR OF REINFORCED RUBBERISED CONCRETE BEAM

A.P.I. Jayanath¹, J.C.P.H. Gamage^{1, *}, E.R.K. Chandrathilaka¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

A considerable number of tires in worldwide, approach end of their service life each year, and a significant portion of these discarded tires are disposed to the environment by landfilling and tire burning without proper treatment. Therefore, disposal of rubber into the environment has created major issues in terms of health, environment, and economics in the world. People looked for an effective way to stop further destruction caused by these discarded rubbers. The utilisation of discarded tires as aggregate for concrete can reduce environmental pollution, and the usage as raw materials, leads to sustainable development and efficient economic growth. Majority of research studies have been focused on the development of rubber-based concrete for non-structural applications. Even though little research studies had shown the suitability of rubberised concrete for structural purposes, none of them have assessed the feasibility for structural applications. This investigation aims to thoroughly explore the structural behaviour of reinforced rubberised concrete beams subjected to transient and cyclic loads, encompassing an assessment of rubberised concrete properties, strength development techniques and flexural behaviour of these beams. Rubberised concrete was prepared by replacing 10% of the fine and coarse aggregates, with rubber particles which were obtained from discarded vehicle tires. Those rubber particles were pre-treated using a 10% NaOH aqueous solution. As for the test specimens, cubes, cylinders, and five reinforced concrete beams were cast to assess the compressive strength, water absorption, splitting tensile strength, and flexural strength. Rubberised concrete samples, both with and without pre-treatment, showed reduced compressive strength compared to normal concrete, with reductions ranging from 35.5 % to 42.58 %. SEM analysis revealed that the presence of rubber particles in the concrete matrix increased porosity and decreased microstructural compactness, leading to weaker interfacial bonding between rubber particles and the cement matrix. Rubberised concrete exhibited higher water absorption compared to normal concrete with an increment of 116.3% when compare with normal concrete due to its higher porosity. Splitting tensile strength tests demonstrated a 53 % decrease in the strength of rubberised concrete mixes compared to normal concrete, primarily attributed to the limited bond strength between rubber particles and the cement paste. In series of four point bending tests were conducted to investigate the behaviour of reinforced rubberised concrete beams under flexure. The results indicate a reduction of 23.07% and 12.5% in moment capacity and workability and increment of deflection compared to normal reinforced concrete beam. However, it exhibited 32.66% higher flexural toughness, indicating its ability to absorb and dissipate energy. As for the recommendations, comprehensive cost analysis should be conducted to evaluate the economic feasibility and life cycle assessment should be conducted to evaluate the environmental feasibility of rubberised concrete compared to conventional concrete.

Keywords: Rubberised concrete, Flexural strength, Cyclic load response, Load-deflection

* Correspondence: kgamage@uom.lk

Investigation on Flexural Behavior of Reinforced Rubberized Concrete Beam



Tire burning



Tire landfilling

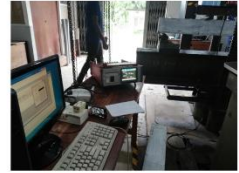


Scarcity of Natural aggregates

Sustainable and economic viable solution

Rubberized concrete

Test setup



Results & Analysis

Compressive strength test results

No	Type	7 days test		28 days test	
		Compressive strength (MPa)	weight (kg)	Compressive strength (MPa)	weight (kg)
1	Normal concrete (OPC)	44.65	8.6	62.7	8.85
2	Rubberized concrete with pre-treatment (10% rubber)	29.05	8.1	40.45	8.1
3	Rubberized concrete without pre-treatment (10% rubber)	25.2	7.75	36	7.7

Concrete type	Water Absorption (%)	Splitting tensile strength (MPa)
NC	3.49	3.539
RuC	7.55	1.664

Experimental Program

Material	Quantity (kg/m ³)
Cement	340
Silica fume	42.5
Fly ash	42.5
Fine aggregate (0-5 mm)	820
Coarse aggregate (5-10 mm)	364
Coarse aggregate (10-20 mm)	637
Water	150
Superplasticizer	7.66

Rubberized concrete is prepared by replacing fine and coarse aggregates by 10% of the volume



0-5mm



5-10mm

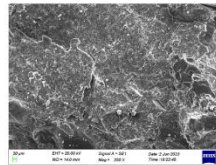


10-20mm

Specimen preparation



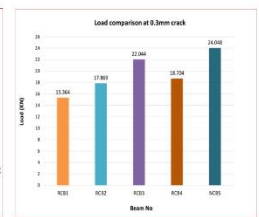
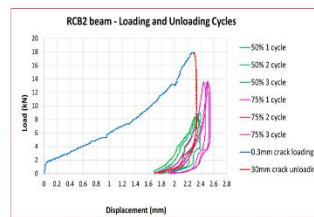
SEM results



Normal concrete



Rubberized concrete



Conclusions

- Rubberized concrete beam indicates a reduction of 23.07% and 12.5% in moment capacity and workability and increment of de-deflection compared to normal reinforced concrete beam
- RuC exhibited 32.66% higher flexural toughness, indicating its ability to absorb and dissipate energy.

INVESTIGATION OF DRYING SHRINKAGE BEHAVIOUR OF CONCRETE WITH COMPOSITE CEMENTS

N.T. Weerasinghe¹, S.M.A. Nanayakkara^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Understanding and investigating the drying shrinkage behaviour of concrete is of paramount importance for maintaining the overall performance and long-term durability of concrete structures. The occurrence of shrinkage-induced cracking can result in aesthetic concerns and functional limitations. Drying shrinkage is influenced by multiple factors, among them the type of cement plays a major role in governing the drying shrinkage behaviour. Therefore, investigating the drying shrinkage behaviour of concrete with a specific focus on composite cement becomes crucial. This study investigates the drying shrinkage behaviour of grade 30 concrete made out of two different cement types, Ordinary Portland Cement (OPC) and fly ash blended cement and checks the validity of the shrinkage model specified in Euro Code 2 (EC2) for local materials and conditions. To obtain the grade 30 mix proportions, a BRE mix design was carried out. Slump tests and compressive strength tests were done to check the suitability of the concrete mix. The required slump through the mix was 100 mm and the obtained slump value was also in the range of 100 ± 25 mm. From each cement type, 3 cubes were prepared and tested after 7 days and 28 days. The measured average 28 days compressive strength of OPC and fly ash blended cement contained concrete was 40.5 MPa and 47.2 MPa respectively. For the drying shrinkage test, moulds with 75 mm \times 75 mm \times 280 mm were used. After curing for 3 days and 7 days all the specimens were dried in normal room temperature and relative humidity conditions. A laser transducer was used to obtain the shrinkage values each day after letting them dry. Drying was continued up to about 45 days.

According to the obtained results, corresponding drying shrinkage in concrete with fly ash blended cement showed low values compared to that of concrete containing 100% OPC in both 3 days and 7 days of cured samples. In the first 15 days, it showed little difference between the two cement types, but when the days continued the difference became higher. Therefore, by incorporating fly ash blended cement in concrete mixes, low values for drying shrinkage can be obtained. When the effect of curing is considered, the 7 days of cured samples showed lower values for drying shrinkage than 3 days of cured samples, despite the type of cement used in concrete. When comparing the values obtained from the drying shrinkage equation in EC2 with experimental values, up to about 17 days equation values underestimated the drying shrinkage in concrete and after 17 days equation values tend to overestimate the drying shrinkage in concrete. Since the EC2 equation is not applicable under local scenarios, suitable modifications need to be done for the equations before using it.

Keywords: Drying Shrinkage, Composite Cement, Fly ash blended cement, Ordinary Portland Cement (OPC)

* Correspondence: sman@uom.lk

Investigating the Drying Shrinkage behavior of concrete with composite cement

Drying Shrinkage

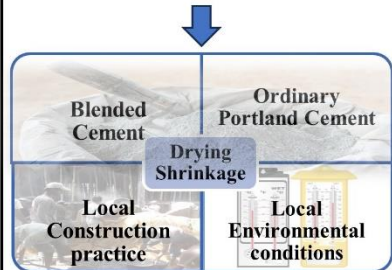
Occurs due to the continuous loss of capillary moisture from hardened concrete to the surrounding environment.

Considerable volume reduction

Possibility of cracking

Crack control to achieve structural integrity and durability

This study investigates,



Experimental Works

PERPARATION OF MOULDS



Size: 75 mm × 75 mm × 280 mm

BRE MIX DESIGN

Grade 30 Concrete (For 0.02 m ³)	Cement (kg)	Fine aggregates (kg)	Coarse aggregates (kg)	Water (kg)	Admixtures
	8.0	16.0	22.0	3.6	8 ml

SLUMP TEST



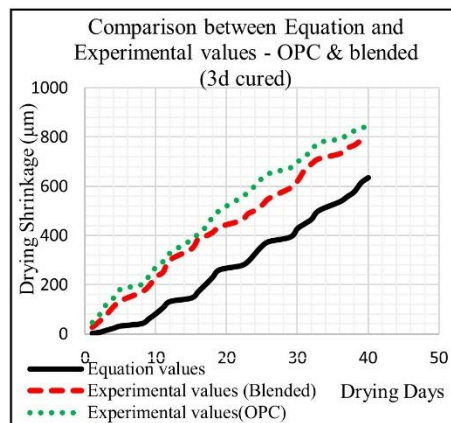
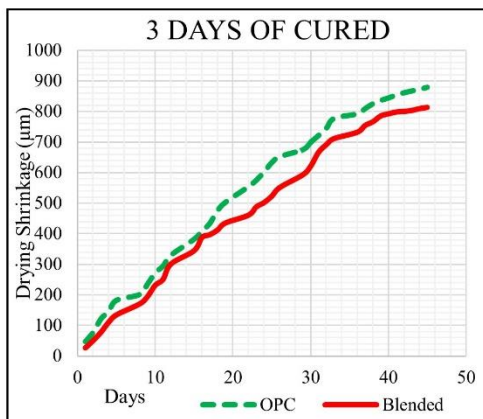
DRYING SHRINKAGE TEST



COMPRESSIVE STRENGTH TEST



Results and Analysis



Conclusions

- Incorporating fly ash blended cement in concrete mixes reduces drying shrinkage compared to concrete made solely with Ordinary Portland Cement
- Drying shrinkage equations provided in Eurocode 2, are not suitable for accurately estimating drying shrinkage in the Sri Lankan context

DEVELOPMENT OF A NOVEL WASTE BASED INSULATED PLASTER WITH WATER PROOFING ABILITY FOR ROOF SLABS

D.D. Weerakkody ¹, J.C.P.H. Gamage ^{1, *}, E.R.K. Chandrathilaka ¹, K. Selvaranjan ²

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Department of Civil and Structural Engineering, University of Sheffield

The cement industry, notorious for its significant contribution to global greenhouse gas emissions, has drawn increasing attention in recent years due to its environmental impact. As we strive to combat climate change, one crucial area of focus is improving the thermal performance of buildings, which not only reduces energy consumption but also enhances thermal comfort for occupants. Among the various components of a building's thermal envelope, roof slabs stand out as key contributors to heat transfer, accounting for a substantial 50-60% of overall heat exchange. Addressing this thermal challenge necessitates innovative solutions, and one such solution that has gained attention is the use of Rice Husk Ash (RHA) as a sustainable material to augment thermal insulation in roof slabs. This approach aligns with the broader goal of sustainable construction practices and the reduction of greenhouse gas emissions by employing controlled waste disposal techniques that transform waste materials into timely-needed sustainable building materials. The core concept behind this novel approach involves the manipulation of the material's microstructure. To achieve low thermal conductivity, the RHA is employed to induce a pore structure within the material. This pore structure acts as a barrier to heat transfer, significantly enhancing the insulation properties of the roof slabs. Simultaneously, the gaps and voids within the microstructure of the material are filled with non-conductive Waste Brick Powder (WBP). This dual-purpose protection not only improves the thermal performance of the roof but also contributes to enhanced waterproofing abilities. The benefits of this innovative product are impressive, particularly when compared to existing alternatives available in the market. In a comparative analysis, this new material demonstrated a remarkable 69.5% reduction in thermal conductivity, making it an effective solution for minimising heat transfer through roof slabs. Moreover, it exhibited an outstanding 89% improvement in its waterproofing abilities, which is crucial for maintaining the structural integrity of buildings and ensuring the comfort of occupants. This groundbreaking development represents a significant stride towards sustainable construction practices. By harnessing waste materials like RHA and WBP, we not only reduce the environmental footprint of construction but also produce materials that enhance energy efficiency and comfort within buildings. As we continue to address the pressing challenges of climate change, solutions like these offer a glimmer of hope for a more sustainable and environmentally friendly future in the construction industry. In conclusion, the integration of Rice Husk Ash and Waste Brick Powder in roof slab construction is a pioneering approach that holds great promise for reducing greenhouse gas emissions, improving thermal comfort, and advancing sustainable construction practices. This innovation not only contributes to energy-efficient building design but also underscores the importance of repurposing waste materials to create valuable and environmentally responsible building materials.

Keywords: Thermal Comfort; Waste Utilisation; Thermal Insulation; Waterproofing; Green Building Material

* Correspondence: kgamage@uom.lk

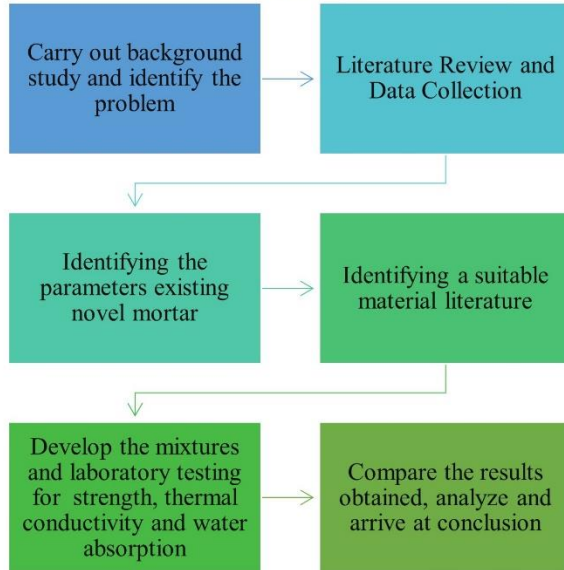
DEVELOPMENT OF A NOVEL WASTE-BASED INSULATED PLASTER WITH WATERPROOFING ABILITY FOR ROOF SLABS

Scope

Add waterproofing properties to waste-based novel insulating mortar developed using RHA by the University of Moratuwa researchers, which possesses only thermal insulation properties.

To improve the waterproofing properties, cement was partially replaced by **Waste Clay Brick Powder(WBP)**

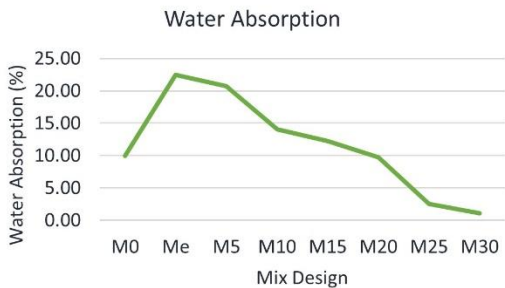
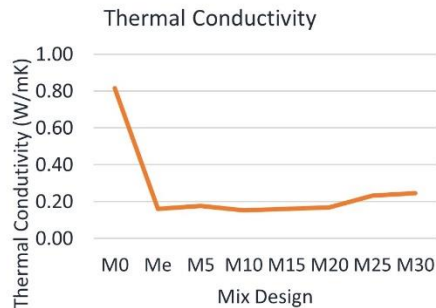
Methodology



Experimental Program

Control Mix	<ul style="list-style-type: none"> Cement: sand= 1:3 Water/binder ratio 0.5
Existing Mortar	<ul style="list-style-type: none"> Cement: sand= 1:3 but sand replaced by 30% RHA by weight Water/binder ratio 0.5
Mix Design	<ul style="list-style-type: none"> Eight different mortar mixtures- Varying WBP cement replacement percentages (5%,10%,15%,20%,25%,30% cement by weight)

Results



Conclusion

30% replacement of cement with WBP in RHA-based mortar shows significant improvements.

- ✓ 89% reduction in water absorption
- ✓ 69.5% reduction in thermal conductivity

EURO-CODE COMPLIANT ADAPTIVE LAYOUT OPTIMISATION OF TWO-DIMENSIONAL STEEL TRUSSES

G.M.D. Denuwanthi ¹, H.M.S.T. Herath ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Truss optimisation plays a vital role in the design and analysis of various engineering structures, ranging from bridges to aerospace applications. Over the years, researchers have proposed numerous numerical methods to achieve optimal truss configurations, considering factors such as weight minimisation, stiffness maximisation, and cost efficiency. However, despite the significant progress in the field, the absence of universally accepted standards for determining the optimum truss solution remains a challenge. This paper presents a novel methodology for optimising steel trusses using Euro-code standards as a reference framework specifically focusing on pin-jointed truss systems. The proposed methodology aims to combine numerical optimisation algorithms with the relevant design provisions outlined in Euro-code, ensuring compliance with structural integrity and safety criteria.

The process involves a Python script for convex optimisation and the numerical optimisation algorithm employs an adaptive member-adding solution scheme which provides a computationally efficient means of generating near-optimum trusses for the problems. The objective function of the optimisation algorithm is to minimise the total structural volume of the truss and the process satisfies the force equilibrium at each node of the truss as well as limiting stress criteria as defined in the Euro-code.

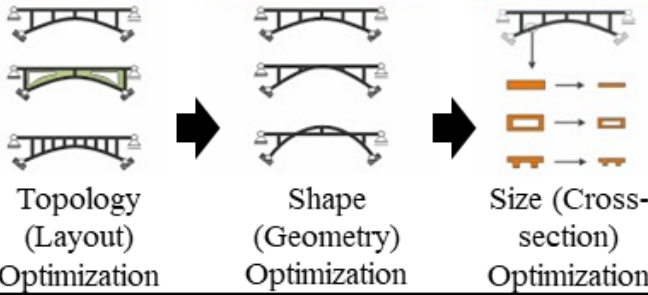
The research provides a thorough overview of the relevant Eurocode provisions that pertain to steel trusses. Initially, the optimisation studies employ a method to handle layout and geometry optimisation simultaneously to determine the optimal layout of the truss structures, taking into account practical and manufacturing constraints. Then, the methodology progresses to size optimisation which involves optimising the member cross-sections to enhance their stiffness and overall structural performance. Finally, the use of commercially available steel sections for the construction of optimised trusses is assessed to avoid financial challenges due to the high costs associated with additive manufacturing technologies within the context of Sri Lanka. To ensure the scientific robustness and practical applicability of the proposed methodology, rigorous examinations are conducted using practical examples.

Keywords: Truss Optimisation, Steel Trusses, Layout Optimisation, Geometry Optimisation, Size Optimisation

* Correspondence: sumuduh@uom.lk

EURO-CODE COMPLIANT ADAPTIVE LAYOUT OPTIMIZATION OF TWO-DIMENSIONAL STEEL TRUSSES

TRUSS OPTIMIZATION



THEORY

Objective Function

The objective function is to minimize the total structural volume of material.

$$\min_{a,q} V = \mathbf{l}^T \cdot \mathbf{a}$$

$$\mathbf{a} = [a_1, a_2, \dots, a_m]^T$$

$$\mathbf{l} = [l_1, l_2, \dots, l_m]^T$$

Constraints

Force equilibrium

The forces of each node must be in equilibrium

Limiting stress criteria

Each member must have a cross sectional area that is large enough to carry the force being transmitted

EN 1993 Part 1-1:

For tension members

$$\frac{q_i^k}{N_{t,Rd}} \leq 1.0$$

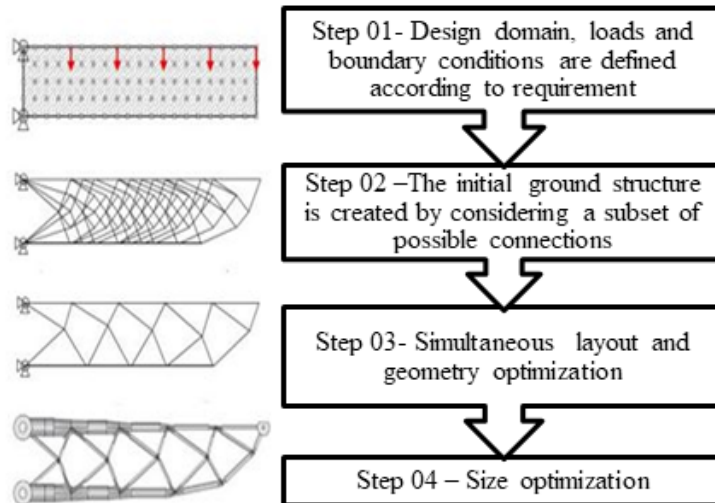
$$N_{Rd} = \text{Min}\{N_{pl,Rd}, N_{u,Rd}\}$$

For compression members

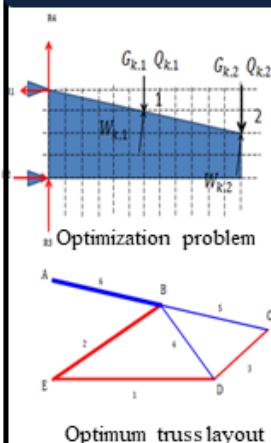
$$\frac{q_i^k}{N_{c,Rd}} \leq 1.0$$

$$N_{Rd} = \text{Max}\{-N_{b,Rd}, -N_{c,Rd}\}$$

PROPOSED FRAMEWORK



IMPLEMENTATION



Loading	G_k	Q_k	W_k
Purlin 1	1296.13	2280.00 N	1923.41 N
Purlin 2	755.80 N	1260.00 N	1062.94 N

Member	Length (m)	N_{Ed} (kN)	Selected section	N_{Rd} (kN)	Utilization ratio (N_{Rd}/N_{Ed})	Volume (cm^3)
1	2.25	-7.92	CHS 33.7 / 2	-9.35	0.85	423.3
2	1.58	-16.28	CHS 33.7 / 2	-17.82	0.91	304.9
3	0.90	-5.71	CHS 16 / 3.2	-6.46	0.88	115.8
4	1.06	4.48	CHS 10.2 / 0.6	4.98	0.90	19.2
5	1.52	4.55	CHS 10.2 / 0.6	4.98	0.91	27.5
6	1.52	17.49	CHS 12 / 2.3	19.27	0.91	106.5
Total Structural Volume						997.3

DEVELOPMENT OF AN IMPROVED EMPIRICAL FORMULA TO PREDICT THE DEFLECTION OF PLATES UNDER BLAST LOADS

R.M.I.C.B. Rathnayaka ¹, P.L.N. Fernando ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The world is moving forward with the advances in technology which has had both positive and negative impacts. One such negative impact has been the increment of terrorist attacks on structures around the world. Civil Engineers have focused on blast-resistant structures. Blast-induced loading on structural elements poses a significant challenge in engineering design due to its high-intensity load within an extremely short time duration. The present study aims at studying plate elements and deflection is one of the main criteria that govern the behaviour of plates. Several past studies have aimed to determine the deflection of plates under blast loads, but the accuracy of the results as well as the high experimental costs raises concerns regarding its feasibility. A numerical-based approach such as the Finite Element Method can be computationally expensive. The present study focuses on empirical methods, which have been found to be an effective and efficient method of predicting deflection under blast loads. Several empirical equations developed based on particular sets of experimental data can be found in the literature. But a shortcoming in such equations has been their applicability for any general case. Hence, the present research focused on developing an improved empirical equation to predict the deflection of plates under blast loads by reducing shortcomings identified in the existing equations.

An extensive literature review was conducted to analyse existing empirical formulas and identify the relevant parameters associated with plate deflection. According to past study data, there were three main failure modes. But here, failure mode I (plate deflection) was considered. Plate sizes under uniform load conditions were below 180 mm and under localised load conditions were below 400 mm. Furthermore, charge weights and standoff distances were below 150 g and 100 mm, respectively. Based on past experimental results, the present study provides two improved empirical equations to predict the deflection of square and rectangular plates under blast loads of uniform and localised types. The equation consists of several non-dimensional parameters which take into account factors such as the magnitude of the blast load, blast load impulse, loading type, standoff distance, yield stress, plate dimensions, and materials density. The singular valued decomposition method combines those parameters, and the validation process includes comparing the predicted deflection values with the corresponding measured deflections from experimental data sets available in published literature. According to the validation, all the data points under uniform loads were within the $\pm 10\%$ reliable error percentage range and data points under localised loads were within the $\pm 15\%$ reliable error percentage range. Overall, the proposed improved empirical equations offer a more accurate and practical solution for predicting plate deflection under blast loads, contributing to the advancement of blast-resistant structural design. This will be of use in applications such as blast doors, blast shield-armed vehicles, protective barriers and general blast-resistant structures.

Keywords: Deflection, Plates, Empirical, Non-dimensional parameters, Blast loads

* Correspondence: lakshithaf@uom.lk

DEVELOPMENT OF AN IMPROVED EMPIRICAL FORMULA TO PREDICT THE DEFLECTION OF PLATES UNDER BLAST LOADS

Main parameters related to deflection of plates under blast loads

- Blast load impulse (I)
- Standoff distance (S)
- Loading type (Uniform or localised)
- Charge weight (T.N.T equivalence)
- Yield stress (σ)
- Plate density (ρ)
- Plate dimensions (B, L, t)
- Charge diameter (R)

Improved empirical equations- Uniform load type

$$\frac{\delta}{t} = 0.0886(\Phi q)^{1.1292} \left(\frac{L}{B}\right)^{-0.1834} \left(\frac{L}{t}\right)^{0.3182}$$

Improved empirical equation-Localised load type

$$\frac{\delta}{t} = 0.3588(\Phi q l)^{1.1102} \left(\frac{L}{B}\right)^{0.1205} \left(\frac{L}{t}\right)^{-0.0051} \left(\frac{R}{t}\right)^{-0.025}$$

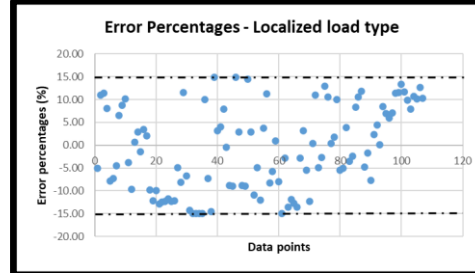
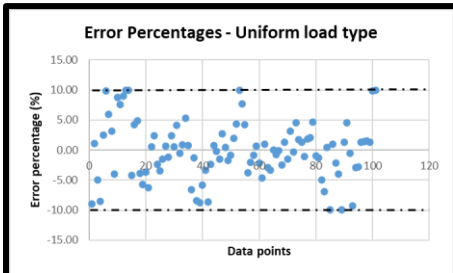
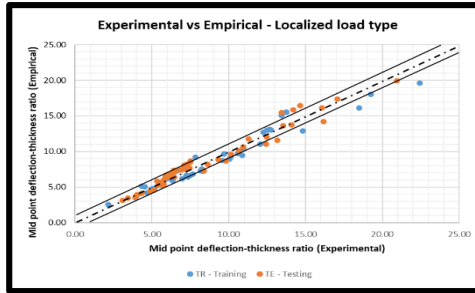
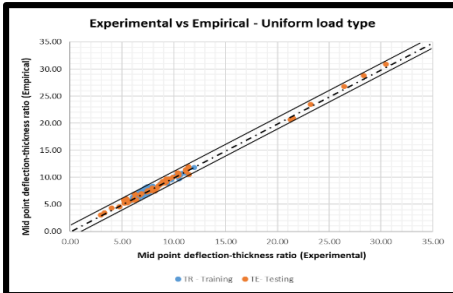
Non-dimensional parameters related to plate deflection

Deflection / Thickness	$\frac{\delta}{t}$
Non-dimensional Impulse parameter (Uniform)	$q = \frac{I}{2t^2(BL\rho\sigma)^{1/2}}$
Non-dimensional Impulse parameter (Localised)	$ql = \frac{I(1 + \ln(\frac{LB}{\pi R^2}))}{2t^2(BL\rho\sigma)^{1/2}}$
Slenderness parameter	$\frac{L}{t}$
Aspect ratio	$\frac{L}{B}$

CONCLUSION

All the data points under uniform loads are in between $\pm 10\%$ error range, and data points under localised loads are between $\pm 15\%$

VALIDATION



The two solid lines ($1\pm\delta/t$) are plotted to explain the fitting precision. results show that 100% of the data is within a reliable range

The two solid lines ($1.5\pm\delta/t$) are plotted to explain the fitting precision. results show that 100% of the data is within a reliable range

MODELLING STRUCTURAL STEEL ELEMENTS UNDER VARIOUS CORROSIVE ENVIRONMENTS

R.M.R.P.M. Rathnayaka¹, H.M.S.T. Herath^{1,*}

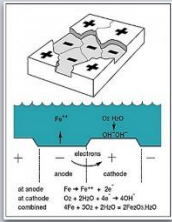
¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Atmospheric corrosion can affect age-related structural degradation, leading to changes in the structural integrity of metals. European codes provide only general provisions to prevent the effects of corrosion during the lifetime of steel structures. Currently, there is only a few studies have been done considering realistic varying corrosion thickness loss models and almost all of them focus only on extreme corrosion conditions like in industrial, coastal, and urban areas. In this paper, the behaviour of axially loaded corroded steel sections under exposure to different atmospheric corrosivity conditions are investigated. First, five different critical corrosion loss models are proposed to represent actual corrosion decay scenarios including the control specimen (CM0), one uniform thickness loss model (CM1) in which corrosion occurs in the entire cross-section, and three varying thickness loss models (CM2, CM3 and CM4) in which corrosion occurs only in some parts of the cross-section. The corrosion rate model is selected based on the ISO 9224:2012 to estimate the amount of corrosion thickness loss of steel with the time of exposure. ISO 9223:2012 is used to classify atmospheric corrosivity into six different categories namely, Very Low Corrosivity (C1), Low Corrosivity (C2), Medium Corrosivity (C3), High Corrosivity (C4), Very High Corrosivity (C5), and Extreme Corrosivity (CX) considering both high and low corrosivity conditions. Next, with the help of Eurocode 3 guidelines, an analytical framework is established to calculate both the tensile and compression capacities of corroded steel I-sections subjected to axial loads. Prediction of residual cross-section capacities with the changing cross-section is achieved through a programme designed to perform repetitive calculations using MATLAB environment. Results are validated using numerical modelling results after performing both linear and non-linear analyses for different cross-sections by ABAQUS Explicit Solver. The obtained results not only help in designing steel members exposed to corrosion but also in explaining possible reasons for the variations of cross-section capacity in different scenarios. Both tensile and compression capacities get reduced with the corroded age and the residual capacity gets reduced when the severeness of the corrosivity increases from C1 to CX. It is observed that sudden changes may take place in compression capacity curves because of the changes in the cross-section class from class 3 to class 4. This change can cause a member to fail by local buckling before overall buckling or material crushing. The probability of being subjected to local buckling failures is higher in higher corrosive environments like C5 and CX. Results show that the reduction factor in compression capacity is less than 5% which is a very minimal value even after the exposure of 50 years for corrosivity categories from C1 to C4. It suggests that failures are unlikely to happen when exposed to those four corrosive environments. For corrosivity categories C5 and CX, the reduction factor is approximately 10% and 35%, respectively. Therefore, unexpected structural failures can occur during the lifetime of structures, in those two environments. Since the CM1 corrosion loss model has the highest area reduction due to corrosion, it has the highest capacity reduction factor of 0.35 while the other three models (CM2, CM3, and CM4) have a factor around 0.1-0.2. This work can be extended to investigate the behaviour of flexural members subjected to corrosion losses in various corrosive environments.

Keywords: Atmospheric Corrosion, Buckling, Axial Members, Structural Steel

* Correspondence: sumuduh@uom.lk

Background



“The annual global cost of corrosion is roughly 3.4% of the world's gross domestic product.” - NACE

Corrosion

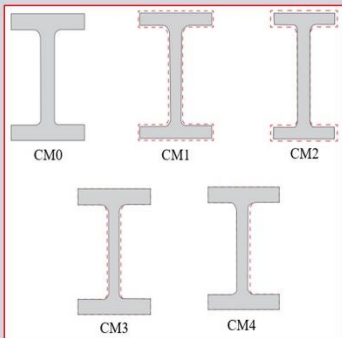
Material Loss

Structural Failures

Research Methodology

1. Corrosion Loss Model

- CM0 – Control specimen
- CM1 – Uniform loss
- CM2, CM3, CM4 – Varying loss



2. Corrosion Rate Model

- According to,
- ISO 9224 (2012)
 - ISO 9223 (2012)

$$d(t) = \begin{cases} r_{cor} t^B, & t \leq 20 \\ r_{cor} [20^B + B(20^{B-1})(t - 20)], & t > 20 \end{cases}$$



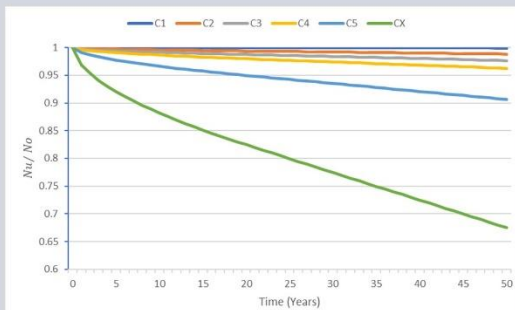
3. Analytical Framework

- Formed based on,
- EN 1993-1-1: General rules and rules for buildings
 - EN 1993-1-5: Plated structural elements

4. Designed Programme

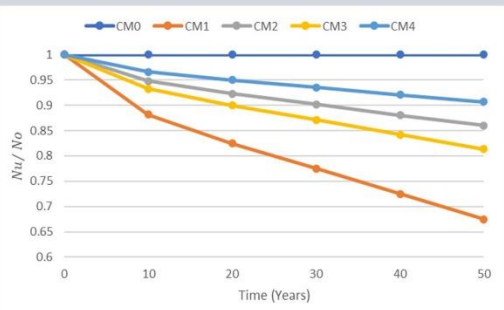
Results

Effect of Corrosivity Category



Capacity Reduction Factor
 $CX > C5 > C4 > C3 > C2 > C1$

Effect of Corrosion Loss Model



Capacity Reduction Factor
 $CM1 > CM3 > CM2 > CM4 > CM0$

PREDICTING FIRE-INDUCED SPALLING IN CONCRETE TUNNEL LININGS USING MACHINE LEARNING TECHNIQUES

S.M.D.T. Sembanayake¹, T.G.P.L. Weerasinghe^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Fire-induced spalling is the phenomenon where the outer cracked or delaminated layer of a concrete element detaches due to the exposure to high temperatures during a fire. Spalling is a phenomenon that has raised concerns in the research community since the 19th century. Since then, many experimental, analytical, numerical, and other studies have been conducted around the world to explain this phenomenon. However, an accurate model to predict the occurrence of spalling remains elusive, particularly for tunnel linings.

Tunnel fires have drawn increasing attention and raised more concerns in recent decades. The rapid growth of freight transportation, particularly flammable ones such as fuel, increases the potential to cause a rapid-fire spread. When compared to building fires, tunnel fires can be more destructive due to their high temperatures, quick heating rates, prolonged duration, and uneven temperature distribution inside the tunnel.

Spalling is a complex phenomenon with a high degree of randomness that interdepends on too many factors. The occurrence of spalling phenomena is significantly influenced by various microstructural properties of concrete. Internal factors such as concrete permeability, moisture content, water-cement ratio, and aggregate type have a significant impact on spalling. Furthermore, temperature, heating rate, humidity, and loading conditions are some of the external factors that affect spalling. To gain a comprehensive understanding of this phenomenon, it is crucial to consider the interdependencies among these various factors and their combined effects.

The current method used in industry to evaluate the performance of a concrete tunnel lining is to test the specimen in large-scale furnaces. However, this method has several limitations. It requires the use of large-scale furnaces, which is time-consuming, expensive, and difficult to replicate due to their dependence on specific concrete mixtures and test setups.

Alternative approaches, such as Machine Learning (ML), can be considered to overcome these challenges. Recent advancements in data analytics & ML have demonstrated their capability to solve such complex problems. This study aims to create a framework for predicting fire-induced spalling in tunnel linings using several ML techniques.

Python programming language was utilised to develop this framework and Jupyter Notebook was used as the web based interactive platform. Using the previously published fire test data, a new dataset was created, and after performing the appropriate preprocessing, it was fed into 10 distinct ML techniques. These includes 7 ensemble techniques and 3 traditional ML techniques. Then the developed model was further refined using hyperparameter tuning & k-fold cross-validation techniques. The results of this model revealed that it is possible to forecast the occurrence of spalling with an accuracy of more than 90% using ensemble ML techniques.

Keywords: Spalling, Tunnel linings, Machine learning, Ensemble machine learning

* Correspondence: pasinduw@uom.lk

Fire Induced Spalling

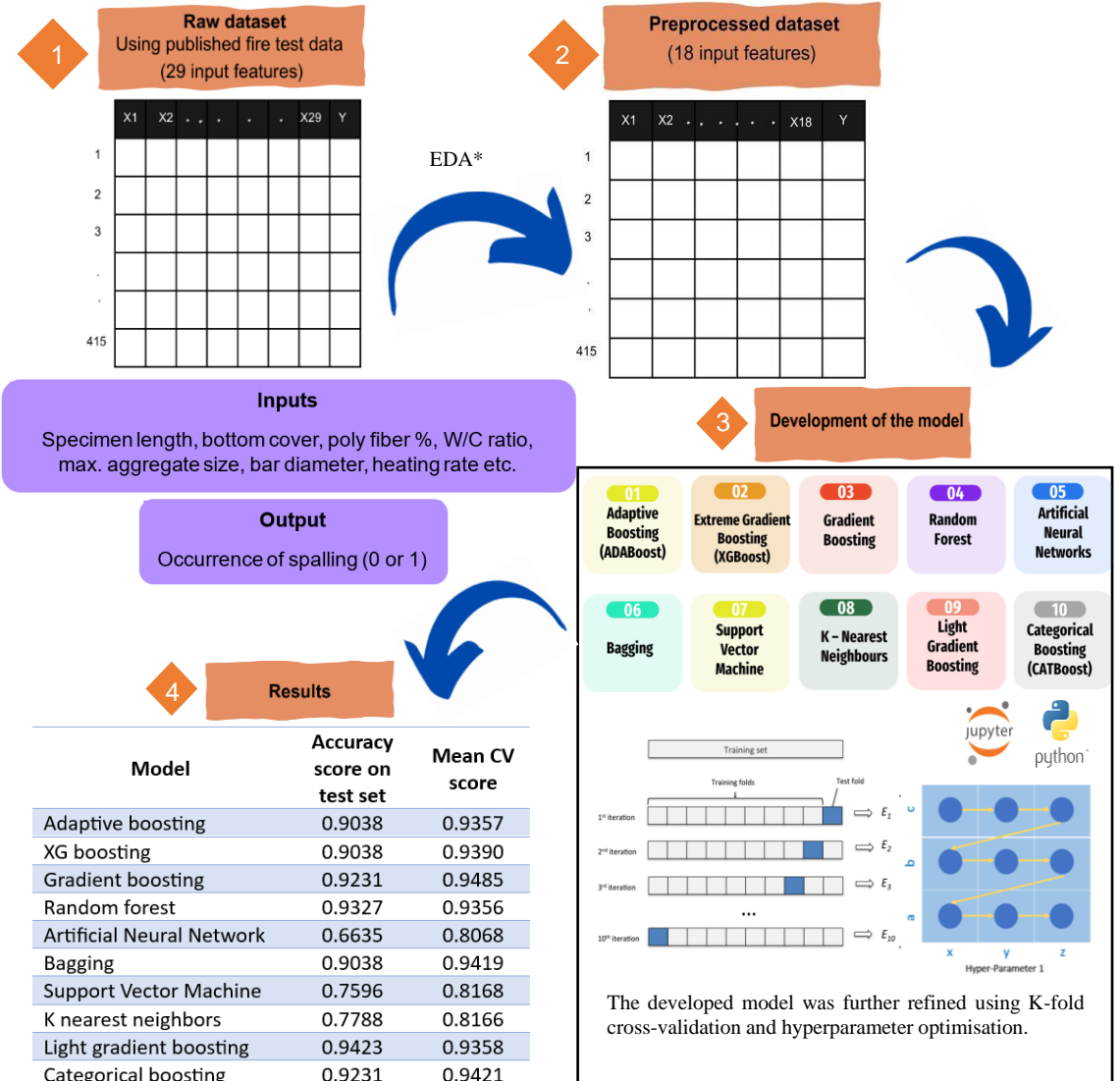


Spalling refers to the detachment of the cracked or delaminated surface layer from a concrete member.

The current method used in industry to prevent fire induced spalling is to test tunnel lining using special furnaces.

- Time consuming
- Much expensive
- Limited to specific concrete mixtures & testing setups
- Requires large scale furnaces

Aim of the study:
Development of a framework for predicting the fire-induced spalling in tunnel linings using advanced ML techniques.



Occurrence of spalling can be accurately predicted using several ML techniques (up to about 90% accuracy), except ANN, SVM & KNN

- EDA* - Exploratory Data Analysis**
- Remove redundant input features in a logical manner
 - Make the model less sensitive to noises & outliers
 - Address the overfitting issue

STUDY ON BUILDINGS SUITABLE TO BE CONSTRUCTED IN HOT, WINDY COASTAL REGIONS

D.W.T.S. Dissanayake¹, K. Baskaran^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

As Sri Lanka is a small island located in the Indian Ocean close to the equator, most of the built-up areas are close to the coastal belt and subjected to hot temperatures. Due to the diurnal temperature changes, coastal belt is subjected to windy climate. This research focuses on the impacts and mitigation measures to avoid the impacts for the buildings that are constructed in the regions where the hot, windy, and coastal conditions exist.

Due to the existence of these conditions, the designers must go through lots of design standards to ensure the building does not fail during the execution. Otherwise, lots of serviceability problems can occur when the building is in use. Sometimes after realising these problems later, the owners may have to withdraw the buildings. This research focuses on studying concrete made up of recommended cement types to be used in the regions where the above-mentioned challengeable environmental conditions exist.

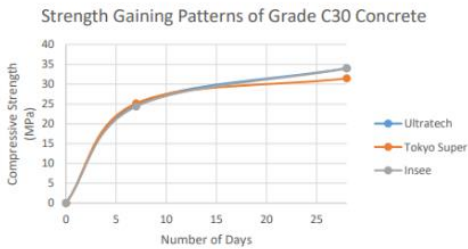
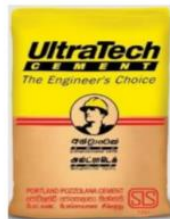
Since in the coastal regions, the chloride ion density in the atmosphere is very high it can be expected the penetration of these chloride ions into the concrete structures and reaction with the steel reinforcements and hence deterioration of reinforcement and concrete can happen. On the other hand, since the higher temperature, the possibility of propagating the cracks on the structural elements is high. Due to these cracks, concrete deterioration is induced as the chloride ions can penetrate through the concrete easily.

Some of the cement manufacturers have realised these problems and have recommended some types of cement to overcome these challenges. This research focuses on the behaviour of different types of cement that have been recommended by the manufacturers when they are subjected to tests like, the Compressive strength test, Rapid Chloride Ion Penetration Test, and Splitting Tensile Strength. The concrete specimens were cast by three different types of cement including Ultratech (Portland Fly Ash Cement) Tokyo Super (Hydraulic Blended Cement), and Insee (Marine Plus) to carry out the mentioned tests.

Keywords – Cement types, RCPT Test, Compressive Strength Test, Splitting Tensile Strength Test

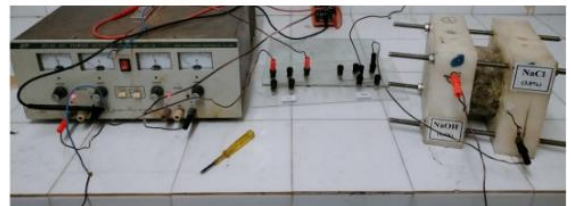
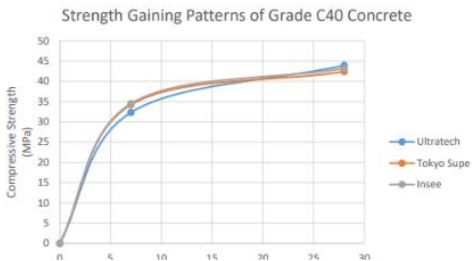
* Correspondence: baskaran@uom.lk

STUDY ON BUILDINGS SUITABLE TO BE CONSTRUCTED IN HOT, WINDY COASTAL REGIONS



RECOMMENDED USAGE

 FOR STRUCTURES	 FOR BRIDGES	 FOR HOUSES
 CORROSION RESISTANT	 FOR MARINE & MARSH	 FOR READY MIX CONCRETE
 UNDERGROUND TANKS	 AVAILABLE IN BULK	



STUDY ON EFFECTIVENESS OF WATERPROOFING IN BUILDINGS DURING THE DESIGN, CONSTRUCTION, AND MAINTENANCE PHASES OF A STRUCTURE

D.M.D. Priyashan ¹, P.L.N. Fernando ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Waterproofing is a critical aspect of building construction, ensuring longevity, durability, and structural integrity. There are several waterproofing methods used for buildings around the world. Among these, integral waterproofing, surface coating, and sheet membrane systems are the most commonly used methods in Sri Lankan building projects. The prevalence of water leakage issues in buildings throughout Sri Lanka has become a significant concern. In order to address this problem effectively, it is essential to thoroughly investigate the causes of waterproofing failures occurring during the various phases of a structure's lifecycle, namely design, construction, and maintenance.

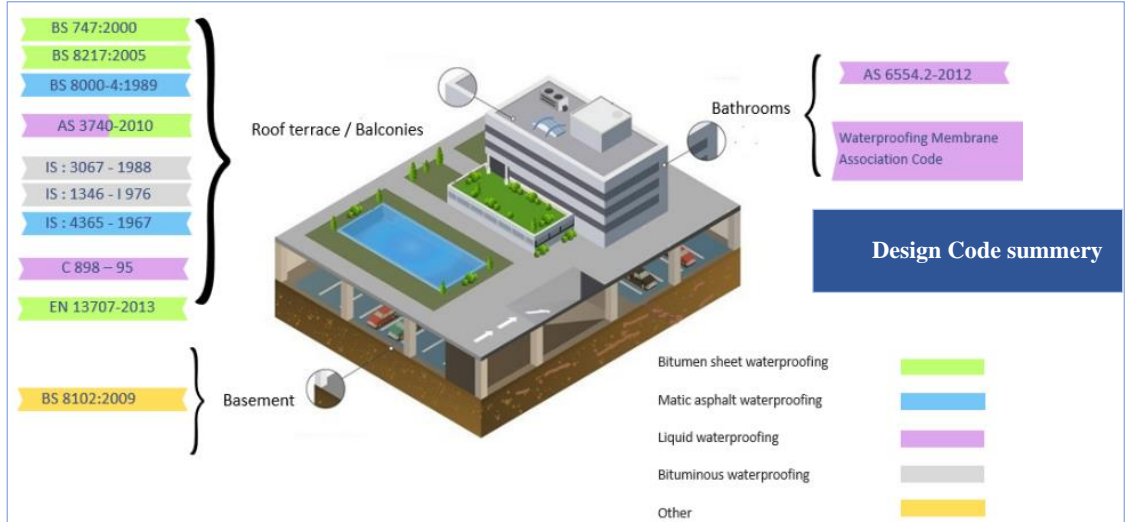
To this end, the research was conducted along three strands. Firstly, the provisions available for waterproofing in the design standards were studied and the findings were summarised, with the intention of promoting these among the practicing engineers and identifying any gaps that require further research. It was found that British, Australian, Indian and European codes provide guidelines on carrying out effective waterproofing for different parts of a structure. Secondly, industrial professionals were interviewed during field surveys and were presented with a questionnaire to identify the issues related to waterproofing when constructing and maintaining the structures. Some of the key issues that were highlighted include using unskilled laborers, not following proper procedures for waterproofing systems, high installation cost, high cost of waterproofing materials and poorly sought joints and can lead to structural related problems in the Sri Lankan building construction sector. As such, this highlighted the prevailing gaps in terms of the specified standards and the existing practices. Thirdly, a laboratory experiment was conducted to assess the performance of some of the existing waterproofing materials available in the Sri Lankan market. A comparison of integral waterproofing materials and surface coating materials was done based on the water absorption test. There were 4 surface coating materials and 2 waterproofing admixtures used as integral waterproofing materials. The water absorption test was done with oven drying procedure and without oven drying procedure. Cementitious waterproofing material gave the best results compared to the control cubes, in terms of the 7-day average water absorption percentage. The bituminous coating material gave the best result after the completion of the oven drying procedure. Overall, recommendations to improve the standards and practices of waterproofing structures in Sri Lanka were concluded based on data collected from the three research strands.

Keywords: Integral waterproofing, Surface coating, Internal and external waterproofing, Waterproofing issues, Water absorption test

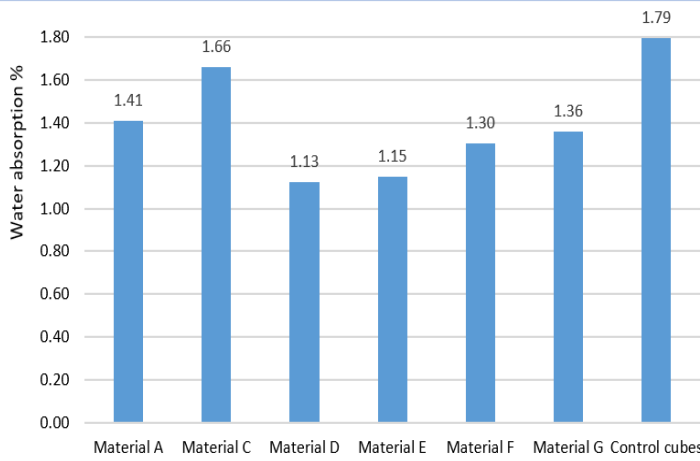
* Correspondence: lakshithaf@uom.lk

STUDY ON EFFECTIVENESS OF WATERPROOFING IN BUILDINGS DURING THE DESIGN, CONSTRUCTION, AND MAINTENANCE PHASES OF A STRUCTURE

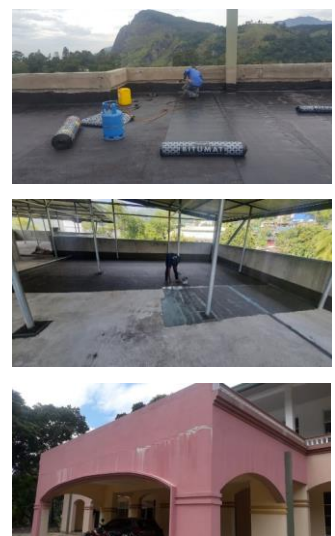
Water leakage problems in Sri Lankan buildings result from inadequate focus on waterproofing during design, construction, and maintenance. Design codes lack detailed waterproofing guidance, construction often neglects waterproofing, and limited data hinders technological advancements in waterproofing systems.



Experiment on effectiveness of commercially available waterproofing materials in Sri Lankan market



Site visits



Conclusion

- Common waterproofing practices may lack adherence to proper procedures, emphasizing the need for design codes and guidelines.
- Varied performance of waterproofing materials highlights the importance of quality and cost, urging improvements in Sri Lanka's offerings.
- Unskilled labour, inadequate supervision, and design deviations impact construction, stressing the significance of following waterproofing guidelines.

INVESTIGATE THE STRUCTURAL PERFORMANCE OF PAD FOOTINGS WITH DIFFERENT GROUND IMPROVEMENTS

D.C. Hondamuni¹, H.G.H. Damruwan^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

When the footings are constructed on weaker soils, several structural enhancement techniques such as use of larger footings, micro piles, or different ground improvement techniques such as use of concrete cylinders and use of filling materials or low-grade concrete are being used in practice. However, there is a limited understanding of the effectiveness of these different techniques. The aim of this research is to provide a design guideline/ framework for design engineers when constructing column footings in domestic buildings on weaker soils. This study pursue the following objectives: Identifying current design practices used by the engineers when constructing domestic buildings on weaker soils, Developing comprehensive Finite Element (FE) models using MIDAS software to investigate the behaviour of column footings with the varying embedment depths, Conducting a parametric study to investigate the behaviour of column footings with the implementation of identified strength enhancement techniques, and comparison of the results to identify feasibility of identified strength enhancement techniques.

This research investigates the structural adequacy of the above techniques by using the MIDAS GTS-NX FE analysis software. Footing and soil were modelled two dimensionally and three dimensionally in drained conditions incorporating soft clay soils and dense sand. Validation process was carried out comparing theoretical settlements and settlements from the FE model. Mesh sensitivity analysis was carried out to optimise the computational process. A comprehensive study was carried out with developed models to investigate the effect of embedment depth of the footing, effect of use of concrete cylinders, influence of soil replacement with quarry dust and impact of low-grade concrete layers below the footing. The comprehensive modelling techniques developed in this research could be used for further studies in different ground improvement techniques and will provide an idea about the feasibility of enhancement techniques to make necessary structural enhancements and ground improvements when constructing domestic buildings on weaker soils, thus reducing the costs.

This study concluded that for a typical footing stress range of 150-175 kN/m², optimum embedment depth lies within the range of 0.6 m to 1 m. Within this range, the load versus settlement curve demonstrates a desirable linearity, suggesting that the footing can accommodate the expected stresses while minimising excessive settlement, and increasing the depth of the cylinder has a noticeable effect on reducing settlement by 16% -17% but beyond approximately 1.2 m in height, there is no noticeable impact on the settlement. This study also concluded that use of quarry dust replacement can reduce overall settlements in drained conditions by 50% - 60% while bearing capacity can be increased by 45% to 55%. Optimum depth of soil replacement can be taken as between 1 m – 1.2 m for the embedment depth of 0.8 m. and use of Grade 15 concrete layer below the footing can reduce the settlements and enhance the bearing capacity. Implementation of 150 mm – 250 mm thick M15 concrete layer underneath the footing can reduce settlements by 55% - 60% for 210 kPa of pressure.

Keywords: Pad Footing, Settlements, Bearing Capacity, Ground Improvement, Concrete Cylinders, Finite Element Analysis

* Correspondence: hasithad@uom.lk

INVESTIGATE THE STRUCTURAL PERFORMANCE OF PAD FOOTINGS WITH DIFFERENT GROUND IMPROVEMENTS

Background

Ground Improvement Techniques

- use of larger footings
- use of concrete cylinders
- use of filling materials or low-grade concrete

Aim – To provide a design guideline/framework for design engineers when constructing column footings in domestic buildings on weaker soils.

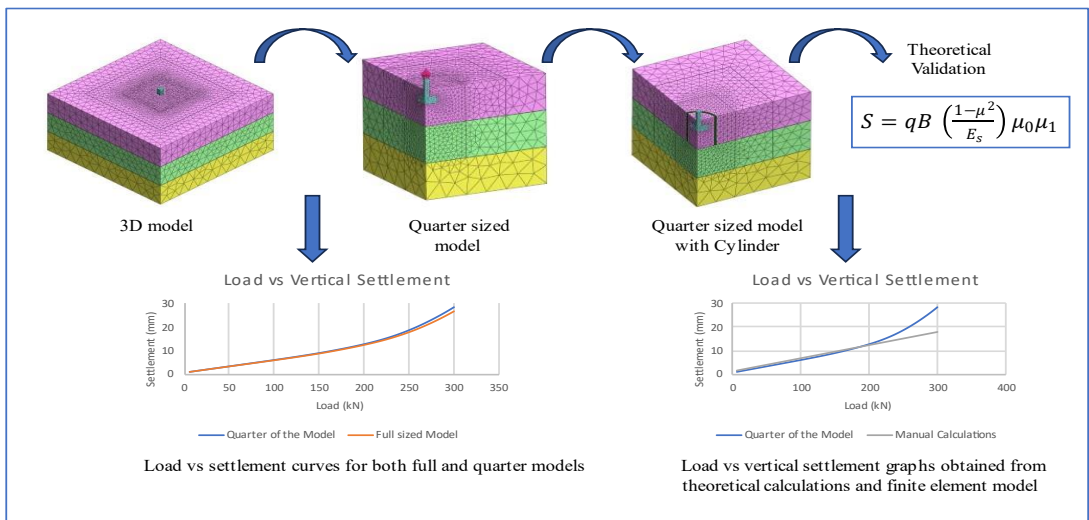


Individual Pad Footing

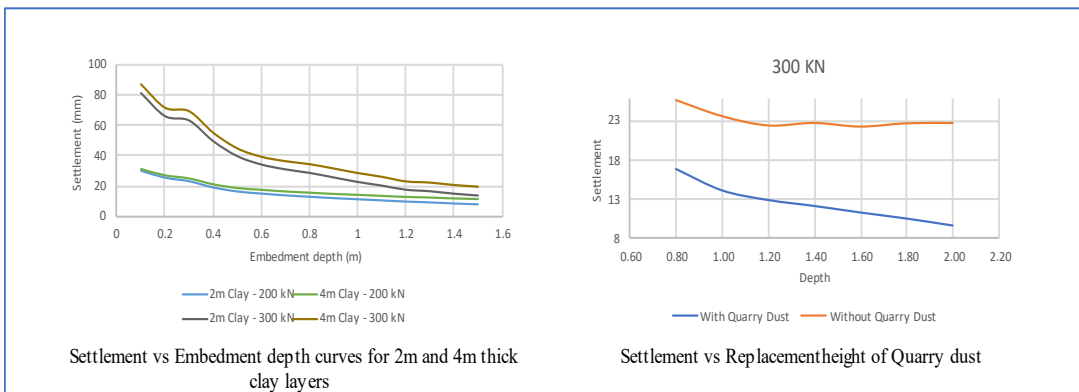
Objectives

- Identify current design practices used by the engineers when constructing domestic buildings on weaker soils.
- Develop comprehensive FE models using MIDAS software to investigate the behavior of column footings with the varying embedment depth
- Conduct a parametric study to investigate the behavior of column footings with the implementation of identified strength enhancement techniques.
- Compare the results to identify feasibility of identified strength enhancement techniques.

Methodology



Results



UTILISING BOTTOM ASH FROM WASTE-TO-ENERGY PLANTS FOR SUSTAINABLE CEMENT BLOCK PRODUCTION

S. Tharsan¹, K. Baskaran^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Bottom ash emerges as a by-product from the combustion of municipal solid waste in energy generation plants. The global predicament surrounding the management and disposal of bottom ash, an aftermath of waste-to-energy facilities, remains significant. The use of improper disposal methods has engendered substantial health and environmental predicaments, necessitating pragmatic solutions. This research scrutinises the plausibility of harnessing bottom ash as a substitute for fine aggregate, specifically in the context of cement block fabrication. The study meticulously probes into the mechanical, thermal, and durability characteristics of cement blocks that incorporate bottom ash, all while meticulously adhering to guidelines. Establishing a consistent mixture is pivotal; it entails maintaining a volume ratio of 1:6:3 for cement, fine aggregates, and quarry chips, steadfastly retaining a cement-to-water ratio of 0.8. Central to the investigation is the precise crafting of solid cement blocks measuring 300 mm x 100 mm x 150 mm, accomplished through the conventional table vibratory compaction method. The primary thrust of the study involves methodically incorporating varying percentages of bottom ash into the block matrix, progressing incrementally in steps of 10% across a range spanning from 0% to 60%.

Critical evaluations of the cement blocks' compressive strength and water absorption capabilities were meticulously undertaken at predefined intervals of 7, 28, and 56 days. Conspicuous trends surfaced, unequivocally establishing a direct correlation: higher proportions of bottom ash invariably led to a commensurate reduction in the density, compressive strength, durability, and specific heat capacity of the resultant cement blocks. Counteractively, water absorption capacity exhibited an incremental rise in tandem with augmented proportions of bottom ash. The findings of the research emphatically suggest that within the purview of modest and intermediate-scale cement block production, tailored for load-bearing walls within residential structures not exceeding four stories, the substitution of a substantial fraction of conventional fine aggregate with scrupulously sieved bottom ash from waste-to-energy plants is thoroughly conceivable. The specific mix proportions meticulously examined within the ambit of this investigation convincingly advocate for the replacement of up to 50% of the fine aggregate with bottom ash.

In summative essence, this investigation profoundly underscores the latent potential of repurposing bottom ash a seemingly intricate waste byproduct as a prized resource within the expansive domain of the construction industry. Notably, this approach does not merely address the challenges entailed in inadequately handling bottom ash but also tangibly contributes to sustainable construction practices by effectively mitigating the demand for traditional fine aggregates. While the parameters of this inquiry are judiciously delimited, they form the underpinning for the possibility of wide-ranging future research and innovation, engendering the conscientious utilisation of waste byproducts in forging ecologically attuned construction materials.

Keywords: Bottom ash; Cement block; Strength; Water absorption

Correspondence: baskaran@uom.lk

UTILIZING BOTTOM ASH FROM WASTE-TO-ENERGY PLANTS FOR SUSTAINABLE CEMENT BLOCK PRODUCTION

Authors:

S. Tharsan
Department of Civil
Engineering
University of
Moratuwa

Dr. K. Baskaran
Senior lecturer
Department of Civil
Engineering
University of
Moratuwa



PROBLEM STATEMENT

Our country has faced a **problem in disposal** of solid waste bottom ash

Therefore, there are lots of ash at the ash yard, which leads to a series of environmental problems such as air, water, soil pollution and a huge land area occupied by the ash yard

There may be scarce due to higher utilization of sand, hence bottom ash is a best alternative to replace sand

AIM

To maximize the use of bottom ash from municipal solid waste to energy plants as a partial replacement for river sand in the manufacturing process of cement blocks

OBJECTIVES OF THE RESEARCH

Identify the optimum percentage of bottom ash that can replace sand in manufacturing cement blocks

Evaluate the strength and other properties of the cement blocks to ensure performance with respect to the corresponding standards



ANALYSIS OF RESULTS

After 7, 28, and 56 days, the compressive strength and water absorption of the cement blocks are tested. The findings indicate that increasing the proportion of bottom ash reduces the density, compressive strength, durability, and specific heat capacity of the blocks while increasing water absorption



CONCLUSIONS

- Satisfies the structural requirements up to **50%** of the replacement level
- The produced blocks pose **no health hazards** whether in use or handling
- Cement blocks incorporating 50% BA as a sand substitute exhibit a compressive strength of **6.45 Nmm⁻²** (exceeding the required value of 5.5 N/mm²) and a **28-days water absorption value of 181.77 kgm⁻³** indicating their suitability for construction
- **Cost effective**
- Moreover, these blocks are **light-weight**, with a 12% reduction in density compared to conventional cement blocks
- These blocks can be used for **load-bearing walls in residential buildings up to four stories**

ANALYSING THE NON-LINEAR BENDING BEHAVIOUR OF ULTRA-THIN WOVEN COMPOSITES AT HIGH CURVATURES

T.M.H. Tennakoon¹, H.M.Y.C. Mallikarachchi^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Deep space missions require self-deployable structures built of ultra-thin materials which can be carried to space in a limited space. Therefore, a growing demand for ultra-thin woven composites has been identified in space engineering applications. Understanding their mechanical behaviour is crucial for the effective optimisation of future structures because they experience extreme curvatures when in use in both folding and deploying mechanisms. It is more challenging to predict the overall mechanical behaviour of these composites due to their complicated geometry and nonlinear behaviour of its constituent parts. A common method to solve this problem is multiscale modelling, in which the system is simultaneously described by multiple models at varying scales. Micromechanical, mesomechanical and macromechanical scales are taken into consideration for woven fibre composites.

Physical experiments revealed that ultra-thin woven fibre composites show a significant drop in bending stiffness at higher curvatures. The first objective of the study focuses on checking whether there is a thickness reduction of the plies at high curvatures which can be a possible reason for the reduced bending stiffness at high curvatures. As the second objective, it is expected to introduce air voids in resin to capture the non-linear bending response of woven fibre composites observed under high curvatures.

Due to the deformation of the fibres and the weave structure at higher curvatures, woven fibre composites may exhibit variations in thickness. Resin matrices usually have lower stiffness compared to the reinforcing fibres. As a result, when the composite is subjected to higher curvatures, the fibres on the inner side of the curve may experience compression, leading to a reduction in thickness, while the resin matrix tends to flow and redistribute in response to the applied forces. The flow of resin can have both positive and negative effects on the thickness variation. On one hand, the ability of the resin to flow and redistribute can help accommodate the compression of the fibres and reduce the overall thickness reduction.

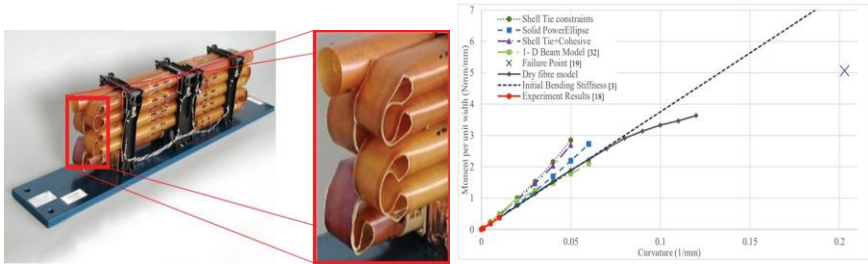
According to the obtained results from the Dry Fibre model and the Resin model, except for the mid-section of the Dry Fibre model, there is no significant thickness variation at other locations compared to the original thickness in both the Resin model and Dry Fibre model. Although there is a thickness reduction at the mid-section of the dry fibre model, at high curvatures thickness starts to increase again which is against the experimentally observed bending behaviour. So, according to the obtained thickness variation results from the two models, there is no clear connection between bending stiffness reduction and thickness variation.

To check the effect because of voids, Fibre Volume Fraction of the composite was used. The Fibre Volume Fraction is defined as the ratio of the volume of fibres present to the total volume of the layer. From the second objective, it was observed that there is a 6-8 % reduction in longitudinal stiffness, transverse stiffness, and shear stiffness with the void ratio. Variation in the Poisson's ratio with the void ratio is low compared to other mechanical properties.

Keywords: Deployable Structures, Woven fibre composites, Representative Unit Cell, Bending Stiffness, Fibre volume fraction

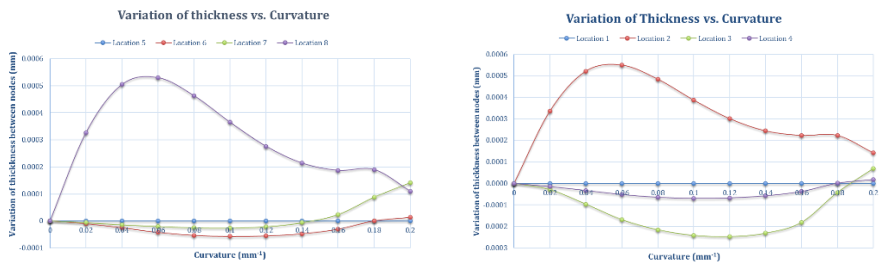
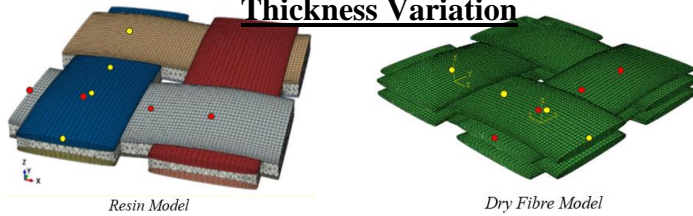
* Correspondence: yasithcm@uom.lk

ANALYSING THE NON-LINEAR BENDING BEHAVIOUR OF ULTRA-THIN WOVEN COMPOSITES AT HIGH CURVATURES

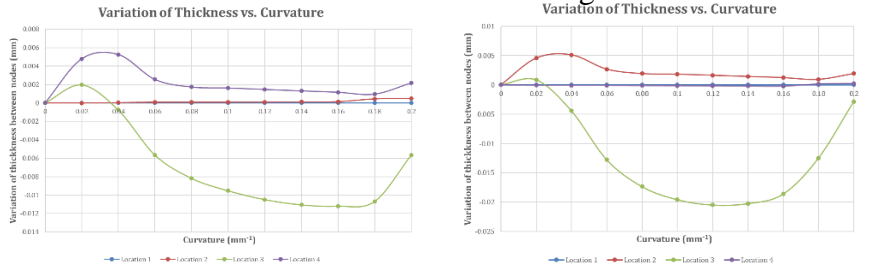


Non-linear bending behavior of woven fibre composites at high curvatures

Thickness Variation



Thickness Variation in the Bending Direction



Thickness Variation in the Transverse Direction

Change in Mechanical Properties of Woven Fibre Composites with Void Ratio

Property	Property Value		Change, %
	Void Ratio, 0 %	Void Ratio, 20 %	
Fibre volume fraction, V_f	0.6183	0.5745	-7.08
Longitudinal stiffness E_1 (N/mm ²)	145360	135300	-6.92
Transverse stiffness $E_2 = E_3$ (N/mm ²)	10390	9600	-7.60
Shear stiffness $G_{12} = G_{13}$ (N/mm ²)	3367	3095	-8.08
Poisson's ratio, $\nu_{12} = \nu_{13}$	0.28	0.29	3.57

NATURE-INSPIRED SOLUTIONS FOR ENHANCED IMPACT RESISTANCE OF STRUCTURES

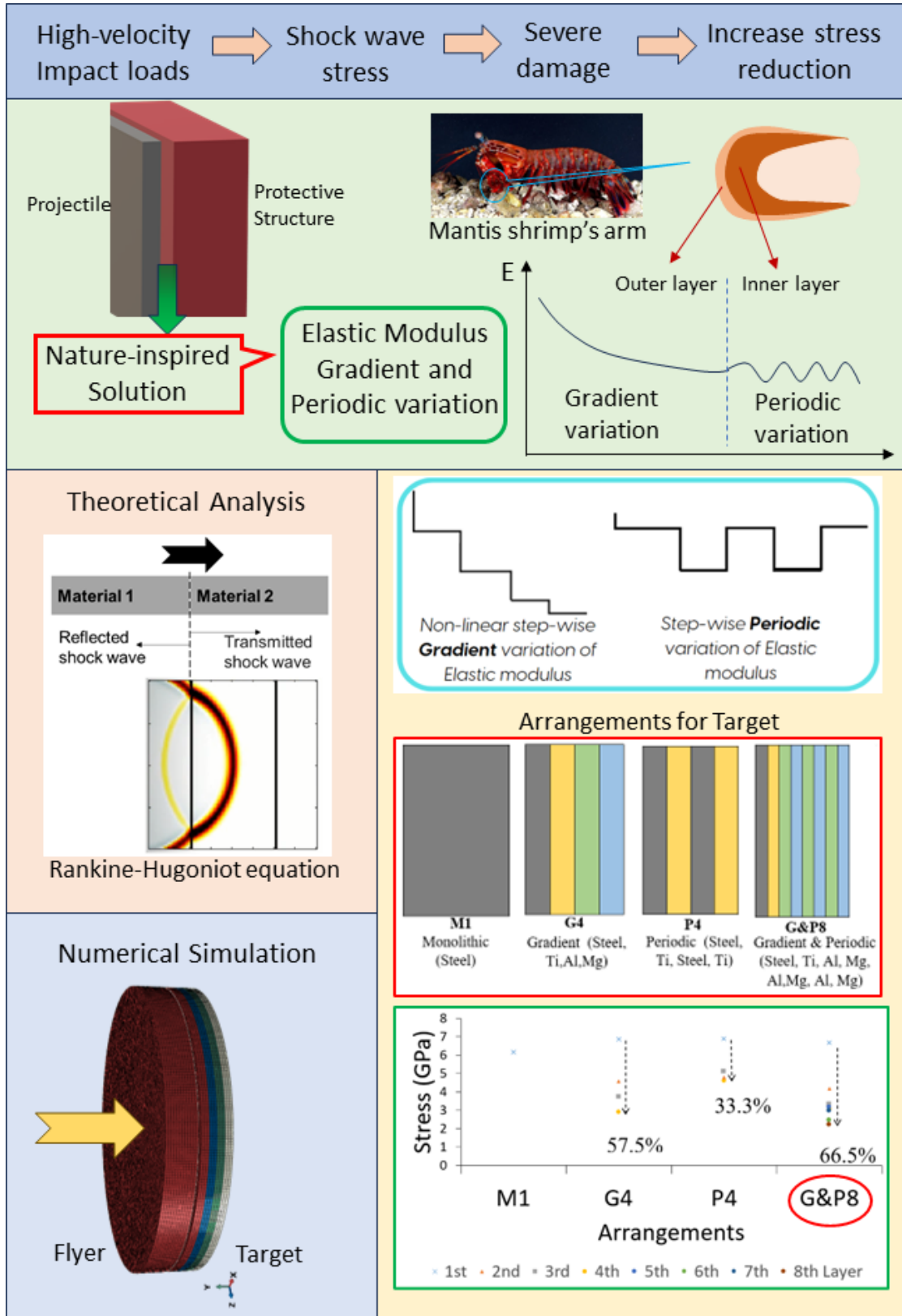
H.M.T. Sajana¹, P.L.N. Fernando^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

High-velocity impact loads pose significant challenges due to their potential to generate dynamic responses in structures, which can cause severe damage. Structural engineers face an evolving challenge in designing structures that can effectively resist impact and blast loads. Active and passive mitigation systems are two different categories of mitigation systems. Active mitigation systems are based on detection and reaction systems, while passive mitigation systems use energy absorption and wave propagation characteristics to mitigate the effects of high-velocity impacts and shockwaves. This study investigates nature-inspired solutions to minimise damages from high-velocity impact loads on structures. By analysing the basic elements of several existing biological systems and their contribution towards the structural integrity of these systems, key potential characteristics that can be translated into impact-resisting structures have been identified. The primary focus centres on the mantis shrimp arm, drawing insights from its remarkable mechanical properties and translating them into structural engineering applications. In the present study, a solution that is inspired by the mantis shrimp arm has been developed as such, a multilayered structure was designed using metallic materials that use the mantis shrimp arm's concept of elastic modulus gradient variation. The study pursues three objectives: to identify the mechanisms employed by biological systems for impact resistance, to investigate effective and efficient systems considering the impact resistance using theoretical analysis and numerical simulations, and to propose feasible combinations of the system to resist impact loads for enhanced impact load mitigation. Based on a theoretical analysis involving shock wave propagation, this system demonstrated the potential to reduce the magnitude of the stress waves during an impact-loading event. Further numerical analysis of this system was carried out using the nonlinear finite element software ABAQUS, where the impact of a metallic flyer at a known velocity on a target of the multilayered structure was simulated. The magnitude of the incident stress wave of the final material in the target was obtained to evaluate the performance of this system. The results demonstrated that the proposed multilayered system has the potential to reduce the magnitude of the incident stress waves in the system when compared to the monolithic system with no variation of the elastic modulus. The arrangement of gradient variation of elastic modulus results in a pressure reduction of approximately 66% and 58% in theoretical and numerical analyses, 41% and 33% in stepwise periodic variation, and 80% and 67% in combined gradient and periodic variations. The study reveals that incorporating materials with gradient variations in elastic modulus in the layered structure can effectively reduce pressure waves than the monolithic structure. The combined arrangement of gradient and periodic structures can potentially improve mitigation performance. The findings suggest further research on microstructural aspects, comparison with different biological systems, experimental studies, and deeper design and optimisation of combined arrangements. These findings contribute to developing innovative engineering solutions and paving the way for structures that can withstand high-velocity impact loads effectively.

Keywords: Elastic modulus gradient; Impact resistance; Nature-inspired; Multilayered structure; Stress waves.

* Correspondence: lakshithaf@uom.lk



NUMERICAL INVESTIGATION ON THE EFFECT OF WIND ON FAÇADE FIRE PROPAGATION OF A HIGH-RISE BUILDING IN SRI LANKA

L.R.W.M.I.M.Lankadhikara¹, T.G.P.L.Weerainghe^{1,*}, R.M.S.Dananjaya²

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Department of Infrastructure Engineering, University of Melbourne, Melbourne

The façade is one of the most critical structural elements of a building. It serves as a barrier between the building's inside and the outside environment. Beyond aesthetic appearance, the façade also plays a critical role in providing a protective barrier against external elements, enhancing energy efficiency, and contributing to the overall safety of the building occupants. New energy-efficient lightweight materials with good thermal insulation properties are used for facades worldwide. Poor façade performance may result in catastrophic fire spread, building damages, and fatalities during a fire. Several factors like façade material, design and layout of the building, and external factors like wind can contribute to the fire spread in building façades. The influence can be favourable or unfavourable in accelerating or extinguishing the fire growth. Conducting large-scale testing to investigate various facade fire scenarios might not be possible due to practical limitations and expensive and time-consuming procedures. To overcome these limitations, using numerical simulation has gained prominence in studying facade fires. Numerical modelling of facade fires can be accomplished using the combined capabilities of Fire Dynamic Simulator (FDS) and PyroSim software, which simulates the fire as Computational Fluid Dynamics (CFD) models.

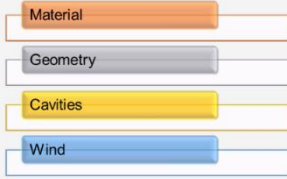
In this study, the primary consideration is given to examining the effect of wind on fire propagation along the façade of a high-rise building in Sri Lanka during windy conditions. The reference building (Height: 127 m with 41 floors) with rectangular shaped building geometry including U-shaped geometry at its shortest dimensional sides, having a combustible façade made of Aluminium composite panels and located in Colombo District in Sri Lanka, is modelled using PyroSim software. U-shaped geometry is critical due to its influence on the chimney effect. In the context of U-shaped geometry, the chimney effect refers to the phenomenon where a U-shaped space or channel within a building acts as a vertical conduit, facilitating the upward movement of smoke, hot gases, and flames during a fire. The fire spread along the façade, the effect of the U-shape geometry of the building, and the influence of wind speed and wind direction (parallel - 0°, perpendicular - 90°, angled to the façade surface - 45°) toward the rapid spread of fire are examined using temperature recordings of thermocouples. The results are compared to a reference case of no wind. Results comparison of the validated models has shown a significant impact from the U-shape façade geometry, wind speed, and wind direction for the fire growth and extinguishing along the façade. The results indicate that the fire propagation is critical when the wind is present. According to the results, the vertical spread of the fire is faster when the wind is parallel to the façade surface, creating a chimney effect, channelling the fire along the open side of the U-shape and potentially impacting multiple floors. When the wind blows parallel to the façade surface, lateral fire spread is significantly accelerated in the blowing direction. When the wind blows perpendicular to the façade surface, the lateral fire spread has been slowed compared to the other two wind scenarios. The wind can push the fire diagonally along the facade, potentially spreading the flames horizontally and vertically. When the wind flows angled to the façade surface, the potential fire spread is high in both horizontal and vertical directions. The windward direction shows rapid lateral fire spread, while the opposite direction shows a slower spread. The findings guide for reducing the rapid spread of devastating façade fires in high-rise buildings during windy conditions.

Keywords: Façade fire propagation, Combustible cladding, Building geometry, FDS modelling, External wind

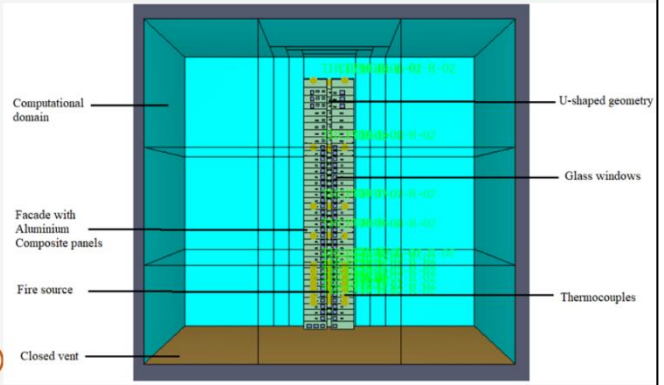
* Correspondence: pasinduw@uom.lk

NUMERICAL INVESTIGATION ON THE EFFECT OF WIND ON FAÇADE FIRE PROPAGATION OF A HIGH-RISE BUILDING IN SRI LANKA

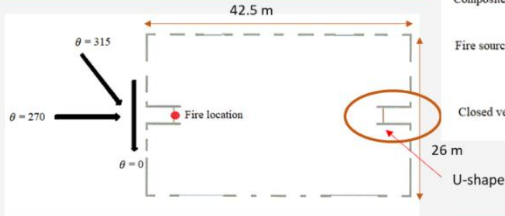
FACTORS AFFECTING FACADE FIRE



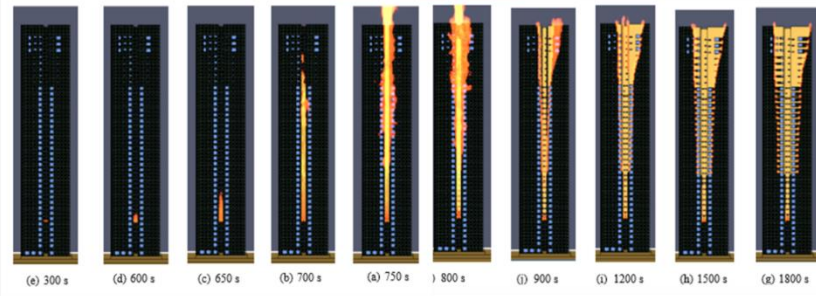
NUMERICAL SET-UP



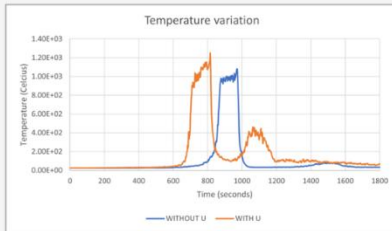
BUILDING GEOMETRY AND WIND EFFECT



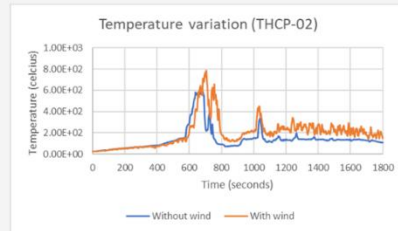
RESULTS



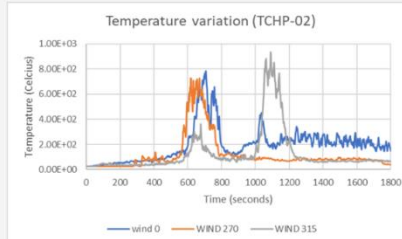
FLAME PATTERN VARIATION



THE EFFECT OF BUILDING GEOMETRY (WITH AND WITHOUT U-SHAPED GEOMETRY)



THE EFFECT OF WIND (WITH AND WITHOUT WIND)



THE EFFECT OF WIND DIRECTION (PARALLEL, PERPENDICULAR AND ANGLED WIND BLOWING DIRECTIONS TO THE FAÇADE SURFACE)

INVESTIGATE THE BEHAVIOUR OF GLASS BALUSTRADES UNDER HUMAN IMPACT LOADS

T.W.M.C. Wanigasooriya¹, H.G.H. Damruwan^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Glass balustrades are extensively used in various settings and are frequently subjected to different impact loads, including rigid or soft body impacts (human impacts). Ensuring the safe design and installation of glass balustrades to withstand these impact loads is crucial for minimising the risk of injuries caused by falling glass fragments. This research studies the behaviour of simply supported glass panels when subjected to different impact locations and speeds.

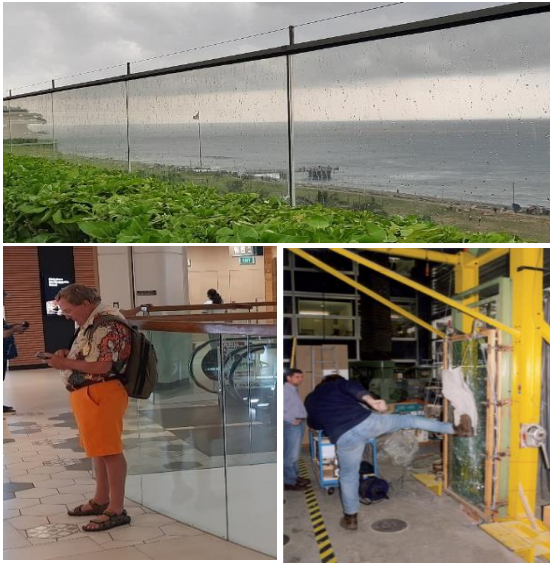
A comprehensive field survey was carried out to investigate the support conditions, glass types, and their behaviour under human impact loads. A Finite Element (FE) model of a pendulum impact test was developed to analyse and understand the response of tempered glass panels under human impact loads. Specifically, the horizontal and vertical strains of the glass plate were used to validate the FE model.

Additionally, a parametric study was carried out to examine the deflection patterns of the glass plate under impact loads, considering various impact locations and speeds. This research highlights the lack of public awareness regarding the safety requirements of glass balustrades, emphasising the need for education and guidelines.

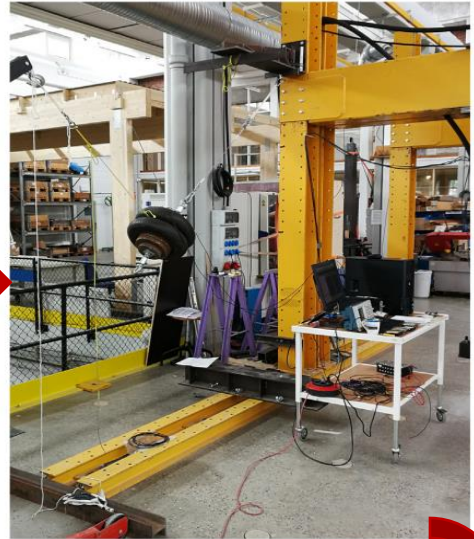
Results obtained from the FE model agreed well with experimental data for drop heights below 700 mm, while acceptable deviations (-10% to +10%) are still observed for higher drop heights. Furthermore, the impact location significantly influences the maximum deflection in glass balustrades, with shifts towards the impact location observed at higher impact energies. The research findings highlight that the horizontal strain consistently surpasses the vertical strain across all drop heights. These insights provide valuable information for glass balustrades' design, installation, and maintenance processes, ensuring their safety and dependability in real-life situations involving soft body impact loads, such as human impacts.

Keywords: Glass Balustrades, Soft Body Impacts, Explicit Dynamic Analysis, Tempered Glass, Finite Element Analysis

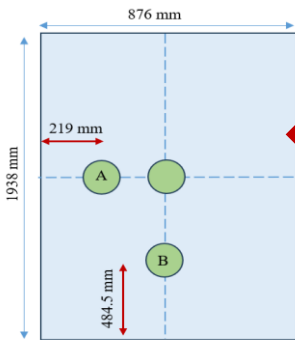
* Correspondence: hasithad@uom.lk



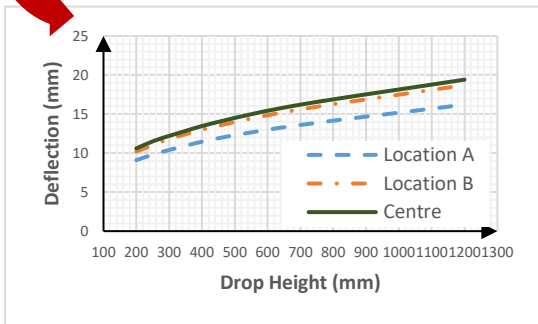
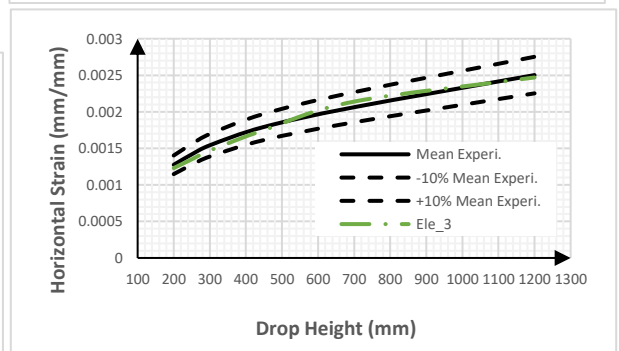
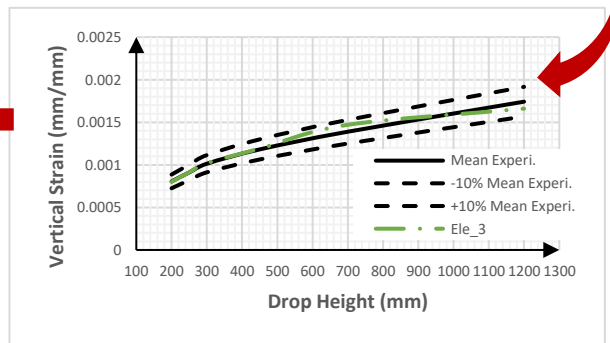
Human impact loads on Glass Balustrades



Soft body impact test setup



Variation of impact locations



Deflection vs Drop height with varying impact locations

Comparison of vertical and horizontal strains with FE model of glass panel with 3 number of through thickness elements (Ele_3)

EFFECTS OF POROSITY AND DISTRESSES IN CONCRETE ON ULTRASONIC PULSE VELOCITY READINGS

M. Mayooraan¹, J.C.P.H. Gamage^{1,*}, E.R.K. Chandrathilaka¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Ultrasonic Pulse Velocity (UPV) testing is a crucial non-destructive technique employed in the evaluation of concrete structures, providing insights into concrete properties and identifying potential damage. In this study, we delve into the intricate relationship between UPV readings and various factors, such as concrete age, concrete mix type, and the presence of discontinuities like voids and cracks. Understanding the impact of these variables on UPV readings is essential for accurate and reliable assessments of concrete integrity. Concrete age plays a significant role in UPV measurements. Over time, the UPV values notably increase, reflecting the maturation and strengthening of the concrete. To establish a link between UPV and concrete strength, we analysed equations sourced from existing literature and compared their applicability, particularly for early age concrete. These equations proved invaluable in estimating concrete strength from UPV values, with minimal deviations observed in the case of 10% and 15% processed Sugarcane Bagasse Ash (SCBA) blended concrete mixes. However, a different trend emerged for 20% SCBA blends, where significant deviations were observed, suggesting that the UPV strength evaluation method may not be suitable for such high SCBA inclusion levels. The incorporation of processed SCBA into concrete mixes revealed intriguing results. SCBA, known for its pozzolanic properties, played a crucial role in enhancing UPV values, particularly in the case of 20% blends. This increase in UPV values can be attributed to additional chemical reactions promoted by SCBA and the improved compactness of the concrete. For 10% and 15% SCBA blended concrete, UPV equations from the literature demonstrated remarkable accuracy in estimating concrete strength, aligning closely with the results obtained from destructive concrete cube tests. This finding underscores the practical utility of UPV as a non-destructive strength assessment tool, especially for concrete blends incorporating moderate levels of SCBA. Another critical aspect explored in this study is the influence of discontinuities, such as voids and cracks, on UPV values. The presence of these flaws in concrete led to a noticeable decrease in UPV readings. This phenomenon allowed us to leverage UPV testing as an effective means of identifying damage locations within concrete structures and quantifying the severity of cracks. By doing so, UPV testing contributes significantly to the early detection of structural issues, facilitating timely repairs and maintenance.

In conclusion, Ultrasonic Pulse Velocity (UPV) testing emerges as a valuable and multifaceted non-destructive evaluation technique for assessing concrete properties and detecting damage. It provides a reliable means of correlating UPV values with concrete age, estimating concrete strength in SCBA blended mixes, and identifying the presence and severity of voids and cracks within structures. The findings of this study underscore the importance of UPV testing in enhancing our understanding of concrete structures and ensuring their long-term durability and safety. As the construction industry continues to evolve, the incorporation of UPV testing into standard inspection and maintenance protocols is a wise investment in the health and longevity of concrete infrastructure.

Keywords: Concrete properties, Non-destructive testing (NDT), Destructive Testing, Ultrasonic Pulse Velocity (UPV), Reliability of UPV

* Correspondence: kamage@uom.lk

EFFECTS OF POROCITY AND DISTRESSES IN CONCRETE ON ULTRASONIC PULSE VELOCITY READINGS

Objectives

The following objectives are to be achieved:

1. Finding the response of UPV values at different ages of concrete
2. Investigate the variability of UPV measurements in concrete containing different percentages of SCBA (processed sugar cane bagasse ash) as a partial replacement for cement
3. Explore the response of UPV values to the presence of discontinuities such as voids and cracks within a concrete specimen

RESULTS & ANALYSIS

2.3 Concrete strength evaluation through UPV method

UPV values can be utilized to obtain the concrete strength at researchers have proposed equations to correlate UPV values with the concrete compressive strength. In this study investigator has selected two of the most vastly used UPV strength evaluation equations. (Said & Ali, 2021)

$$(1) c = 0.173e^{1.157D} \text{ (Said \& Ali, 2021)}$$

$$(2) c = 1.19e^{0.715D} \text{ (Said \& Ali, 2021)}$$

Where 'c' denotes concrete strength and 'D' denotes UPV values.

Methodology

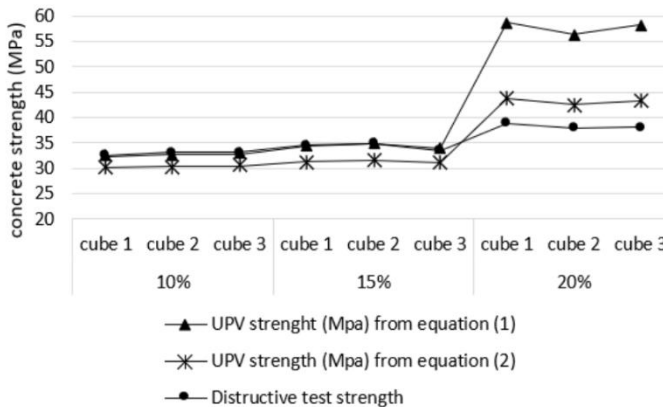
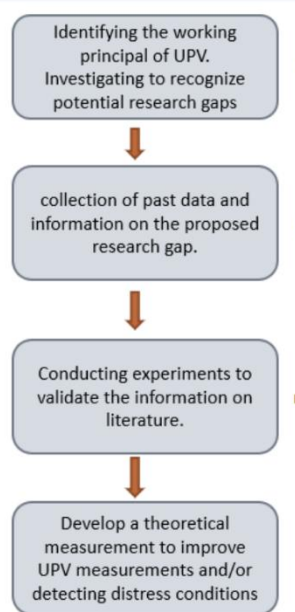


Figure: Comparison between UPV strength and destructive test strength for SCBA blended concrete

CONCLUSION: This research highlights the significance of Ultrasonic Pulse Velocity (UPV) testing in assessing concrete properties and detecting structural damage. UPV values exhibit a clear correlation with concrete age, but caution is advised when using UPV for strength evaluation in concrete blends with high SCBA content. Moreover, UPV testing proves effective in identifying and quantifying the severity of cracks within concrete structures, enhancing our understanding and assessment of their integrity.

USE OF INDUSTRIAL WASTE SLUDGE IN CONCRETE PAVING BLOCKS

B.M.I.M Basnayaka ¹, T.G.P.L Weerasinghe ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The interdependence of a nation's economic momentum with the dynamism of its manufacturing sector is evident. The era of rapid industrialisation brings with it an escalated output of waste. Addressing this surge, particularly regarding the proper management, disposal, or recycling, is paramount, especially when we contemplate the long-term repercussions on both environmental sanctity and public health. While suppressing industrial expansion or sanctioning unchecked waste release might seem like solutions, they are not in the best interests of sustainable economic and environmental goals. Given these challenges, there's a pressing international drive toward converting waste into purposeful, usable products.

In the vast spectrum of industrial waste, sludge emerges as a significant player. This semi-fluid substance, replete with solids and liquids, is a by-product of various water treatment processes. Its nature, whether organic or inorganic, hinges on the kind and extent of contaminants it contains. Through dehydration, one can transform sludge into a more manageable powdered form.


This research casts its lens on the potential of this powdered sludge, a derivative of industrial waste, in concrete paving block construction. The vision here is twofold: advancing towards a greener paving methodology and finding a viable solution to the ever-present sludge disposal issue. The initial stages of the study focused on meticulous chemical scrutiny of the sludge, followed by a sieve assessment to understand its granular composition. Notably, while the granular profile resonated with that of typical fine aggregate, the chemical analysis underscored the dominance of organic particles. Acting on this knowledge, experimental blocks were crafted, with the sludge powder replacing traditional materials like cement and sand. However, these modified blocks manifested a noticeable reduction in compressive strength when juxtaposed against standard concrete blocks. For a deeper dive into the composition, tools like Scanning Electron Microscopy (SEM) were employed to decipher micro-level structures, and Energy-Dispersive X-ray Analysis (EDAX) was used to identify elemental makeup. These sophisticated analyses pinpointed weaker components that did not bolster the material's inherent strength. In a promising turn of events, refining the sludge to purge these weaker elements led to a notable enhancement in block strength, aligning it with industry benchmarks. With these findings at hand, the recommendation is to broaden the scope of research, perhaps by exploring diverse mix ratios, to further optimise the efficiency and application of this innovative approach.

Keywords: Industrial waste sludge, Sustainable paving block, Organic matter in concrete

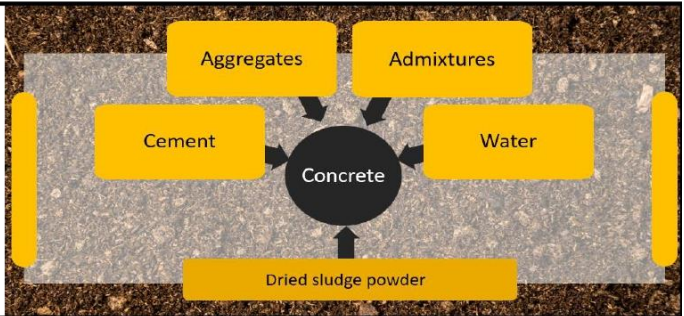
* Correspondence: pasinduw@uom.lk

USE OF INDUSTRIAL WASTE SLUDGE IN CONCRETE PAVING BLOCKS

✓ **AIM**



study the use of industrial waste sludge in concrete paving blocks



Material	Mix ratio	Compressive strength (N/mm ²)				
		Sludge powder (Kg)	Cement (Kg)	Sand (Kg)	Gravel (Kg)	Water (m ³ × 10 ⁻³)
Dried waste sludge from the industrial wastewater treatment plant in Unilever Sri Lanka (PVT) LTD.	Control sample	-	3.65	8.11	7.3	1.825
	Cement replacement (5%)	0.095	3.467	8.11	7.3	1.825
	Cement replacement (10%)	0.191	3.285	8.11	7.3	1.825
	Fine aggregate replacement (10%)	0.383	3.65	7.3	7.3	1.825
	Coarse aggregate replacement (10%)	0.383	3.65	8.11	6.57	1.825

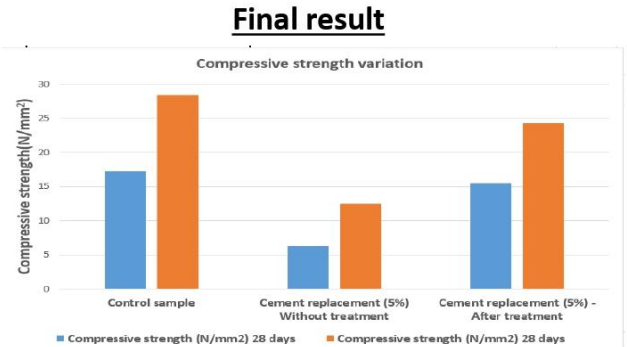
Results of 3 sets of samples

	Compressive strength (N/mm ²)					
	Sample 01(18 blocks)		Sample 02(12 blocks)		Sample 03(24 blocks)	
	07 days	28 days	07 days	28 days	07 days	28 days
Control sample	24.60	29.7	-	-	17.54	28.85
Cement replacement(5%)	-	-	5.01	8.81	7.52	16.13
Cement replacement(10%)	9.59	14.9	-	-	5.15	10.04
Sand replacement(10%)	1.3	2.12	-	-	1.63	3.79
Gravel replacement(10%)	-	-	0.52	3.98	-	-

Sludge was treated to increase the strength of the blocks

Conclusion

- ✓ The direct use of dried sludge powder in concrete paving blocks is not feasible
- ✓ 5% of cement can be replaced after heating the dried sludge powder up to 550^oc



NUMERICAL MODELING OF CHAR LAYER FALLING OFF IN CROSS-LAMINATED TIMBER (CLT)

G.W.K. Naveen¹, T.G.P.L. Weerasinghe^{1,*}, Chamith Karannagodage², Miriam Kleinhenz²

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Department of Civil, Environmental and Geomatic Engineering, ETH Zurich

Cross-laminated timber (CLT) is widely acclaimed in modern construction for its structural prowess, aesthetics, and sustainability. Architects, engineers, and designers increasingly favour this versatile material. Nonetheless, an in-depth exploration of CLT's thermal properties is essential. These properties, including heat transfer, charring, and insulation, significantly impact CLT structures' fire resistance and thermal efficiency. The thermal characteristics of timber, which encompass properties like density, thermal conductivity, and heat capacity, significantly influence its response to fire. As timber undergoes heating, it undergoes pyrolysis, leading to chemical and physical transformations that impact its ignition, combustion, and extinguishing behaviour. Therefore, understanding how thermal properties like thermal conductivity, specific heat, and thermal diffusivity evolve as timber is exposed to elevated temperatures is of utmost importance. While prior research has addressed these thermal properties and integrated them into Eurocode 5, their applicability to CLT is not straightforward. CLT exhibits distinctive behaviour at high temperatures, deviating from traditional timber types. In CLTs, a unique phenomenon arises under elevated temperatures, characterised by the delamination of CLT panels. Delamination occurs when the temperature within the panel exceeds the glass transition temperature of the adhesive, resulting in adhesive softening and a loss of strength. Consequently, the internal layers of CLT become exposed to the fire, lacking the protective char layer characteristic of other timber types. This intricacy necessitates dedicated research on CLTs' thermal properties and behaviour under extreme heat conditions.

This study is dedicated to unravelling the intricacies of CLT panels' thermal behaviour when subjected to high temperatures, explicitly focusing on delamination and its repercussions on thermal properties. Leveraging advanced finite element method (FEM) modelling, developed using SAFIR 2016 software, the study orchestrates simulations replicating CLT panels' response to various high-temperature scenarios. To benchmark these simulations and derive meaningful insights, the study juxtaposes the thermal properties stipulated in Eurocode 5-1-2 (2004) with newly derived properties. This rigorous analysis reveals a misalignment between Eurocode data and the real-world behaviour of CLT, especially in the post-fall-off phase of the fire. Consequently, the study introduces a novel thermal property tailored explicitly for CLT under standard fire conditions (ISO-834).

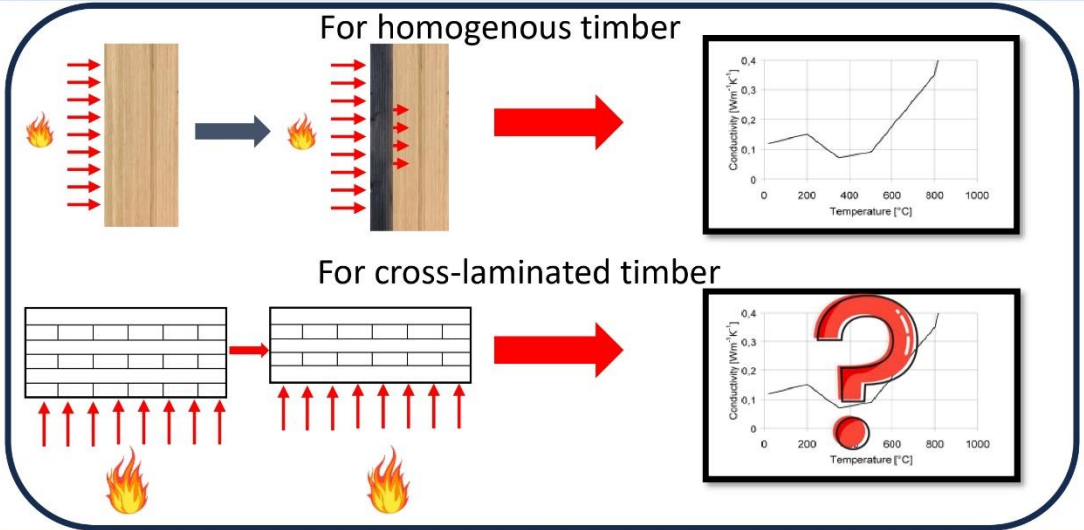
Crucially, the simulations validate the fidelity of the newly derived thermal properties in replicating the actual thermal behaviour of CLT, as substantiated by experimental data. These findings rectify prior inaccuracies and lay the foundation for developing more precise fire-resistant design strategies for CLT structures. Ultimately, this research significantly enhances the safety and performance of contemporary timber buildings operating within high-temperature environments.

Keywords: Cross Laminated Timber, Fire Performance, Delamination, Charring, Thermal properties

* Correspondence: pasinduw@uom.lk

Numerical modeling of char layer falling off in Cross Laminated Timber (CLT)

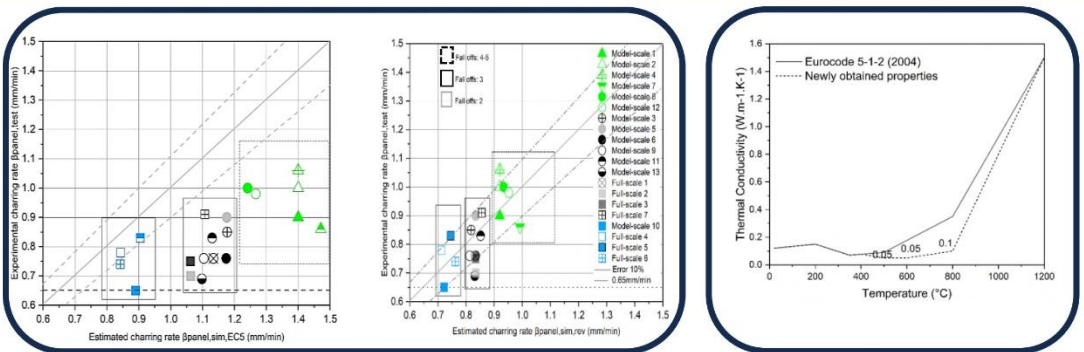
Problem Statement



Methodology



Conclusions



ENERGY EFFICIENCY AND THERMAL COMFORT IN ANCIENT BUILDINGS OF SRI LANKA

H.T. Ravishka ¹, C. Jayasinghe ^{1,*}, I.E. Ariyaratne ¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Ancient buildings stand as timeless witnesses to human architectural prowess, and their adaptability to local climate conditions is a testament to sustainable design principles. This research paper investigates energy efficiency techniques in ancient buildings in Sri Lanka by focusing on maintaining optimal thermal comfort. By examining historical structures in Sri Lanka, this study unveils the ingenious strategies employed by our ancestors to achieve optimal indoor comfort naturally without an external power source such as electricity. A comprehensive literature review was conducted as the first step to examine the scientific behaviour of the design intervention and strategies used in ancient and vernacular architecture. Then, various energy-efficient techniques ingeniously integrated into building design were meticulously examined. This exploration was conducted through a comprehensive analysis of four case studies, namely, ancient mansions - Ehelapola walawwa, Ekneligoda walawwa, Warawala walawwa, and Maduwanwela walawwa, representing architectural achievements of ancient Sri Lankan civilisations. The focus of this investigation encompasses passive cooling strategies, such as natural ventilation, shading devices, thermal mass utilisation, and orientation optimisation. Furthermore, incorporating traditional materials such as wattle and daub, clay, and cow dung, which possess inherent thermal properties contributing to heightened comfort, was investigated.

Research findings highlight the seamless integration of architecture and lifestyle, where courtyards, windcatchers, and underground spaces serve both functional and climatic purposes. Also, the paper offers insights into the adaptability of historical solutions in modern sustainable design. The findings underscore the potential for incorporating traditional techniques into current architectural discourse, fostering a more harmonious relationship between occupants, built environment, and energy consumption. To enhance thermal comfort in modern building designs, incorporating ancient features such as thick brick walls, high plinth levels, and natural ventilation can be considered. Ancient natural ventilation features encompass strategically placed windows, vents, and airflow paths, all contributing to improved indoor air circulation. Wall materials such as clay, stone, wattle and daub, and cow dung reduce heat transfer to the inside. Additionally, the veranda was an essential element in ancient mansions. This natural ventilation mechanism helps to maintain indoor air quality and remove pollutants, thus reducing energy consumption in buildings. Furthermore, integrating internal courtyards or atriums into modern building designs can improve natural lighting, airflow, and ventilation.

In conclusion, this research contributes to a comprehensive understanding of energy efficiency strategies embedded in ancient buildings of Sri Lanka, revealing valuable insights that can guide contemporary architectural practices. By recognising the invaluable lessons imparted by our architectural heritage, architects and designers can navigate modern sustainability challenges while celebrating our predecessors' ingenious achievements.

Keywords: Energy efficiency, Thermal comfort, Passive design, Ancient architecture, Vernacular architecture

* Correspondence: chintha@uom.lk

Energy Efficiency & Thermal Comfort in Ancient Buildings of Sri Lanka

What are the special features in ancient buildings to maintain thermal comfort?



Case Studies



Ehelapola Walawwa



Warawala Walawwa

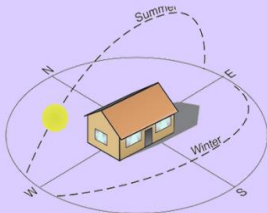


Maduwanwela
Walawwa

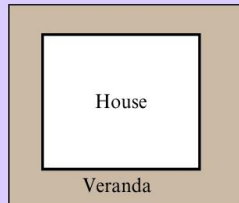


Ekneligoda Walawwa

Findings



North South orientation reduces heat gain



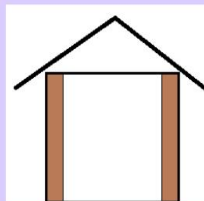
Veranda all around the house act as a thermal buffer



Roof with ventilation holes reduces excess heat



Central courtyard promotes cross ventilation



30 cm thick brick walls reduce heat transfer to the inside by acting as a thermal mass



30 cm high plinth reduces heat conductivity

Conclusion: These findings can be used in modern building design to maintain optimal thermal comfort in indoor environment. It will reduce energy costs for the mechanical ventilation systems.

DAMAGE ASSESSMENT MATRIX FOR LOW-RISE MASONRY HOUSES

G.G.T.D. Wickramathilake ¹, C. Jayasinghe ^{1,*}

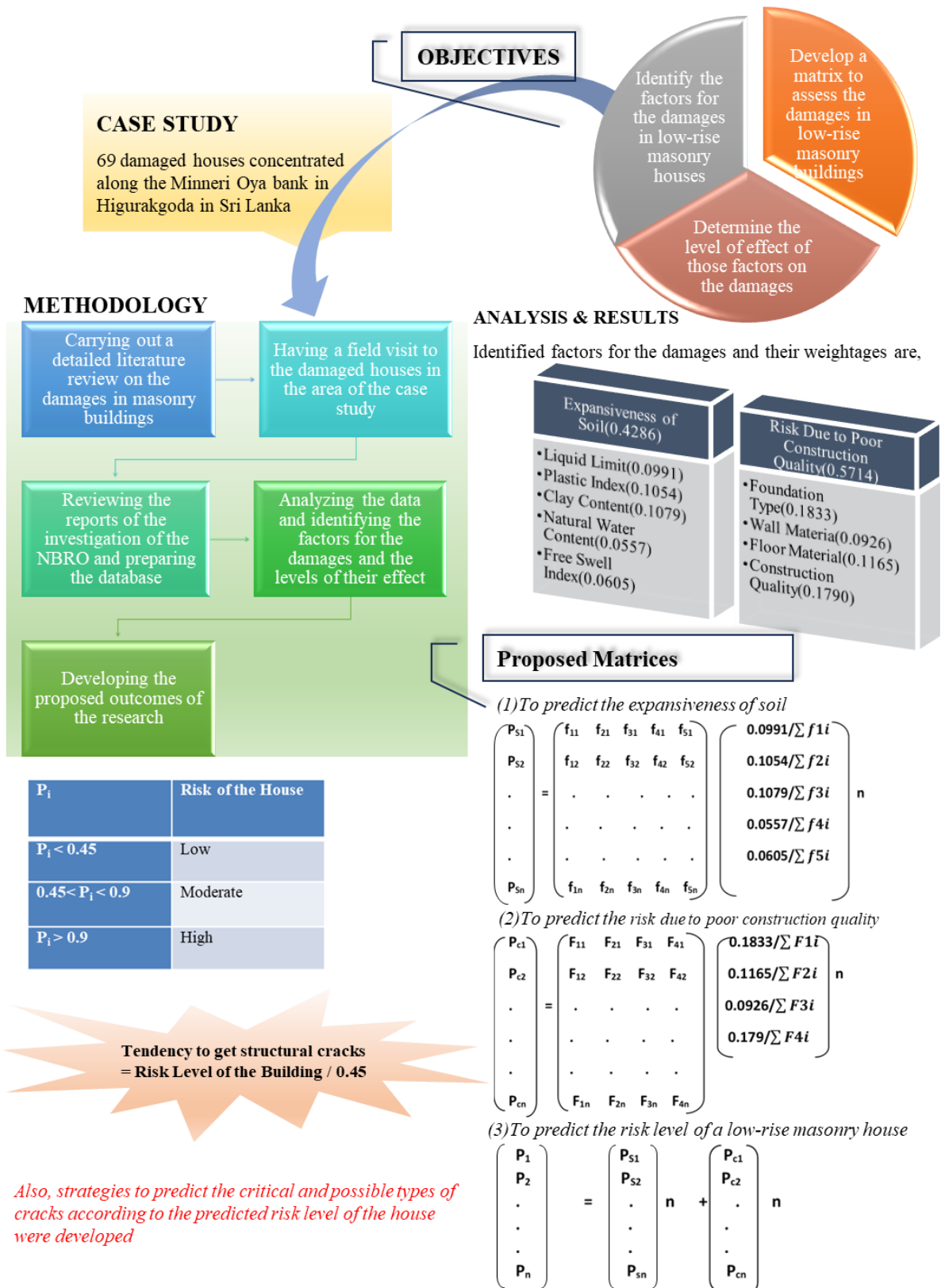
¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Low-rise buildings are susceptible to damage from factors like poor design or construction quality, inadequate supervision, improper drainage, problems due to the soil condition, and adverse climatic conditions. In certain areas where expansive soil is present, especially in floodplain areas, significantly threatens lightly loaded structures due to uplift pressures. The objectives of this study were to identify the factors for the damages in low-rise masonry buildings, the level of effect of those factors for the damages, and develop a matrix to assess the damages in low-rise masonry buildings as a case study based approach. This study was based on the damaged houses which are in Higurakgoda in the North Central province of Sri Lanka and constructed with commonly available materials. Field investigation, detailed review of the reports that had been prepared after the investigation done by the National Building Research Organisation in Sri Lanka, preparation of the database, and analysis of data using Microsoft Excel and Power BI is the procedure followed in this research. All those houses have been constructed in an area that is underlain by the Minneri Oya alluvial deposit layer. Through the detailed analysis, poor construction quality and the expansiveness of the soil were identified as the major factors for damage in the houses in the case study. With the aid of literature, this study considered liquid limit, plasticity index, clay content, natural water content, and free swell index of soil as dominant parameters that describe the expansiveness of soil, as well as the quality of construction, foundation type, wall material, and floor material as the factors affecting risk due to the poor construction quality as satisfaction. After determining the level effect of each considered parameter using the Analytical Hierarchy Process and actual data from the houses in the case study, a matrix that enables the prediction of the risk level of low-rise masonry houses on expansive soil was developed by combining two matrices developed to predict soil expansiveness and the risk level due to poor construction quality. The study also categorises possible damages, proposing an equation to predict the probability of structural cracks occurring in the building and a rationale to predict critical and possible types of cracks based on the risk level of the low-rise masonry house that is predicted using the proposed matrix. Validation of the proposed matrix using actual data demonstrated their accuracy in predicting risk levels. Therefore, when the construction details of the house and soil properties are identified, the outcomes of this research can be used to predict the risk level of low-rise masonry houses, the tendency to get structural cracks, and possible types of cracks. So, these findings can help assess and mitigate potential damage to low-rise buildings in expansive soil areas, enabling better construction practices and risk management strategies.

Keywords: Low-rise masonry buildings, Expansive soil, Damage assessment, Construction quality, Structural cracks

* Correspondence: chintha@uom.lk

DAMAGE ASSESSMENT MATRIX FOR LOW-RISE MASONRY HOUSES



UTILISATION OF INDUSTRIAL SLUDGE IN MUD CONCRETE: INVESTIGATION OF MECHANICAL PROPERTIES

A.M.C.H. Kumarie ¹, Poorni Nanayakkara ¹, R.U. Halwatura ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Turning wastes into building materials is a successful method of producing building materials while promoting sustainability in every aspect. There are many attempts and remarkable products around the world that show promising results of utilisation of waste-based construction materials in small- and large-scale infrastructure developments. Mud Concrete (MC) is a such innovation where the fine and coarse aggregates, which give the enduringness to a typical cement-based concrete, are replaced with soil. Replacing cement in MC with pozzolanic waste materials, preferably fly ash, is a continuation of the study on MC. Recent advancement of this same study is the geo-polymerisation of fly ash in MC using caustic soda thereby developing the strength. Aiming further waste utilisation in mud concrete and reducing energy use, replacing caustic soda with an alkaline waste, and reproducing the mixture is a potential study area, identified. This paper is advanced to investigate the behaviour of geo-polymerisation of fly ash in MC using alkaline industrial wastewater instead of caustic soda and, to assess the mechanical properties and optimise the mix proportions. The study begins with a literature review on soil-based construction, waste utilisation methods, and mud concrete chemistry. The geo-polymerisation process, which requires an alkaline environment, is separately explored as a potential strategy to utilise industrial waste in MC. Industrial wastes which are annually generated in massive amounts and, have a challenging time to dispose of, are considered. Out of those, waste types with high alkalinity are compared and, textile wastewater, the phase before it is turned into sludge, and having pH 13 is selected for further experimentation. The trial mixes are arranged by changing the mix proportions and curing temperature to assess the strength development of MC against critical parameters and, then the results are compared with existing literature findings. As the main outcome of this study, Unconfined Compressive Strength (UCS) is analysed to assess the effectiveness of sludge waste in forming geo-polymers and replacing caustic soda. It could be observed that under the same conditions, both samples with caustic soda mixed and wastewater mixed have the same UCS strength levels. This strength is 33% higher compared to that of the controlling sample with water. This leads to predicting the effect of geo-polymerisation. Further, the influence of soil type, curing temperature, and moisture content on compressive strength development are studied to identify how these key factors are affecting on strength development of MC. The observed optimum moisture content is 0.14 and, the maximum strength gain after maintaining the obtained optimum conditions is 1 MPa. A graph is developed to estimate the amount of waste, namely fly ash and textile wastewater concentration, required to achieve desired strength levels. Recommendations for further analysis include microstructure analysis expanding the study to other industrial sludge waste types and assessing how far this can be generalised. Future work involves investigating factors such as moisture content and fly ash properties to enhance MC strength. Additional tests on leachate, durability, and toxicity are suggested to further convince the use of industrial sludge waste in MC.

Keywords: Mud concrete, Alternative stabiliser, Alkali activation, Geo-polymerisation

* Correspondence: rangika@uom.lk

**Utilization of Industrial Sludge in Mud Concrete:
Investigation of Mechanical Properties**

Thirty three percent strength increase in wastewater-based mud concrete compared to the control conditions, lead to predict the positive effect on the substitution of alkaline textile wastewater to caustic soda in geopolymerization.

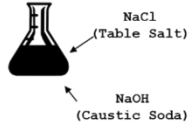
Mud Concrete

Soil:
 Fine Particles → 10%
 Fine Aggregate → (55 - 60)%
 Coarse Aggregate → (30 - 35)%
Main binder: Cement - Minimum 4%
 Moisture Content: (0.80 - 0.20)

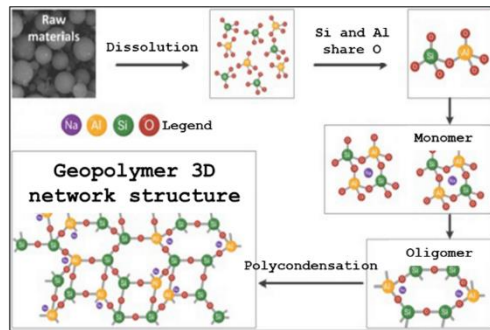
Geo-Polymerized Mud Concrete

Soil:
 Fine Particles → 5%
 Fine Aggregate → 60%
 Coarse Aggregate → 35%
Main binder: Geo-polymers
 Moisture Content: (0.80 - 0.20)

Alkaline Solution

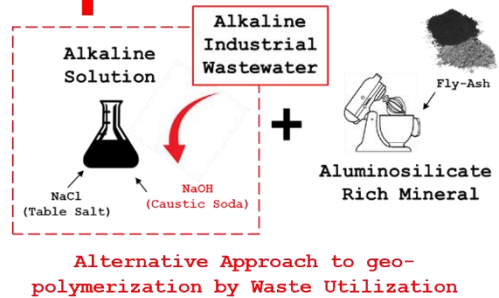


Aluminosilicate Rich Mineral



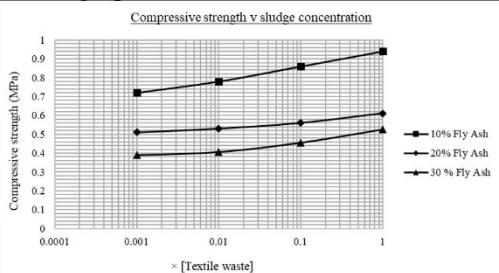
METHODOLOGY

- Experiment 1 {
 - pH testing of the sludge types and assessing the potential use
- Experiment 2 {
 - Checking the selected soil is capable of giving the required proportions of different particle sizes
 - Casting mud concrete by altering NaOH with industrial sludge in ambient temperature and elevated temperature and comparing the strength
- Experiment 3 {
 - Testing the influence of moisture content on strength development
- Experiment 4 {
 - Finding out the optimum fly-ash and waste contents to gain the maximum strength under controlled conditions



MAIN FINDINGS

- Optimum moisture content = 0.14
- Development of Compressive strength versus wastewater concentration and fly-ash content graph



UTILISATION OF INDUSTRIAL WASTE; FLY ASH/BOTTOM ASH TO HASTEN THE INTRINSIC BIOFOULING PROPERTIES IN CEMENT MORTAR: STRENGTH PROPERTIES

M.P.P.C.D. Wijesinghe¹, R.U. Halwatura^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

In recent years, the incorporation of industrial waste materials into sustainable construction practices has emerged as a significant area of interest. This research aims to explore the application of fly ash and bottom ash, both commonly found industrial waste products, in enhancing the biofouling properties of cement mortar. Biofouling, which refers to the accumulation of marine organisms on submerged surfaces, poses a considerable challenge to marine structures, necessitating the development of effective mitigation strategies. This study employs a comprehensive research methodology that involves the preparation of cement mortar samples, wherein varying proportions of fly ash and bottom ash are used as partial replacements for the fine aggregate. To evaluate the physical properties of the mortar mixtures, various replacement percentages in 20% intervals are tested, ranging from 0% to 100%. The assessment is conducted following established standards (IS:4031-1998) and involves the performance of standard tests such as consistency, initial setting time, and final setting time. These tests allow for a comprehensive evaluation and comparison of the different mortar mixtures, providing important insights into their overall quality and characteristics.:4031-1998). In order to comprehensively assess the modified cement mortar, the mechanical properties were evaluated. The compressive strength was tested using the ASTM C109/C109M standard, while the tensile strength was measured through splitting tensile tests following ASTM C496/C496M guidelines. To further understand the impact of biofouling on the modified mortar mixtures, 16 samples were exposed to the intertidal zone at Dikkowita fisheries harbour for three months. Monthly visual observations and photographic documentation were methodically carried out to monitor and document the growth and extent of biofouling on the mortar surfaces. The findings presented in this study offer significant insights into the utilisation of fly ash and bottom ash as additives in cement mortar to enhance its resistance against biofouling. Through a comprehensive analysis of the physical, mechanical, and biofouling evaluations, the study thoroughly evaluates and discusses the most effective replacement percentages for achieving optimal biofouling resistance. This research holds valuable potential for advancing the use of fly ash and bottom ash in cement mortar and further enhancing its performance against biofouling. Using industrial waste materials in cement mortar is an essential practice to promote sustainability in the construction industry while simultaneously minimising the environmental consequences of waste disposal. The implications of our research extend further, as it holds the potential to advance the development of biofouling-resistant cement mortar for marine applications, thereby benefiting both the construction industry and coastal infrastructure development. Additionally, this research offers the possibility of reducing dependence on chemical anti-fouling treatments, thereby paving the way for even more environmentally friendly solutions.

Keywords: Industrial waste, Cement mortar, Biofouling, Mechanical properties, Bio-receptivity

* Correspondence: rangika@uom.lk

Biomass growth over 3 months

Sample No	March	April	May	June
1. Control sample cement-sand, 1:6 ratio				
2. Fly ash- sand ratio, 20%-80% as fine aggregate				
3. Fly ash- sand ratio, 40%-60% as fine aggregate				
4. Fly ash- sand ratio, 60%-40% as fine aggregate				
5. Fly ash- sand ratio, 80%-20% as fine aggregate				
6. Fly ash- sand ratio, 100% as fine aggregate				
7. CTWP- sand ratio, 20%-80% as fine aggregate				
8. CTWP- sand ratio, 40%-60% as fine aggregate				
9. CTWP- sand ratio, 60%-40% as fine aggregate				
10. CTWP- sand ratio, 80%-20% as fine aggregate				
11. CTWP- sand ratio, 100% as fine aggregate				
12. Fume silica- sand ratio, 20%-80% as fine aggregate				
13. Fume silica- sand ratio, 40%-60% as fine aggregate				
14. Fume silica- sand ratio, 60%-40% as fine aggregate				
15. Fume silica- sand ratio, 80%-20% as fine aggregate				
16. Fume silica- sand ratio, 100% as fine aggregate				

Test Results

ratio	Cement (g)	Sand(g)	Industrial Waste Material			Water (ml)	Consistency (mm)	Initial Setting Time	Final Setting Time
			Fly h	CTWP	Fume Silica				
1:6		100%						25min	> 8hours
1:6	58	171	171			80	20	>30min	>30min
1:6	58		342			115	8		
1:6	58	68	274			100	8		
1:6	58	171		171		95	6	>30min	
1:6	58		342			150	3	>30min	
1:6	58	68	274			100	1	>30min	
1:6	58	171			171	135	3	27min	30min
1:6	58				342	235	5	22.5min	36min
1:6	58	68			274	170	3	>30min	

Table 1: Initial Setting time and Final Setting Time Test Results

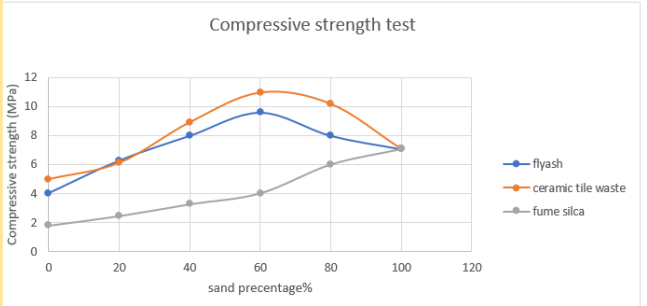


Figure 1: Compressive Strength Test Results

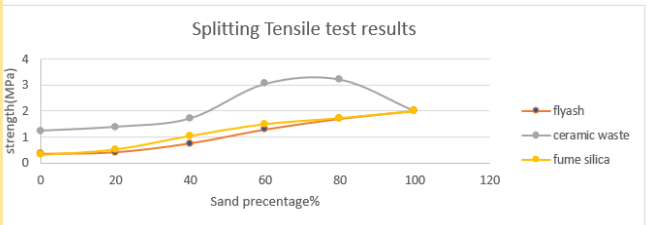


Figure 2: Splitting Tensile Test Results

DEVELOPMENT OF A MODULAR ROOF TILE FOR SLOPED GREEN ROOFS IN THE TROPICS

A.M.M.G. Munasinghe¹, R.U. Halwatura^{1,*}, G.K.P. John²

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Institute of Technology, University of Moratuwa, Homagama

Converting existing sloped roofs to green roofs in Sri Lanka poses challenges due to limited options and costly modifications. This research aims to overcome these barriers by developing a modular roof tile system that enables a smooth and cost-effective transition to green roofs. The proposed system allows for easy replacement of current roofing materials with green roof tiles, minimising the need for major modifications to the existing roof support system. By considering the tropical climate conditions of Sri Lanka, this research fills the gap in green roof studies primarily conducted in temperate regions. The study focuses on determining optimal dimensions and profiles for modular roof tiles through structural analysis and computer simulations.

The methodology employed in the research study was as follows. Initially, a literature review was conducted to gather information on green roofs, research gaps, and roof structure details specific to Sri Lanka. Then examined existing roofing systems in Sri Lanka to understand their characteristics and installation methods. Suitable dimensions for the proposed green roof tile were decided based on the literature review, the study of roofing systems in Sri Lanka, and a laboriousness study. Suitable dimensions were identified as 900mm x 1200mm x 25 mm. Then suitable profiles were selected for the green roof tile based on existing roof tiles and relevant literature. Finite element modelling was utilised to analyse the structural behaviour of the proposed roof tile profiles and identify the most suitable profile for optimal performance. Three initial shapes of corrugations were considered first to determine the best shape. Based on the comparative study of the three different corrugation shapes, it was determined that circular corrugation exhibited the highest reduction in maximum displacement per unit length increased through the introduction of corrugation. To explore the design variations within this profile, the rise and pitch of the circular corrugation were systematically varied, resulting in a total of nine different profiles. During the comparative study of the nine profiles, a specific criterion was applied to select the most suitable profile. Only the profiles that exhibited a displacement of less than or equal to 5mm were considered for further evaluation. Among these profiles, the focus was on identifying the one that demonstrated the highest reduction in maximum displacement per unit length increased through the introduction of corrugation compared to the base profile. After careful analysis and assessment, profile with a rise of 10mm and a pitch of 200mm emerged as the optimal choice, exhibiting a significant reduction in displacement, and fulfilling the established criteria. Thus, this profile was selected as the preferred profile for the proposed green roof tile system. The recommended profile demonstrates significant displacement reduction per unit length increased through the introduction of corrugation and offers favourable characteristics for accommodating the growing medium.

The findings will contribute to promoting sustainable construction practices by providing cost-effective solutions for converting existing sloped roofs to green roofs in Sri Lanka.

Keywords: modular roof tile system; green roof conversion; cost-effective, sloped roofs; Sri Lanka; tropical climate

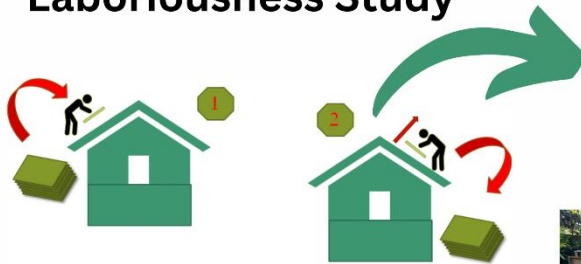
* Correspondence: rangika@uom.lk

DEVELOPMENT OF A MODULAR ROOF TILE FOR SLOPED GREEN ROOFS IN THE TROPICS

Converting existing sloped roofs to green roofs in Sri Lanka poses challenges due to limited options and costly modifications. This research aims to overcome these barriers by developing a modular roof tile system that enables a smooth and cost-effective transition to green roofs.

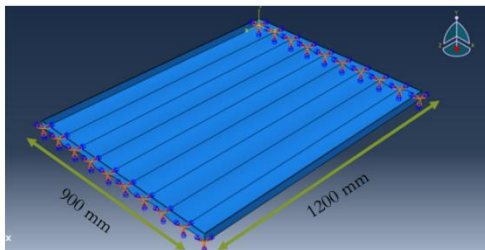


Laboriousness Study

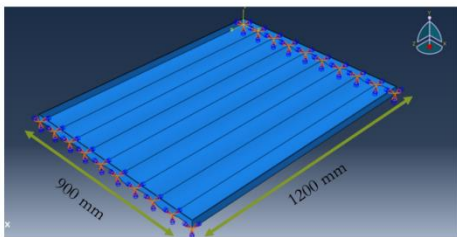


1. Time to take the tiles to the roof and to install the tiles.
2. Time to remove the tiles from the roof to bring the tiles back to the floor and stack them.

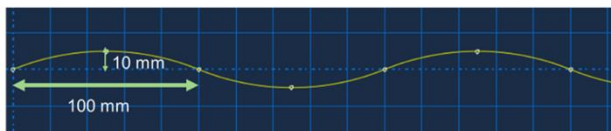
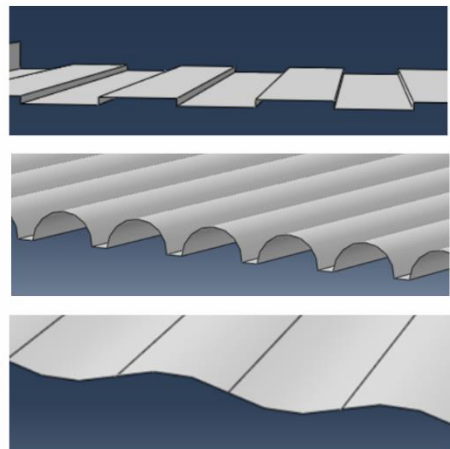
Finalised dimension



Finalised design



Corrugated shapes considered:



TESTING THE APPLICABILITY OF INNOVATIVE TECHNOLOGIES IN IMPROVING CONSTRUCTION SAFETY IN SRI LANKA

T. Fayad¹, C.S.A. Siriwardana^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Safety concerns within the Sri Lankan construction industry are heightened by troubling statistics, as accidents and fatalities frequently arise from site negligence and are amplified by the absence of technology-driven hazard identification tools. Despite advancements, the implementation of such innovative technologies remains suboptimal. Hence, this research study addresses this gap by exploring how innovative technologies can bolster safety in the Sri Lankan construction industry. Considering the extensive research conducted over the past decade, our research was exclusively concentrated on technologies like Building Information Modelling (BIM), Augmented Reality (AR), Virtual Reality (VR), Geographic Information Systems (GIS) and gaming technologies. The research methodology involved conducting a literature review, a desk-based study, and distributing two questionnaires to both civil engineering undergraduate students and professionals. The desk-based study was an extensive literature review, covering facilitators and barriers to innovative technology adoption in construction, potential applications, and implementation benefits. The two questionnaire surveys were strategically designed to enrich insights progressively. The first survey was conducted to assess the readiness and potential for adoption, while the second was designed specifically for professionals to explore the findings in greater detail. This approach ensures a well-rounded perspective, from knowledge assessment to applicability and barrier evaluation. In the first survey, a total of 69 participants joined, comprising 31 professionals and 38 civil engineering undergraduate students. The second survey was directed towards 32 professionals within the Sri Lankan construction industry. As per the results, all five technologies were identified as potential enhancers of hazard identification, safety management, and planning. Furthermore, participants acknowledged that these technologies contribute to improved safety (92%), heightened productivity (85%), and cost efficiency (78%). However, barriers to implementation include stakeholder unawareness (73.9%), financial constraints (69.6%), and limited accessibility (52.2%). Therefore, the recommended measures encompass raising awareness, encouraging teamwork, creating standards for the sector, offering financial incentives, improving technical assistance, and removing barriers with focused tactics. By adhering to these recommendations, the construction industry can expedite the effective integration of innovative technologies, ultimately bolstering its risk management and safety procedures.

Keywords: Construction safety, Technology adoption, Innovative technologies

* Correspondence: chaasi@uom.lk

TESTING THE APPLICABILITY OF INNOVATIVE TECHNOLOGIES IN IMPROVING CONSTRUCTION SAFETY IN SRI LANKA

Construction Safety

Safety concerns in construction are exacerbated by alarming statistics and a lack of technology-driven hazard identification tools.



Methodology

DESK STUDY

It covers topics such as facilitators and barriers to implementing innovative technologies, potential applications, and past implementation advantages.



AIM

Testing the applicability of innovative technologies in improving construction safety in Sri Lanka by conducting a technology readiness assessment.



SURVEY 01

- It gauges readiness and adoption potential
- 69 participants joined, including 31 professionals and 38 undergraduates



Innovative Technologies Addressed

- BIM
- Virtual Reality
- Augmented Reality
- GIS
- Gaming Technologies



SURVEY 02

- It tailored for professionals, delves deeper into findings
- It targeted 32 professionals in the Sri Lankan construction domain



Findings

Barriers in Implementation



- Stakeholder unawareness (73.9%)
- Financial constraints (69.6%)
- Limited accessibility (52.2%)

Applications

- Hazard identification
- Safety management
- Safety planning

Benefits of Implementation

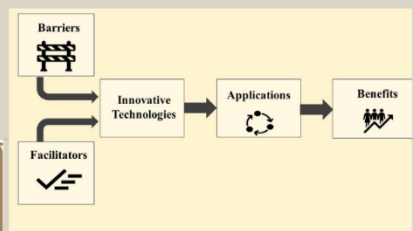
- Improved safety (92%)
- Heightened productivity (85%)
- Cost efficiency (78%)

Facilitators in Implementation



- Raising awareness
- Encouraging teamwork
- Creating standards for the sector
- Offering financial incentives
- Improving technical assistance

Implementation Framework



Conclusion

By adopting the facilitators proposed in this study, the construction industry can enhance safety and harness the potential advantages offered by innovative technologies.

(FAYAD AND CHANDANA, 2023)

ANALYSIS OF THE SHEAR BEHAVIOR OF STABILISED SOIL-CONCRETE INTERFACE IN GEOTECHNICAL STRUCTURES

W.A.W. Wijesingha¹, K.H.S.M. Sampath^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Understanding the behaviour between the interface of soil and concrete structures has a significant role when considering stability and the capacity of geotechnical structures such as shallow foundations, deep foundations, and earth-retaining structures. Quarry dust (QD) is an alternative waste material used for soil stabilisation to improve the engineering properties of existing weak soil, such as bearing capacity, stability, strength, and compressibility. Assessing the respective behaviour of the interface under various mix proportions of QD and the existing soil is important since the geotechnical properties of stabilised soil mainly vary with the mix proportion. This research investigates the influence of different QD and clayey sand (SC) mix proportions on the interface shear behaviour by laboratory experiments with modified direct shear tests. The effectiveness of the clayey sand stabilisation process using QD is demonstrated based on the plasticity characteristics, compaction characteristics, and shear strength of the soil-soil interface and the soil-concrete interface. The results demonstrate that QD provides effective clayey sand stabilisation since the Plasticity Index is decreased by 46.8%, MDD is increased by 11.26%, and Shear Strength is increased by 74.57% under 200 kN/m² of normal stress when the QD percentage in the stabilised soil is increased from 0% to 20%. Also, 40% of QD was obtained as the optimum mix proportion to stabilise clayey sand based on compaction characteristics since MDD is increased up to 40% and again decreased with the addition of QD. This investigation demonstrates that QD provides highly effective shear strength increment to clayey sand, and the shear strength is completely governed by the effect of friction angle beyond 10% QD addition since the cohesion is negligible.

Further, in the second phase, the accuracy of recommended co-relations between interface shear strength properties and soil shear strength properties provided in existing design codes has been assessed, particularly focusing on the QD-based stabilised clayey sand and using two concrete surfaces that have different roughness values (R1 and R2). The results demonstrate that when 20% of QD is added, the Interface Friction is increased by 23.2% in the soil-concrete interface (R1) and 22.5% in the soil-concrete interface (R2), and the obtained Interface Friction Angle Reduction Factors (IFARF) are in the range of 0.72 – 0.95. Therefore, the experimental results concluded that the IFARF, used in current design practices and values recommended in design guidelines, overestimates the interface shear reduction of the SC soil when it is stabilised with QD. In contrast, the Cohesion Reduction Factor (CRF), used in the current design guidelines, underestimates the interface shear reduction of clayey sand and stabilised clayey sand with QD when the contacted concrete surface is smoother than the relative roughness of 0.510 since the obtained CRFs are in the range of 0.52-0.67. Hence, the outcomes of the research conclude that the interface shear behaviour highly varies with the interface soil properties and the surface roughness of the structure; as such, adopting a common interface reduction factor for both friction angle and cohesion is not always accurate for designing geotechnical structures. It is recommended that a design optimisation should be performed by carrying out appropriate interface shear strength tests, considering the soil types and concrete surface properties, especially when the existing soil is stabilised with an additive like QD.

Keywords: Shear Strength, Quarry Dust, Interface, Reduction Factor

* Correspondence: sampathkh@uom.lk

THE SHEAR BEHAVIOR OF STABILIZED SOIL-CONCRETE INTERFACE



Soil-Concrete Interface

Shear Strength

Quarry Dust Stabilization

Geotechnical Structures

METHOD



Plasticity Characteristics
Compaction Characteristics



Soil-Soil Interface Shear Strength
Soil-Concrete Interface Shear Strength



Soil-Concrete Interface (R1)
Soil-Concrete Interface (R2)

The accuracy of recommended correlations between interface shear strength properties and soil shear strength properties is assessed

RESULTS

Optimum QD Percentage → 40% (Based on MDD)

Property	Increment with 20% QD
PI	46.8%
MDD	11.26%
Shear Strength	74.57%
IFARF	23.2% (R1), 22.5% (R2)

Obtained Interface Friction Angle Reduction Factors → > 0.67

Obtained Cohesion Reduction Factors → < 0.67

Conclusion

It is recommended that a design optimization should be performed by carrying out appropriate interface shear strength tests, considering the soil types and concrete surface properties, especially when the existing soil is stabilized with an additive like QD.

STUDY ON THE PARTIAL REPLACEMENT OF SOFT SOILS UNDER SHALLOW FOUNDATIONS

G.H.K.H. Wijesooriya¹, L.I.N. de Silva^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Soft soil replacement is a widely used technique in ground improvement to enhance the subsurface conditions beneath shallow foundations which involves replacing weak and unstable soil types like peat, organic soils, and soft clay with more reliable and competent materials such as crushed concrete, granular soil, or rock boulders. By implementing a soil replacement approach, the bearing capacity of the footing is increased, while the expected settlement is reduced. This leads to improved overall stability and performance of the foundation system. However, there are many instances where the depth to the hard layer is significant and replacing the entire weak soil is not feasible, because of the high costs involved. For relatively small-scale projects, using other ground improvement techniques or deep foundations might not be cost-effective. So partial replacement is a feasible solution.

This paper presents the research on partial soft soil improvement under shallow foundations varying the width and depth of the replacement, soft soil properties, and replacement materials. A two-dimensional plane strain model is developed using the finite element (FE) program, PLAXIS 2D. To ensure its accuracy, the model is initially validated by comparing its results with known cases by Zukri et al., (2018). The constitutive model chosen to represent the soil's behaviour was the Mohr-Coulomb model. The replacement depth is changed to 1B, 2B, and 3B, while the replacement width is adjusted to 1.25B, 1.5B, and 2B. In this context, B represents the width of the footing, which is 1 meter. Then settlement values were obtained from the model. Rock boulders and granular soil were taken as fill materials to evaluate the effect of the replacement material. To examine the influence of the characteristics of the soft soil, Young's modulus, cohesion, and friction angle of the soft soil were adjusted and stiff clay was utilised in place of soft clay.

The introduction of partial replacement techniques leads to a decrease in settlement. Based on the obtained results, it is concluded that increasing the width and depth of the replacement leads to a decrease in settlement. By comparing settlement values, it indicates that there is a significant reduction in the settlement when the replacement width is increased up to 1.25 times the footing width. So, increase beyond 1.25B will not affect more. Therefore, replacement should be conducted at least up to 1.25B. Increasing the depth of partial replacement results in the reduction of the settlement. However, there is a significant reduction in settlement when the ground depth is improved up to 2 times the footing width (2B). Further improvements beyond 2B do not have a significant impact. Therefore, it is recommended to carry out replacement up to a depth of 2B. The foundation's condition can be enhanced by replacing some of the soft soil with more competent materials, such as granular soil or rock boulders.

Keywords: Partial Replacement, Shallow Foundations, Ground Improvement, Finite Element Method, PLAXIS 2D

* Correspondence: nalinds@uom.lk

STUDY ON THE PARTIAL REPLACEMENT OF SOFT SOILS UNDER SHALLOW FOUNDATIONS



MAIN AIM:

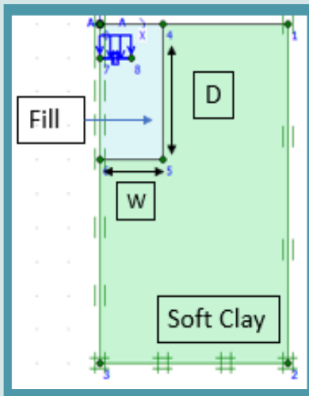
Proposing a set of guidelines/recommendations for partial replacement of soft soils under shallow foundations



Developing FE Models varying

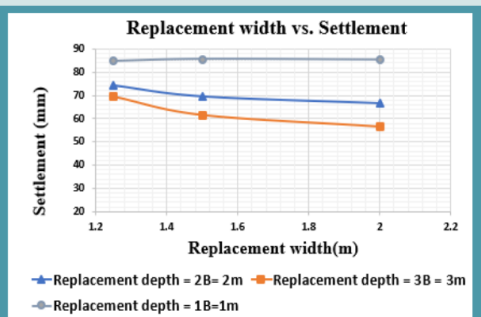
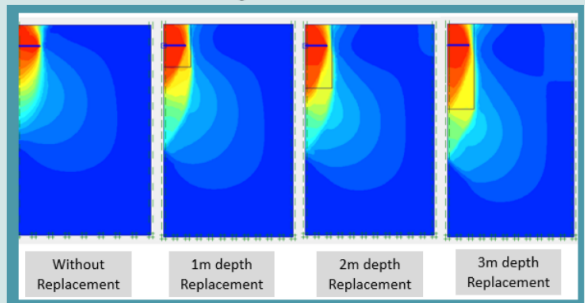
- Depth and width of replacement
- Replacement material
- Soft soil properties

Conclusion & Recommendations



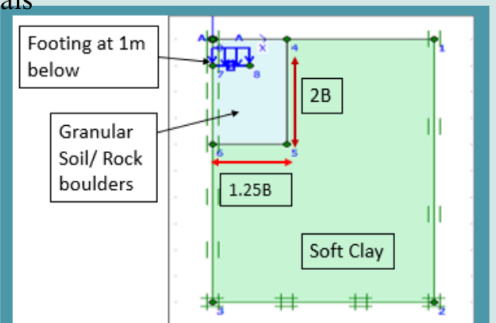
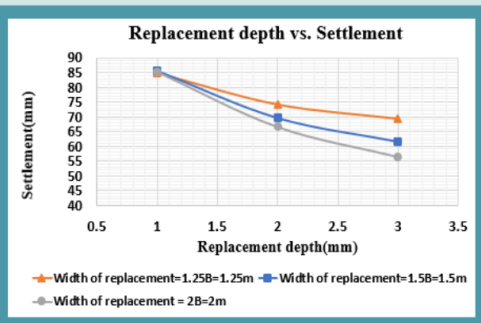
FE Model

- PLAXIS 2D software
- 2m strip footing - Plane strain idealization
- Footing - 01m below the ground level
- Water table - below the footing level



Recommendations

- replacement width of 1.25 times and replacement depth of 2 times the width of the footing
- granular soil or rock boulders as replacement materials



CRITICAL EVALUATION OF AVAILABLE PREDICTIVE MODEL FOR ROOT PERMEATED SOIL STRENGTH USING NUMERICAL MODELING

S.G. Wellage¹, Muditha Pallewatta^{1, *}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Soil bioengineering combines plants' root systems to prevent erosion and stabilise slopes, offering sustainable, nature-based solutions for environmental restoration. Shear strength evaluation of soil bioengineering is discussed under mechanical and hydrological aspects but remains unimproved, highlighting a significant research gap. This research presents a comprehensive investigation on the shear strength improvement of soil through soil reinforcement, focusing on the use of vegetation roots as a reinforcement material. The study combines experimental testing and numerical modelling using Abaqus software to assess the effectiveness of root reinforcement in enhancing soil stability. The experimental phase involved conducting tensile strength tests on natural *Alstonia Macrophylla* roots. Performing large-scale direct shear tests with roots can be a challenging endeavour. Roots have a significant impact on the mechanical behaviour of soil and introduce complexities into the testing process. In this research, Finite Element Analysis (FEA) was implemented in Abaqus to model large-scale direct shear tests involving soils with roots. This approach offered a versatile and powerful means to simulate the complex interplay between roots and soil behaviour. Obtained experimental data, including the Young's modulus value of the root, were utilized for the numerical model calibration. In the experimental phase of the study, a practical approach to quantify the tensile strength of roots was employed. This was achieved using a Universal Testing Machine (UTM), a widely used apparatus for measuring the mechanical properties of materials. However, certain properties such as Poisson's ratio and density for the root were obtained from relevant literature due to the unavailability of specific data. For validation purposes recently conducted direct shear tests results on *Alstonia Macrophylla* root permeated soil were adopted. The numerical model was established using a solid model approach, simulating the actual size of the soil samples, and employing appropriate material properties. The simulation accounted for soil-soil and soil-root contacts using appropriate contact models. In simulating the direct shear test, a "Surface-to-Surface contact" approach modelled soil and root interactions. Soil surfaces were defined as "Master" and "Slave," using a "Penalty formula" for tangential friction and a "hard" contact type for normal behaviour. Roots were treated as embedded bodies with ABAQUS constraints, ensuring realistic contact representation. The results of the numerical simulation demonstrated the stress concentration within the soil, particularly in regions in contact with the root, indicating significant shear strength improvement due to root reinforcement. The obtained shear stress-displacement relationship allowed for the determination of the shear strength of the system. Simulation and experiments showed root-soil shear strength enhancement. Accurate parameters and 3D modelling were vital for reliability. This study's findings provide guidance for root growth regulation and slope protection research. Overall, this research contributes to the understanding of soil reinforcement mechanisms and provides valuable insights into the use of Soil bio engineering as an effective means of enhancing soil stability.

Keywords: Soil reinforcement, Shear strength improvement, *Alstonia Macrophylla* root, Numerical modelling, Direct shear test, Contact modelling, Soil stability

* Correspondence: mudithap@uom.lk

CRITICAL EVALUATION OF AVAILABLE PREDICTIVE MODELS FOR ROOT-PERMEATED SOIL STRENGTH, USING NUMERICAL MODELLING

Introduction

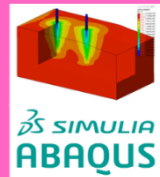


- Performing Large scale direct shear tests is one approach to measure both mechanical and hydrological effect fro tree roots.

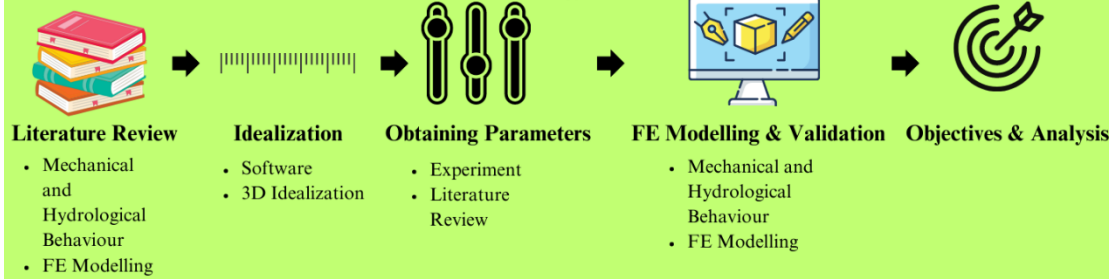
soil bioengineering is a technique that uses living plants to provide engineering functions such as slope stabilization, erosion control, and water quality improvement. performing large scale direct shear test for various types of vegetation to create data base to use in soil bio engineering work is very time consuming and costly work.

Summary

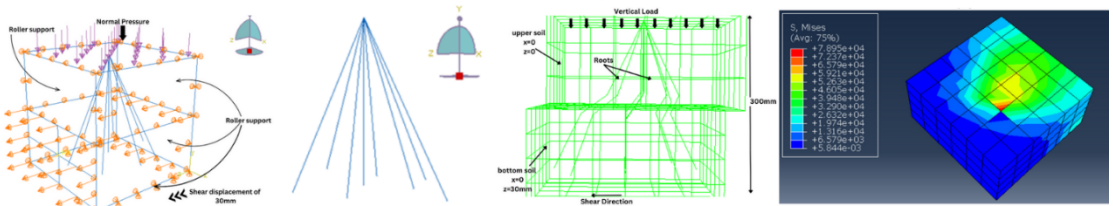
- SO, as a solution Finite element modeling of large direct shear test will be done using ABAQUS FEM software will used in numerical modeling. Finite element model will be able to use in the industry as a graphical user interface with further development.



Methodology

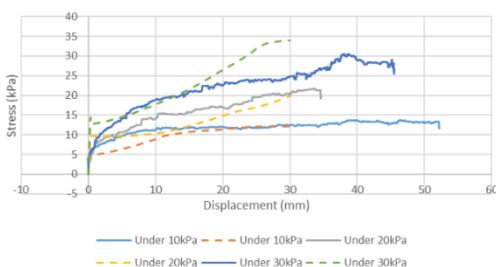


Numerical Modeling



Results

Shear stress vs Displacement



Conclusion

- *Alstonia macrophylla* (Attonia Tree) roots enhance soil shear strength significantly.
- Plant roots resist shear force, improving shear resistance in root-soil composite.
- Shear strength has a linear relationship with vertical pressure using the same root method.

ESTABLISHMENT OF A RELATIONSHIP BETWEEN LANDSLIDE SUSCEPTIBILITY ZONATION AND THRESHOLD RAINFALL INTENSITIES

G.M. Jayasundara ¹, S.A.S. Kulathilaka ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Landslides induced by heavy rainfall pose a common geotechnical hazard in Sri Lanka. Sloping grounds in Sri Lanka are made of rocks at different levels of weathering, residual and colluvial soils. The parent rock's mineralogical composition influences the heterogeneous nature of these weathering profiles. Slopes in the region have deep groundwater tables and unsaturated soil profiles with high matric suction during dry periods. However, prolonged rainfall leads to slope instability due to the loss of matric suction and the potential formation of a perched water table or the rise of the groundwater table.

National Building Research Organisation (NBRO) has developed the landslide hazard zonation maps of Sri Lanka at 1:50000 and 1:10000 for districts where landslide risk is high based on the overall hazard rating (score) determined by terrain factors. The terrain factors are bedrock geology and geological structures, type and natural soil cover and thickness, slope range and category, hydrology and drainage, land use and management and landform. In landslide hazard zonation maps, sloping grounds are divided into regions of different hazard levels: Safe slope, landslide not likely to occur, a modest level of landslide hazard and landslides are to be expected.

To supplement that zonation, it is essential to identify the threshold rainfall intensities causing a disastrous situation in zones of different landslide susceptibility. Currently, the threshold rainfall values are determined by previous experience.

Researchers have developed different empirical statistical relationships to identify threshold intensities that vary with local landslide factors and site-specific. Given the significant material variations in Sri Lankan slopes, relying solely on statistical approaches is inappropriate. Landslide susceptibility level-specific thresholds based on numerical studies would be necessary to make reliable decisions regarding early warning and remedial measures. In this research, landslides where the triggering rainfall data is available are back analysed to establish a relationship between landslide susceptibility zonation and threshold rainfall intensities.

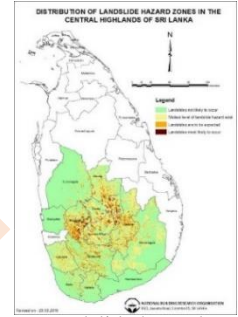
The SEEP/W 2018 software was used to model rainwater infiltration and the consequent changes in the pore water pressure. The results of the above seepage analysis were then transferred to SLOPE/W software to analyse the slope stability. Initially, recent landslides (Pinnawala landslide and Kithulgala landslide) where rainfall records are available was back analysed and threshold rainfall values for these two slopes was established. The level of hazard of these two landslide areas was identified using the landslide hazard zonation maps of Sri Lanka that developed by National Building Research Organisation (NBRO). A relationship between landslide susceptibility zonation and threshold rainfall intensities can be established by doing this analysis on several landslides that rainfall data was available.

Keywords: Landslides; Rainfall Threshold; Groundwater Table; Unsaturated; Matric Suction; Infiltration

* Correspondence: sas@uom.lk

How Rainfall Causes Landslides???

The landslide hazard zonation maps of Sri Lanka at the scale of 1:50000 and 1:10000 for districts where the risk of the landslide was developed by NBRO based on terrain factors.



Landslide hazard zonation map (1:50000)

But, threshold limits currently used in Sri Lanka are empirical based on past experiences.

To issue more reliable early warnings it is important to develop threshold rainfall values on a mechanistic basis.

Back Analysis of Landslides Where Rainfall Records Are Available

Infiltration of Rainwater

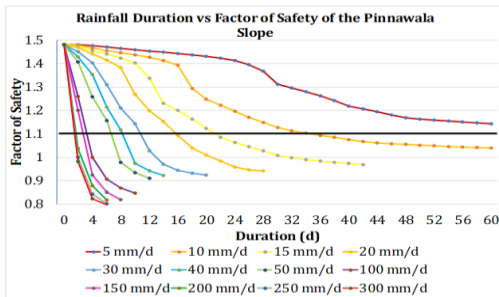
Reduction of Matric Suction/increase of pwp

Loss of Shear Strength

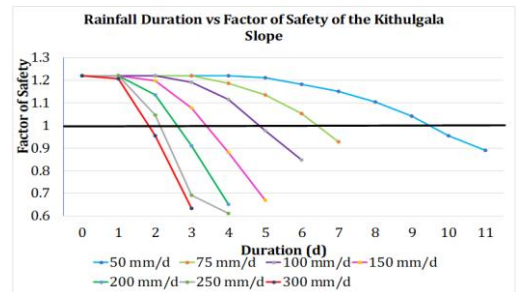
Instability

The Pinnawala and Kithulgala landslides were back analysed and both landslide areas are on a **modest level of landslide hazard zonation** in the landslide hazard zonation map.

Pinnawala Landslide Analysis



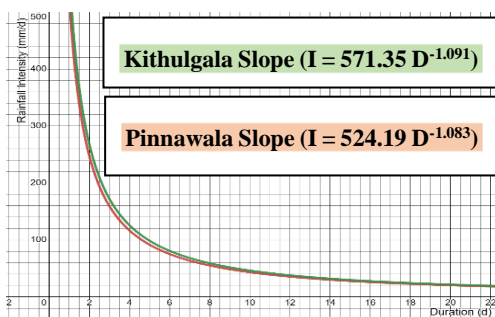
Kithulgala Landslide Analysis



Conclusion and Recommendations

By analysing the data, the rainfall threshold for the **modest level of landslide hazard zonation** is determined to be described by the equation. $I = (524.19 \text{ to } 571.35) D^{(-1.083 \text{ to } -1.093)}$ where **I** represents rainfall in mm per day, and **D** represents the duration in days.

Suggested appropriate threshold rainfall intensities for different levels of warnings for areas that landslide risk of modest level.



Threshold rainfall intensities for both Pinnawala and Kithulgala Landslides

Threshold Rainfall Value	Warning
120 mm	Be on alert on the possibility of landslides.
160 mm	Danger of landslides and cut slope failure exists.
250 mm	Evacuate a safe place.

Similar analysis should be performed on all reported landslides where rainfall records are available. Then the more reliable threshold rainfall intensity values for each hazard level can be determined.

INVESTIGATING THE IMPACT OF CLIMATE CHANGE ON RAINFALL-TRIGGERED LANDSLIDES IN KEGALLE DISTRICT

L. Gunasinghe¹, L. Gunawardhana^{1,*}, C. Samarasuriya², A. Wijemanna³

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Department of Earth Resources Engineering, University of Moratuwa, Moratuwa

³ Meteorological Department, Sri Lanka

Landslides present a significant peril to lives and economies, notably in Asia where over 18,000 deaths and \$8 billion in economic losses occurred due to landslides from 1998 to 2017. These events stem from a range of factors, including steep terrain, geological features, and extreme rainfall. Rainfall, influenced by climate change, emerges as a key factor in increasing landslide vulnerability. The IPCC projects intensified rainfall and droughts due to global warming, heightening landslide risks. Recognising this, the study focuses on the Kegalle District, Sri Lanka, to investigate the impact of climate-induced shifts in rainfall patterns on landslide susceptibility. The findings aim to provide decision-makers with insights for proactive measures.

The Kegalle District in Sri Lanka, a landslide-prone area, has experienced an increase in landslides despite a history of fewer occurrences. The study used the HadGEM3-GC31-LL model from CMIP6 to project potential shifts in future rainfall patterns. The baseline period selected for analysis is 1975-2015, while two Shared Socioeconomic Pathways: SSP2-4.5 and SSP5-8.5 were considered for future projections. Statistical downscaling was performed using the Long Ashton Research Station Weather Generator, and missing values (0.2%) were filled using the Multivariate Imputation by Chained Equations method. Daily rainfall data from Ratnapura station was distributed across the study area (Figure 1) using the gridded Climate Hazards group InfraRed Precipitation with Station (CHIRPS) dataset (with a grid resolution of 5 km x 5 km). A Python code generated bias-correction factors for accurate future rainfall projections. Historical landslide events categorised by the NBRO in the 2016-2021 period were correlated with days of excessive rainfall to gauge susceptibility.

Figure 2 shows the average number of days with daily rainfall exceeding 73 mm during the 2016-2021 period. The minimum rainfall threshold for triggering past landslides was identified using NBRO data. The number of days above this threshold was used to define the range of days required for triggering landslides, slope failures, and cutting failures (Table 1). Figure 3 shows potential changes in these events from projected rainfall by SSP2-4.5 during the 2031-2060 period. Results show that the extreme category (4.2-6 days/year) expands throughout the catchment area in the future compared to the observational period. Similar effects were observed in different magnitudes for both SSP scenarios in two different periods (Table 2).

The findings of this research concluded that the rainfall effect on landslide susceptibility can be significant and that climate change effects could exacerbate the likelihood of landslides in the future. To enhance the accuracy of the analysis, it is recommended to incorporate additional landslide-triggering factors for the susceptibility analysis.

Keywords: Climate Change, Landslides, Downscaling, GIS, Disaster Management

* Correspondence: lumindang@uom.lk

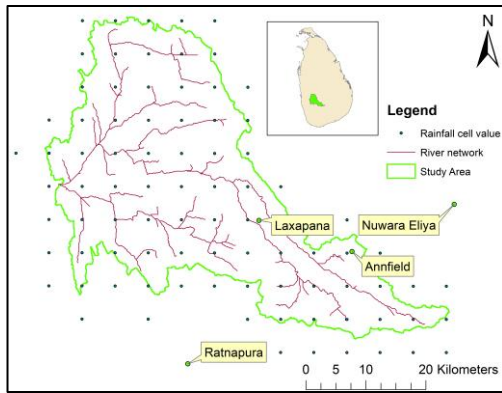


Figure 1: Study area and the coverage of CHIRPS data

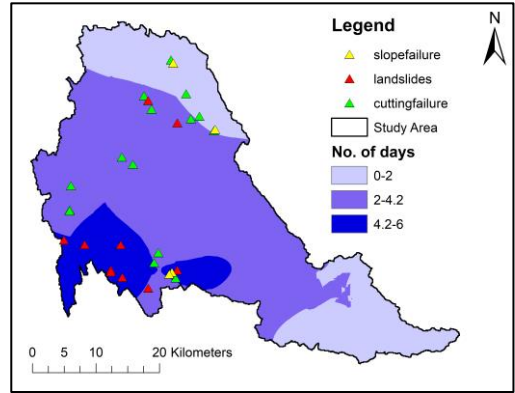


Figure 2: Distribution of the number of days exceeding the threshold

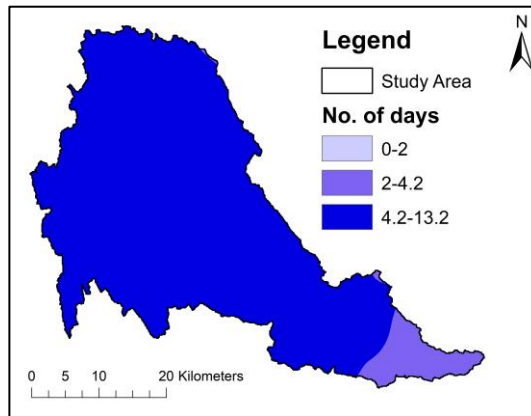


Figure 3: Distribution of the number of days exceeding the threshold for SSP2-4.5 (2031-2060)

Table 1: Accuracy of Results

Category	Number of events	Range of Days	Accuracy
Landslide	10	4.2-6	70%
Cutting Failure	15	2-4.2	60%
Slope failure	4	0-2	50%

Table 2: Comparison of Results

Scenarios	Observations	SSP2 (2031-2060)	SSP2 (2071-2100)	SSP5 (2031-2060)	SSP5 (2071-2100)
Area coverage of the extreme category (%)	12	94	100	100	100

OCCURRENCE OF EXTREME HYDROLOGIC EVENTS IN THE KELANI RIVER BASIN AND IMPACT OF CLIMATE CHANGE ON RIVER FLOW REGIME

H.K.A. Madhuranga ¹, R.L.H.L. Rajapakse ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Climate change is a severe and growing issue with visible and disproportionate impacts in many parts of the world. Recent studies state that climate change is occurring at a relatively faster and even more critical rate than previously expected. Climate consequences such as harsher heat waves, longer droughts, more frequent floods, increased sea level rise, and storm surges are already experienced worldwide. Climate change is expected to impact Sri Lanka through changes in rainfall patterns, sea level rise, and increased temperature. Climate change-related variations in temperature and rainfall patterns can result in more prolonged droughts and frequent floods. The IPCC's 6th Assessment Report on Climate Change states that the average global surface temperature is anticipated to increase, ranging from 1.1-1.8 °C, 2.3-3.6 °C, 3.3-4.7 °C, and 3.3-6.7 °C, 4.3-7.8 °C under SSP1, SSP2, SSP3, SSP4, and SSP5 scenarios, respectively, relative to 1986-2014 (IPCC, 2022). The Kelani River basin, which experiences yearly flooding, is one of Sri Lanka's most vulnerable basins (Dissanayaka & Rajapakse, 2019).

The study aims to evaluate how climate change may affect river flow change and the occurrence of extreme hydrologic events in the Kelani River basin. This study uses a hydraulic model to analyse river flow and precipitation data to identify extreme hydrological events and simulate river flow while considering the effects of extreme rainfall. The study also aims to determine future trends in river flow variation caused by climate change. Observed rainfall, streamflow, and Simulated Future Streamflow using GCM data were used to identify future trends of river flow variation due to climate changes based on the HEC-HMS hydrological modeling process.

The results revealed that the Hanwella sub-basin exhibits a variation in the range of -35.2% to 37.46% in the annual mean streamflow percentage under assumed climate change scenarios. This study also aims at developing quantitative estimates to handle the impacts of these extreme hydrological events, and flood events become more frequent when considered for SSP5 scenarios than SSP2 scenarios. The model results can be used to understand better catchment characteristics and its hydrologic response to rainfall under the impact of climate change scenarios. The return periods for floods in the Kelani River basin were calculated using the projected future data for both SSP2 and SSP5 scenarios. The results indicated a significant decrease in return periods, particularly in the SSP5 scenario, indicating that future flood events will occur more frequently. Applying the Gumbel distribution is appropriate for the frequency analysis of the Kelani River basin. This statistical method permits the analysis of extreme events and provides valuable insights into the frequency and magnitude of particular hydrological phenomena within the basin.

Keywords: HEC-HMS modeling, Runoff elasticity, Frequency analysis

* Correspondence: lalith@uom.lk

OCCURRENCE OF EXTREME HYDROLOGIC EVENTS IN THE KELANI RIVER BASIN AND IMPACT OF CLIMATE CHANGE ON RIVER FLOW REGIME

Introduction

- Climate change involves long-term temperature and weather variations, accelerating faster and more critically than anticipated
- Sri Lanka experiences altered rainfall, higher temperatures, leading to increased frequency of floods and droughts

Significance of Research

- Climate change causes more frequent floods and longer droughts, damaging infrastructure and risking lives
- Predicting extreme events helps proactive solutions for basic needs of community. Quantitative studies are vital for addressing river flow impacts
- Kelani River basin is highly vulnerable for frequent annual floods in Sri Lanka

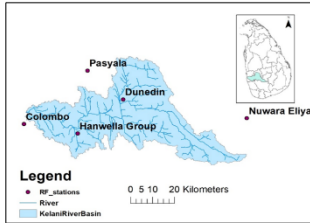


Figure 1: Kelani River basin

Objectives

To identify the impacts of extreme hydrologic events and identify mitigation measures in the Kelani River basin on river flow impending climate changes. For that following specified objectives were addressed

- To identify extreme hydrologic events related to river flow or precipitation
- To use a hydraulic model to simulate river flow with the effect of extreme rainfall
- To identify future trends of river flow variation due to climate change

HEC-HMS Model

- Governing equation in the HEC-HMS model is the water mass balance equation
- The HEC-HMS model is a versatile tool that can be utilized for a variety of flood-related investigations

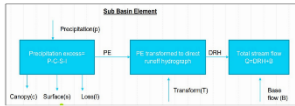


Figure 2: Governing equation in the HEC-HMS model

Frequency Analysis

- Flood frequency analysis utilizes historical data and statistical distributions such as Gumbel, Log-Normal, and Weibull to estimate future flood probabilities and magnitudes
- Gumbel distribution is preferred for extreme value analysis due to its accurate match with observed values

General Circulation Models (GCMs)

- General Circulation Models (GCMs) are computer-based mathematical models
- GCMs are essential tools for understanding past climate changes, studying present climate conditions, and making projections about future climate scenarios
- At every grid cell, GCMs resolve respective equations to compute temperature, precipitation etc.

Climate Scenarios

- The Shared Socioeconomic Pathways (SSPs) are a set of scenarios developed by the scientific community to explore different future trajectories of greenhouse gas emissions, land use, and socio-economic development (IPCC, 2022)

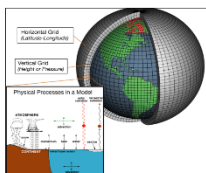


Figure 3: Physical process in a GCM (NOAA (climate.gov))

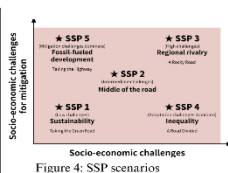


Figure 4: SSP scenarios (IPCC, 2022)

Result and Analysis

Calibration of HEC-HMS Model

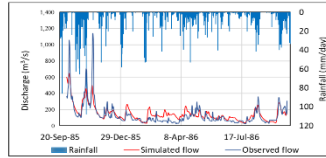


Figure 5: Hydrograph for calibration period for Hanwella sub-basin (1985/1986)

Validation of HEC-HMS Model

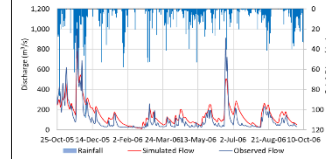


Figure 6: Hydrograph for validation period for Hanwella sub-basin (2005/2006)

Frequency Analysis for Future Predicted Data

- The future period is divided into short-term (2025-2040), mid-term (2041-2070), and long-term (2071-2100)
- Frequency analysis was performed for precipitation and streamflow data. For the SSP5 scenario, discharge values were much higher than observed, while for SSP2, they were slightly higher

Frequency Analysis for Discharge Under SSP2 and SSP5 Scenarios

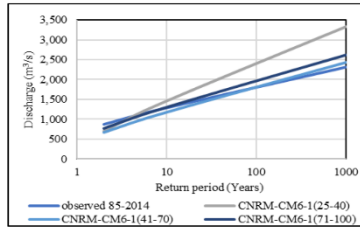


Figure 7: Frequency distribution of extreme events for Kelani River Basin under SSP2 scenario



Figure 8: Frequency distribution of extreme events for Kelani River Basin under SSP5 scenario

- Return periods for floods in the Kelani River basin were calculated using future data for SSP2 and SSP5 scenarios. Results suggest an increased frequency of future flood events

Table 1: The Return Periods for the extreme events under SSP2 and SSP5 scenarios

Date of Flood	Discharge (m³/s)	Return Period in Years According to Observed Data	Return Period in Years According to the SSP2 Scenario	Return Period in Years According to the SSP5 Scenario
06/05/1992	1,076	4	4	1
04/21/1999	1,282	10	7	1
11/22/2005	1,209	7	6	1
04/29/2008	1,408	17	9	1
06/01/2008	1,308	11	7	1
01/05/2016	1,630	25	12	2

Conclusions

- Flood frequency analysis shows that different climate change scenarios have distinct variations in precipitation and streamflow values according to their severity
- The Gumbel distribution is suitable for frequency analysis in the Kelani River basin, allowing analysis of extreme events
- Flood events are expected to increase under the SSP5 scenario compared to SSP2

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EVALUATING THE EFFECTS OF CLIMATE CHANGE ON HYDRAULIC GRADIENT AND LANDSLIDE SUSCEPTIBILITY IN THE KEGALLE DISTRICT

N. Wijayaweera¹, L. Gunawardhana^{1,*}, C. Jayaminda¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

Landslides are considered one of the recurrent natural disasters spread worldwide, causing significant property damages and fatalities. Hydraulic gradient is one of the triggering factors affecting landslide hazards. Depending on the material, landslide bodies can hold a significant amount of groundwater. The effect of the hydraulic gradient is discussed in terms of decreasing suction head, rising groundwater table, groundwater exfiltration from bedrock, and hydraulic uplift pressure below the landslide. Furthermore, Climate change causes changes in rainfall regime and evapotranspiration, which reduces the amount of water recharge aquifers. As a result, the hydraulic gradient increases resulting in groundwater flowing faster and being depleted more quickly. This dynamic maturity of the hydraulic gradient and its spatial variation can be estimated using a groundwater simulation model.

Kegalle district in Sri Lanka is listed as one of the highly vulnerable areas for landslides by the National Building Research Organisation (NBRO), Sri Lanka. Heavy rainfall generally occurs in the area during the southwest monsoon season, causing variably saturated soil conditions and reducing the shear strength. This study simulated the spatial distribution of hydraulic gradient in an area covering 1,523 km² using the United States Geological Survey (USGS) modular finite-difference flow (MODFLOW) model. The study area was divided into 4,148 active square grids with an approximate 70 m × 55 m grid resolution coverage. The area was conceptualised as a single-layer aquifer with an average depth of 200 m. The model's upstream and downstream sides were considered constant head boundaries, and their magnitudes were estimated by drawing equipotential lines using groundwater level data at nine observation wells in the study area. Annual total rainfall during the 2007-2017 period at the Holombuwa rain gauge station was used to estimate the groundwater recharge. The model was run in a steady state and the hydraulic conductivity, groundwater recharge, and river conductance parameters were calibrated using observations at nine wells. When projecting future rainfall, outputs from the CNRM-CM6-1-HR Global Climate Model (GCM) for two shared socioeconomic pathways (SSP3-7.0 and SSP5-8.5) were downscaled using the quantile mapping method to the local scale for the near-term (2020-2050) and the long-term (2070-2100) periods. The increase in the annual average rainfall for each scenario was calculated and the same percentage of change was assumed for groundwater recharge in estimating hydraulic gradient in the future.

Past events in the study area categorised as landslides, slope failures, and cutting failures recorded by the NBRO were obtained for the 2016-2021 period. These observed events were compared and matched with simulated hydraulic gradient distributions in the study area. A 60% match for the present period was observed between the landslide observations and the range of hydraulic gradient identified as critical. Future projections indicate a 0.03-1.57% change in landslide-susceptible areas with the greatest changes estimated for the SSP5 scenario.

Keywords: Disaster Management, MODFLOW, Groundwater, GCM, Climate Scenarios

* Correspondence: lumindang@uom.lk

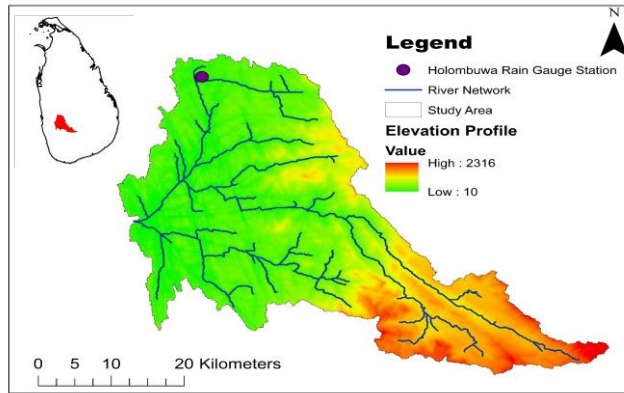


Figure 1: Study Area

Table 1: Rainfall Data

Period		Annual Mean Precipitation (mm)	Increase in Annual Total Rainfall (%)	Increase of Landslide Susceptible Area
Historical (1975 - 2014)		2,766	-	-
SSP 3-7.0	Near-Term Period (2020 - 2050)	2,843	3%	0.03%
	Long-Term Period (2070 - 2100)	3,104	12%	0.08%
SSP 5-8.5	Near-Term Period (2020 - 2050)	2,983	8%	0.05%
	Long-Term Period (2070 - 2100)	3,435	24%	1.57%

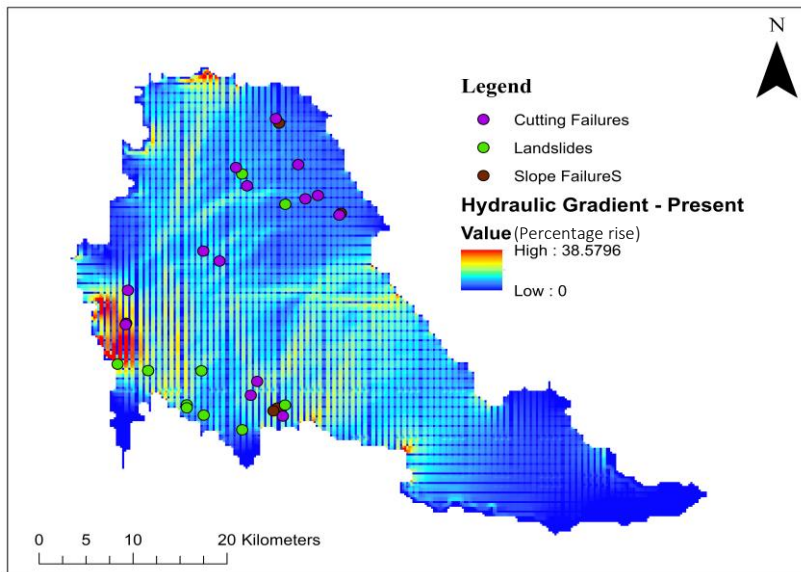


Figure 2: Relationship between Hydraulic Gradient and Landslide for the Base Line Period

EFFECTIVENESS OF IT APPLICATIONS ON CONSUMER COMPLAINT FOR IMPROVEMENT OF WATER SUPPLY: A CASE STUDY WITH CLUSTER ANALYSIS

G.D.P Fernando ¹, P.K.C De Silva ^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

One of the most significant concerns of humankind has been the provision of adequate quantities and quality of water. Unfortunately, modern water distribution networks are complex and challenging to manage due to increased levels of urbanisation, varying consumer demands, and limited resources. Therefore, authorities must make critical decisions to solve problems associated with different phases and time frames of water distribution networks. Most of the management issues are challenging to solve using conventional problem-solving techniques. One of the versatile approaches for solving these management problems is to use customer complaints to develop optimisation techniques. National Water Supply & Drainage Board (NWSDB) receives various complaints about their services. This thesis presents a case study on the Biyagama water supply scheme, focusing on analysing leakage occurrence in the pipeline network. The study utilised a dataset collected by the National Water Supply and Drainage Board (NWSDB) for three years. Aim is to investigate the factors influencing leak occurrence in the Biyagama water supply scheme and develop a comprehensive understanding of pipe network vulnerability, with the objective of informing targeted maintenance strategies and improving the overall reliability and efficiency of the water supply system. The primary objective was to investigate the factors influencing leakages in the network and develop a comprehensive understanding of pipe network vulnerability. The research employed the K-means algorithm, implemented using the Python programming language, to conduct a cluster analysis of the dataset. The analysis incorporated factors, including age, inner diameter, and hydraulic parameters, such as pressure and velocity, to identify patterns and correlations associated with leak occurrence. The cluster analysis results revealed that age physical characteristics and hydraulic parameters alone were insufficient to explain the variations in leak frequency among the clusters. To account for this, additional factors were considered, including pipe material, installation quality, maintenance practices, temperature, soil condition, traffic load and environmental conditions. Incorporating hydraulic parameters, such as pressure and velocity, provided valuable insights into the relationship between fluid dynamics and leak vulnerability. High fluid velocities also correlated with leak occurrence. The findings emphasise the complexity of pipe network vulnerability and highlight the importance of considering multiple factors in assessing leakage occurrence. By gaining a comprehensive understanding of the factors influencing leaks, stakeholders can develop targeted maintenance strategies and improve the overall reliability and efficiency of the water supply system. This research contributes to the field of water supply management by providing insights into the vulnerabilities of pipe networks and the factors influencing leak occurrence. The findings can inform decision-making processes for infrastructure maintenance and support the development of sustainable water management strategies.

Keywords: Water supply, Leakage occurrence, Cluster analysis, K-means algorithm, Pipe network vulnerability

* Correspondence: kasunds@uom.lk

Pipe ID	Inner Diameter(mm)	Age (Years)	Frequency (Leaks per 1 km)
3	83	12	5.49
4	83	12	4.06
5	58	12	38.64
10	198	12	1.66
12	102	12	6.55
23	58	12	12.83

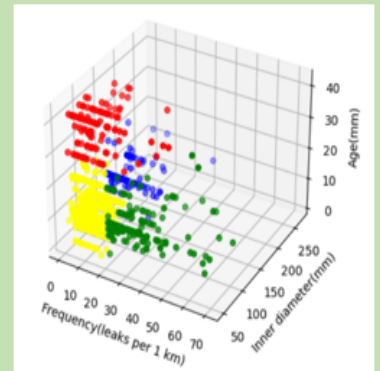
Sample of data

Pipe ID	Inner diameter(m)	Age(years)	Frequency (Leaks per 1 km)	Cluster number
3	83	12	5.49	3
4	83	12	4.06	3
5	58	12	38.64	1
10	198	12	1.66	2
12	102	12	6.55	3

Clustered data

Cluster No	Cluster Size	Inner Diameter(mm)	Age (years)	Leakage Frequency (leaks per 1 km)
0	117	76.84	37.44	12.23
1	184	69.45	12.52	30.89
2	105	165.3	11.59	8.58
3	839	70.85	11.87	9.07

Mean values of factors for each cluster



3D scatter plot of clustered data

Indicates expected and unexpected results.

Incorporate hydraulic parameters.

Cluster No	Cluster Size	Inner Diameter (mm)	Age (years)	Leakage Frequency	Pressure (m)	Velocity (m/s)
0	117	76.84	37.44	12.23	43.43	0.249
1	184	69.45	12.52	30.89	42.87	0.479
2	105	165.3	11.59	8.58	42.27	0.189
3	839	70.85	11.87	9.07	39.55	0.195

Velocity act as a critical factor explains reasons for some of the unexpected results.

Conclusion

unexpected results challenge traditional assumptions and highlight the complexity of factors influencing leak occurrence in pipe networks. Further research and analysis are necessary to delve deeper into these unexpected findings and comprehensively understand the underlying mechanisms.

ASSESSMENT OF TSUNAMI HAZARDS AND EXPOSURE OF SRI LANKA: CASE STUDY IN SOUTH-WESTERN COAST

U.A.M. Kanishka¹, A.H.R. Ratnasooriya^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

This research focuses on assessing the exposure of Sri Lanka's southwestern coast to tsunami hazards. Tsunamis are a series of ocean waves triggered by impulsive disturbances, such as undersea earthquakes, volcanic eruptions, landslides, and cosmic explosions. The catastrophic impact of tsunamis, as demonstrated by the devastating Indian Ocean tsunami (IOT) event in December 2004, underscores the urgent need for an effective early warning system to mitigate the loss of life and property in coastal regions.

The study specifically examines the vulnerability and exposure of the southern coastline ranging from Rathgama to Dadalla. The Community Model Interface for Tsunami (ComMIT) is used in the research's numerical simulation. Access to a precomputed tsunami scenario database and the MOST (Method of Splitting Tsunami) model created by the NCTR (National Center for Tsunami Research) is made possible through ComMIT, a user-friendly graphical interface. The model simulates tsunami waves with magnitudes ranging from 7.6 to 9.2 Mw, originating from selected unit sources along the Sunda trench in Indonesia and the Makran fault in Pakistan. The Sunda Arc is a volcanic arc that formed the islands of Java and Sumatra. Makran fault is located to the northwest off the coast of Pakistan. Makran trench is less affected relative to Sunda arc. For this research study five zones in Sunda trench and one zone in Makran fault are taken for segmentation of unit sources.

By combining the model's output with Green's law, the research calculates the maximum wave heights at a depth of 1 m. This data is crucial in identifying the levels of tsunami exposure along the coastal stretch. Furthermore, it enables the accurate projection of the exposure, facilitating the incorporation of lag-time effectively into early warning systems.

The findings of this study will contribute to enhancing the understanding of tsunami hazards in Sri Lanka and specifically the southwestern coastal region. Exposure assessment will aid in issuing timely and accurate warnings, minimising the potential for fatalities and injuries in future tsunami events. Ultimately, the research aims to improve disaster preparedness and enhance the resilience of coastal communities in Sri Lanka to mitigate the impacts of tsunamis.

Keywords: Tsunamis, Exposure assessment, ComMIT, Early warnings, Sunda trench

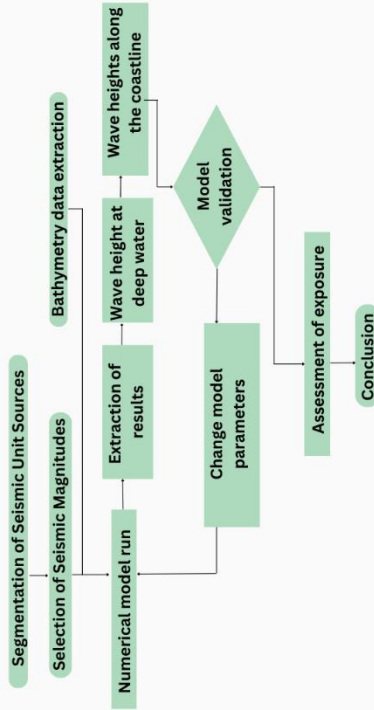
* Correspondence: ahrr@uom.lk

ASSESSMENT OF TSUNAMI HAZARDS AND EXPOSURE OF SRI LANKA: CASE STUDY IN SOUTH-WESTERN COAST

Objectives

- To study potential tsunami hazards along the selected coastline
- To analyze tsunami generation scenarios, unit source parameters and run a model for different scenarios
- To assess the exposure using the wave heights and establishing a database to the selected coastal area

Methodology



Earthquake Parameters for Modelling

Leonard (2010)

$$\log Mw = 2.5 \log(L) + 7.96$$

$$\log W = 0.667 \log(L) + 1.24$$

Hanks and Kanamori (1979)

$$Mw = \frac{2}{3} \log(Mo) - 6.1$$

Greenslade et al. (2011)

$$Mo = \mu L W uo$$

For Sunda trench, $\mu = 4.48 \times 10^{10} \text{ N/m}^2$

Mw = Moment magnitude

Mo = Seismic moment

L = Fault length

W = Fault width

μ = Shear modulus / Rigidity of Earth

uo = Slip of rupture

Segmentation of Unit Sources

For this study five zones in Sunda trench and one zone in Makran fault have been taken for segmentation of unit sources.

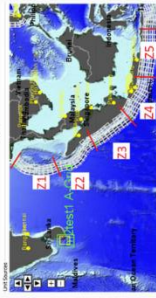


Figure 1: Unit source zones in Sunda trench

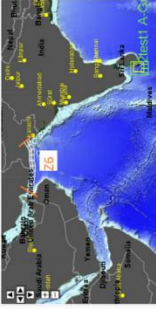


Figure 2: Unit source zones in Makran fault

Selected Locations

Table 1: Selected locations

Point	Depth (m)	Latitude (° N)	Longitude (° E)
1	-46	6.096	80.096
2	-44	6.058	80.108
3	-44	6.044	80.12
4	-49	6.025	80.131
1a	-75	6.045	80.068



Figure 3: Selected locations

- Focused on the assessment of tsunami exposure along Rathgama to Dadalla.

Exposure Assessment

Table 2: Exposure Level at Location 1

Moment magnitude	21	22	23	24	25	26
7.5	None	None	None	None	None	None
7.6	None	None	None	None	None	None
7.8	None	None	None	None	None	None
8.0	None	None	None	None	None	None
8.2	None	None	None	None	None	None
8.4	None	Low	None	None	None	None
8.6	None	High	None	None	None	None
8.8	None	High	Low	None	None	None
9.0	Low	High	High	Low	None	None
9.1	Medium	High	High	Medium	Low	None
9.2	High	High	High	High	Low	None

Table 3: Exposure Level at Location 2

Moment magnitude	21	22	23	24	25	26
7.5	None	None	None	None	None	None
7.6	None	None	None	None	None	None
7.8	None	None	None	None	None	None
8.0	None	None	None	None	None	None
8.2	None	None	None	None	None	None
8.4	None	Low	None	None	None	None
8.6	None	High	None	None	None	None
8.8	None	High	Low	None	None	None
9.0	Low	High	High	Low	None	None
9.1	Medium	High	High	Medium	Low	None
9.2	High	High	High	High	Low	None

Table 4: Exposure Level at Location 3

Moment magnitude	21	22	23	24	25	26
7.5	None	None	None	None	None	None
7.6	None	None	None	None	None	None
7.8	None	None	None	None	None	None
8.0	None	None	None	None	None	None
8.2	None	None	None	None	None	None
8.4	None	Low	None	None	None	None
8.6	None	High	None	None	None	None
8.8	None	High	Low	None	None	None
9.0	Low	High	High	Low	None	None
9.1	Medium	High	High	Medium	Low	None
9.2	High	High	High	High	Low	None

Table 5: Exposure Level at Location 4

Moment magnitude	21	22	23	24	25	26
7.5	None	None	None	None	None	None
7.6	None	None	None	None	None	None
7.8	None	None	None	None	None	None
8.0	None	None	None	None	None	None
8.2	None	None	None	None	None	None
8.4	None	Low	None	None	None	None
8.6	None	High	None	None	None	None
8.8	None	High	Low	None	None	None
9.0	Low	High	High	Low	None	None
9.1	Medium	High	High	Medium	Low	None
9.2	High	High	High	High	Low	None

NON-REVENUE WATER REDUCTION STRATEGIES FOR AN URBAN WATER SUPPLY SCHEME: A CASE STUDY FOR GAMPAHA WATER SUPPLY SCHEME

W. S. D. De Silva¹, A. H. R. Ratnasooriya^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

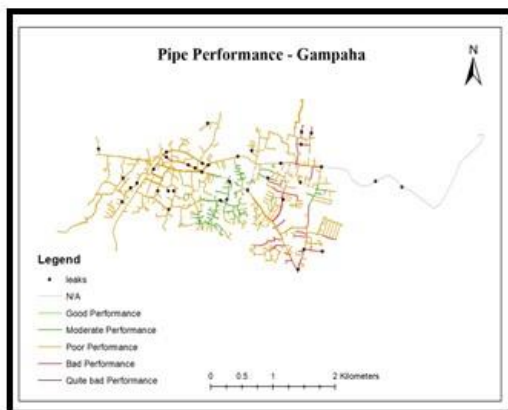
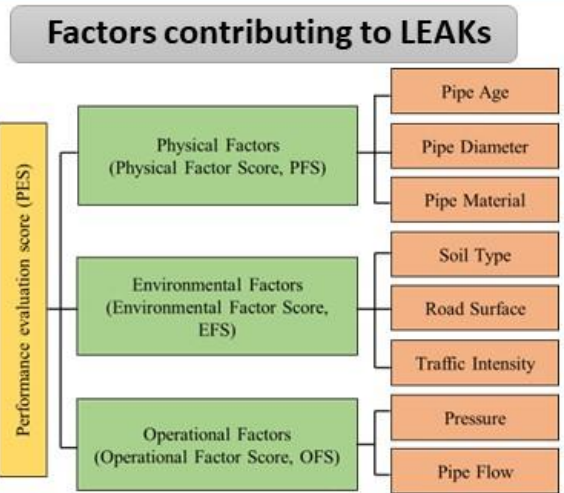
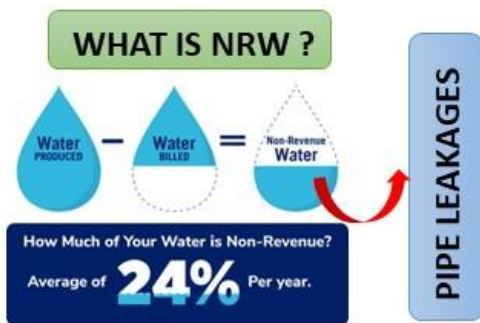
The urban water supply industry faces numerous challenges, including inadequate water supply relative to public demand, outdated infrastructure causing water loss, substandard services throughout the distribution process, and management and staff mindset towards service provision. Rapid urbanisation and population growth have further strained water resources and infrastructure, exacerbating these challenges. The presence of high levels of Non-Revenue Water (NRW), which encompasses both physical losses (leakages) and commercial losses (unauthorised consumption and inaccurate metering), further exacerbates these challenges, coupled with limited availability of funds for infrastructure improvement and maintenance. NRW poses a barrier to sustainability not only due to energy and water loss but also due to revenue loss for water utilities, impacting their financial viability. Therefore, this research aims to focus specifically on the issue of NRW to contribute to sustainable water management, addressing both environmental and economic concerns. The research objectives include not only exploring and discussing water losses in the transmission and distribution system but also analysing the socio-economic factors that contribute to NRW. By delving into the socio-economic aspects, the study aims to provide a holistic understanding of the issue, considering factors such as affordability, consumer behavior, and illegal water tapping. To accomplish these objectives, the study employs the Analytic Hierarchy Process (AHP), a widely recognised decision-making tool that allows for a structured evaluation of complex multi-criteria problems. By utilising AHP, the research assesses various factors contributing to pipe leakages and NRW. The AHP methodology enables the identification and prioritisation of key factors influencing pipe leakages, providing valuable insights for enhancing the performance and maintenance of water distribution systems. By identifying the factors contributing to pipeline leakage and NRW, proactive measures can be implemented to prevent and control leaks at an early stage, thereby shifting from a reactive to a proactive approach in water management. This transition will enable the industry to detect and address leakage issues more effectively, leading to improved overall water management and a reduction in NRW. The research also acknowledges the importance of public awareness campaigns and community engagement in reducing NRW, as informed consumers can play a crucial role in leak detection and reporting. The research focuses on the Gampaha Water Supply Scheme as a case study due to its relevance to the challenges faced by urban water supply systems in many developing countries. The findings of this research will provide practical recommendations for policymakers and water management authorities to optimise water supply systems, minimise losses, and enhance sustainability in urban water supply schemes. This research contributes to the ongoing discourse on sustainable urban water management by addressing the critical issue of NRW. Through these efforts, the research aims to pave the way for more resilient and efficient water supply systems that can cater to the needs of growing urban populations while minimising resource wastage and financial losses.

Keywords: Non-Revenue Water; Urban Water Distribution; Water Leakage; AHP Analysis

* Correspondence: ahrr@uom.lk

NON-REVENUE WATER (NRW) REDUCTION STRATEGIES FOR AN URBAN WATER SUPPLY SCHEME:

A CASE STUDY FOR GAMPAHA WATER SUPPLY SCHEME



Main factors	Weights (W _i)	Sub factors	Weights (W _j)
Physical	0.43	Pipe Age	0.68
		Pipe Diameter	0.14
		Pipe Material	0.18
Environmental	0.14	Soil Type	0.57
		Road surface	0.14
		Traffic Intensity	0.29
Operational	0.43	Max. Pressure	0.88
		Max. Flow	0.12

CONCLUSIONS: The model considered various main factors, including physical, environmental, and operational factors, as well as their corresponding sub-factors. Among the main factors, the physical and operational factors obtained the highest weight coefficient of 0.43, while the environmental factor had a coefficient of 0.14. High pressure values leads to leaks than other sub factors.

EFFECTIVENESS OF IT APPLICATIONS ON CONSUMER COMPLAINTS FOR IMPROVEMENTS IN WATER SUPPLY: A CASE STUDY WITH ANALYTIC HIERARCHY PROCESS

Chamath De Silva¹, L. Gunawardhana^{1,*}, Harsha Abeykoon²

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² National Water Supply & Drainage Board, Sri Lanka

Consumer complaints are crucial to improve the quality of any service. These complaints mean expressions of consumers' dissatisfaction with the services they receive. Not handling consumer complaints efficiently and neglecting the complaints can delay the service provider's work. On the other hand, successful attendance to these complaints helps to increase the reliability of the services and reduce negative attitudes of consumers, which in turn boosts the reputation of the service provider. In the context of the National Water Supply and Drainage Board (NWSDB), customer complaints have been instrumental in identifying pipeline leakages. The objective of this study is to identify the factors that affect leakages and, accordingly, develop a susceptibility map for the Biyagama area of the Gampaha district.

According to past studies, various factors contribute to leakages in water distribution networks, such as pipe age, diameter, pressure, length, and depth of placement. In this study, the United States Environmental Protection Agency Network Evaluation Tool (EPANET) was used to model the water distribution system in Biyagama area and analyse the hydraulic properties. Considering the qualitative nature of some of the influential factors, multi-criteria decision analysis (MCDA) was employed. The analytical hierarchy process (AHP), which is one of the MCDA techniques, was used to assess the significance of influential factors for pipe leakages. Actual weights for each factor were calculated and normalised. The AHP values were adjusted accordingly and compared with the actual leakage data to calculate the error margin. The weightages with the minimum error were selected for the susceptibility analysis. Accordingly, the analysis reveals the most vulnerable locations for pipe leakages and the importance of influential factors.

The AHP results indicated that the depth of placement, pressure, diameter, pipe length and the water velocity, in accordance with their significance, play a crucial role in identifying leakage locations. The analysis classified the study area based on level of susceptibility for low, moderate, and highly vulnerable classes. The results demonstrated that under highly vulnerable conditions, 415 predicted leakage points out of 2207 (19%) matched the actual leakage points. When considering both high and moderate categories, the accuracy rate was increased to 81%. The study was able to identify the critical areas of the Biyagama water distribution system to efficiently attend to customer complaints. The developed methodology can be applied in other areas of the country to act proactively, which lessens the maintenance cost and avoid or reduce impact of damages.

Keywords: Biyagama, Leakage, Susceptibility Analysis, Urban Water Distribution

* Correspondence: lumindang@uom.lk

A comparison of results between actual leakage points and AHP model simulations in Biyagama area

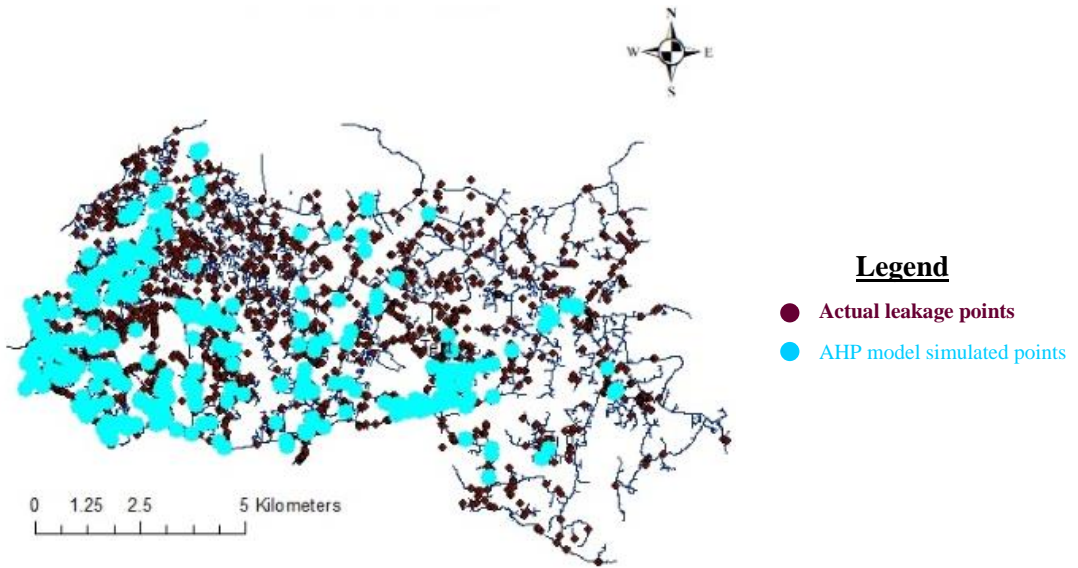


Figure 1: Model simulation under highly vulnerable category with a 19% accuracy level

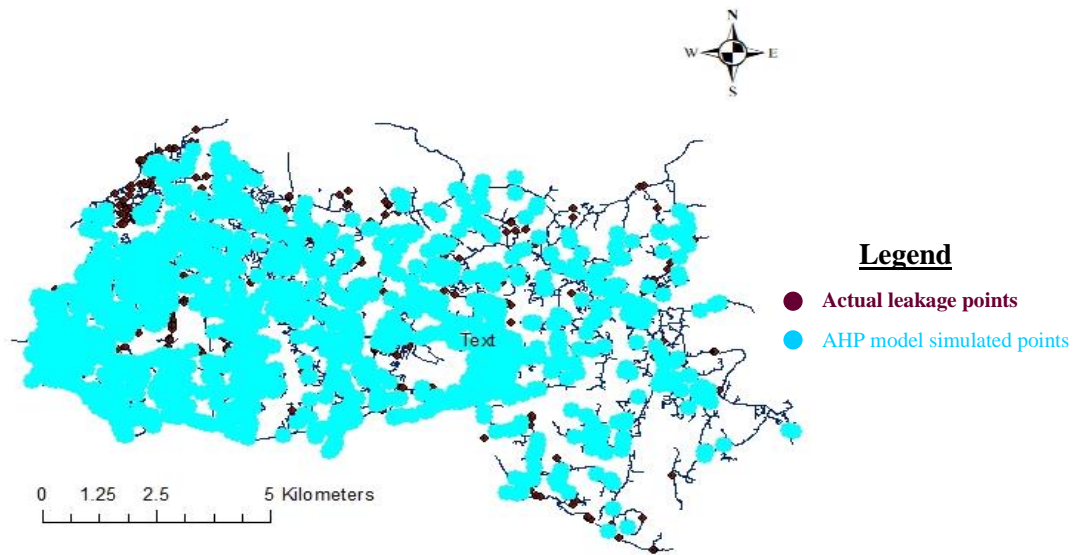


Figure 2: Model simulation under both high and moderately vulnerable categories with an 81% accuracy level

CRITICAL EVALUATION OF TRANSPORT SECTOR NDCS FOR A LOW-CARBON FUTURE

M.K.D. Aponsu¹, J.M.S.J. Bandara^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

The Nationally Determined Contributions (NDCs) of the transport sector have been recognised as one of the most effective measures to reduce greenhouse gas (GHG) emissions. This study aims to conduct a comprehensive and critical evaluation of the NDCs of the transportation sector in Sri Lanka to assess their effectiveness in achieving a low-carbon future. The first set of NDCs was implemented by the Mahaweli Development and Environment Ministry in 2016 and was subsequently submitted to the United Nations Framework Convention on Climate Change. In July 2021, Sri Lanka updated its NDCs, reflecting its ongoing commitment to combating climate change. This research aims to identify the gaps and limitations of current policy and to plan strategies and recommend effective strategies to support the sector's transition to a sustainable future. Through evaluation of the effectiveness of current NDCs, we can provide information on the country's progress toward achieving its climate goals. This research can provide valuable recommendations to policymakers and stakeholders to overcome these challenges and promote sustainable development in the transport sector. To prioritise NDCs, a set of criteria was developed based on research objectives and the specific needs of the transportation sector. These criteria served as a framework for subsequent analysis. A questionnaire survey was administered to gather information from transportation industry professionals and the general public regarding NDCs. The collected data was analysed using suitable statistical approaches, using the Statistical Package for the Social Sciences (SPSS) software as a tool. A list of essential NDCs for the transport sector was established using the prioritised criteria and the feedback obtained from the questionnaire survey. This list served as the basis for the subsequent evaluation and analysis of the identified NDCs. Finally, conclusions were drawn based on the evaluation and analysis regarding the significance and impact of the prioritised NDCs in the transportation sector. This study's results have helped increase awareness of the complexity of emission assessments in the transportation industry and have provided helpful information for planning and policy-making related to sustainable transportation. This research can provide valuable recommendations to policymakers and stakeholders to overcome these challenges and promote sustainable development in the Sri Lankan transport sector. In conclusion, implementing the proposed enhancements for the selected NDCs is crucial to effectively align Sri Lanka with the goals of the Paris Agreement within the designated time frame. Sri Lanka is particularly vulnerable to the impacts of climate change, underscoring the urgency and importance of taking decisive action. It is imperative to prioritise and address the identified issues to mitigate risks, enhance resilience, and contribute to global efforts in combating climate change. By proactively addressing these challenges, Sri Lanka can create a sustainable and climate-resilient future.

Keywords: Nationally Determined Contributions (NDCs), Transportation sector, Greenhouse Gas emission, Low – Carbon future, Evaluation of NDCs

* Correspondence: bandara@uom.lk

CRITICAL EVALUATION OF TRANSPORT SECTOR NDCs FOR A LOW-CARBON FUTURE

Transportation sectors Nationally Determined Contributions :

Table 1 : Recently updated Nationally Determined Contributions of transport sector

NDC #	NDC Action	Timeline
NDC 1	Transport sector system improvement	2021 - 2030
NDC 2	Promote public passenger transport	2021 - 2030
NDC 3	Shift freight to efficient modes	2021 - 2030
NDC 4	Rapid transport for passenger transport	2021 - 2030
NDC 5	Promote non-motorized transport modes	2021 - 2030
NDC 6	Introduce taxes and other instruments to promote public transport	2021 - 2030
NDC 7	Introduce inland water transport modes	2021 - 2030
NDC 8	Modernizing and upgrading of suburban railway	2021 - 2030
NDC 9	Promote electric mobility and hybrid vehicles	2021 - 2030
NDC 10	Improve vehicle fleet efficiency	2021 - 2030
NDC 11	Road infrastructure development	2021 - 2030
NDC 12	Reduce GHG emissions from the marine sector	2021 - 2030
NDC 13	Generic enabling activities	2021 - 2030

- The research evaluates NDCs related to passenger transport in the road and rail sectors in Sri Lanka
- The analysis deliberately excludes the freight and marine transportation sectors.
- NDC 01, which covers the entire transportation system, was excluded from the prioritization process.
- From this point onwards, the evaluation will continue for the following nine NDCs.
- Table one shows the selected NDCs for evaluation. Red text indicates eliminated NDCs.

Multi-Criteria Analysis of Transportation Sector NDCs

Table 2 : Selected criteria and weightages for Multi Criteria Analysis

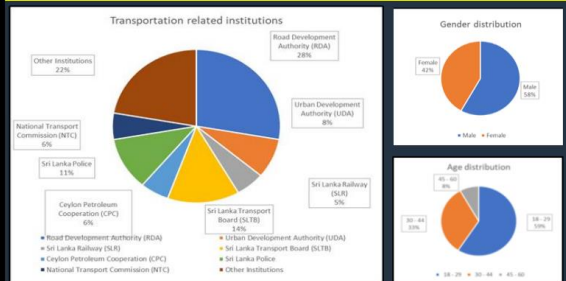
Criteria	Measuring Attribute	Weightage
Desirability Criteria	User Population	10%
	Passenger Kilometres	15%
Feasibility Criteria	Cost-effectiveness	12.5%
	Implementation time	12.5%
Co - Benefit Criteria	Environmental Benefits	20%
	Social Benefits	30%
	Total	100%

Table 3 : Significance Level Scores

Significance	Score
High	4
Moderate	3
Low	2
None	1

- The multi-Criteria Analysis method was used to prioritize the selected NDCs in line with best practices in this investigation.
- These weightages assigned as a demonstration method. Weightages can be change and check the sensitivity as well.

Questionnaire Survey on NDCs in the transport sector



- Survey included individuals working in the transportation industry as well as the general public.
- Total of 98 responses were collected, with 57 responses from male and 41 from female. Among the respondents, 36 were professionals in the transportation.

Evaluation of transport sector NDCs

- The Multi-Criteria Analysis (MCA) scoring process involved referencing the available data, and ranking was established.
- The questionnaire survey was analyzed in two cases: Case 01, which included all responses, and Case 02, which focused on responses from transport sector professionals.
- Conducted statistical analysis using SPSS software. Utilized Friedman tests for determining mean rankings
- Table 5 will display the ranking of criteria for each NDC, indicating their relative importance based on the responses within the context of the NDC.
- There are three selected NDCs were evaluated and proposed suitable enhancements.

Table 4 : Prioritization of NDCs in MCA and Questionnaire surveys

NDC Number	MCA rank	QS rank (Case 1)	QS rank (Case 1)
NDC 02	05	04	05
NDC 04	07	05	07
NDC 05	09	03	02
NDC 06	06	08	03
NDC 08	08	02	06
NDC 09	01	01	01
NDC 10	02	07	04
NDC 11	03	06	09
NDC 13	03	09	08

Conclusions

- In conclusion, implementing the proposed enhancements for the selected NDCs is crucial to effectively align Sri Lanka with the goals of the Paris Agreement.
- Discrepancies attributed to the need for a well-defined framework in designing NDCs
- Absence of established baseline scenarios for some NDC action
- Sri Lanka requires assistance in improving emission data availability and implementing a robust monitoring system.
- Inadequate coordination among transport sector institutions.
- Low public awareness of NDCs in Sri Lanka highlights the need for targeted awareness programs.



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BOOK OF ABSTRACTS

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