Proceedings of the

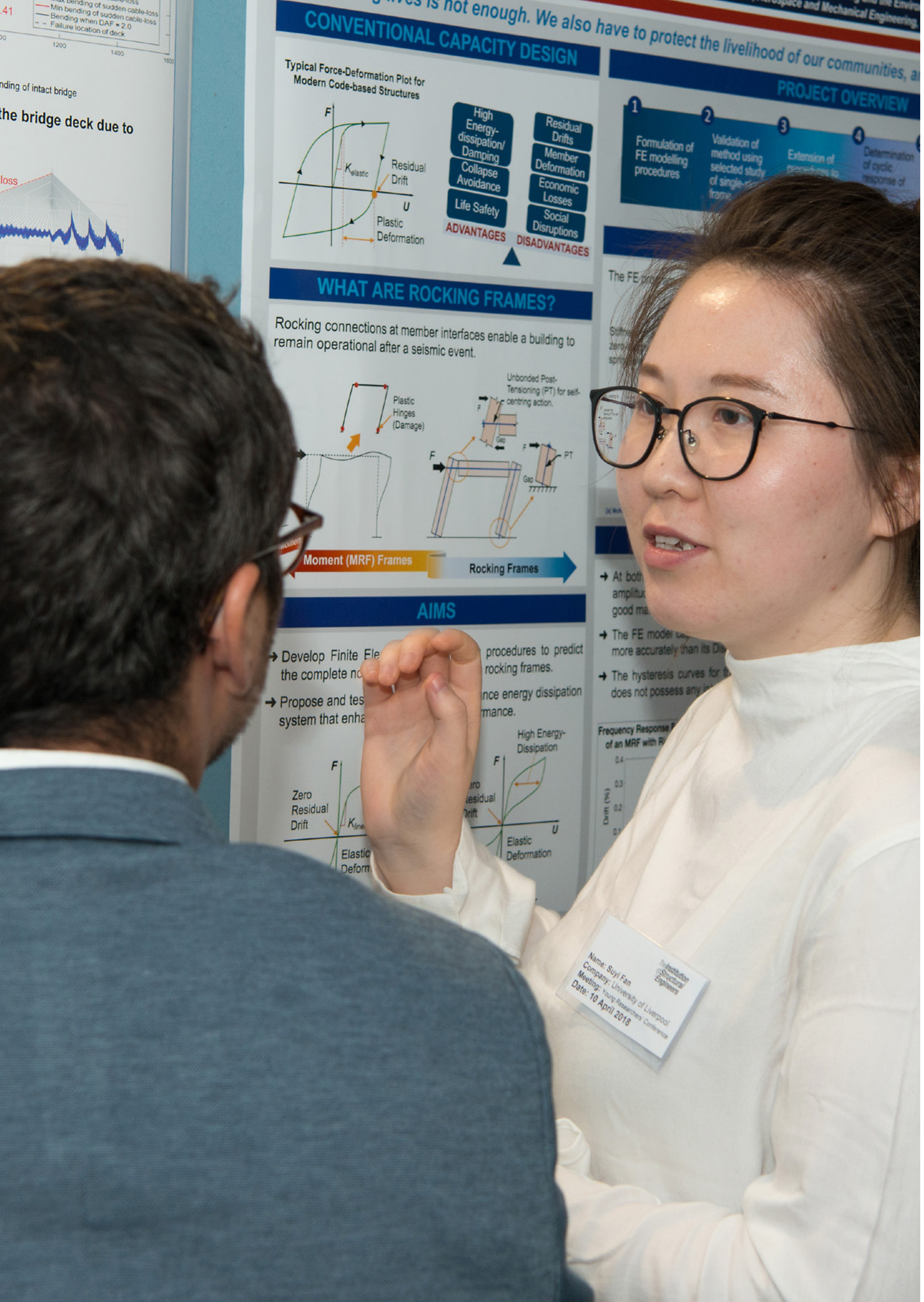
27th Young Researchers Conference

20th March 2025

The Institution of StructuralEngineers

Contents

Synopses



Conference Programme – 20 March 2025

Time	Agenda	Persons
13:00	**Welcome**	Chair: Dr Pete Winslow, Chair of the Research Panel and Director, Expedition Engineering
13:05	Keynote Presentation	**Research-informed structural engineering – a RAAC case study** Chris Goodier, Loughborough University and Andrew Rolf, Mott Macdonald
13:35	Presentation 1 + Q&A	**Structural Performance and Finite Element Analysis of 3D-Printed Concrete Benches** – Rui Luo, National University of Singapore
13:50	Presentation 2 + Q&A	**Design and conceptualization of reusable concrete slab segments** – Benedikt Strahm, University of Stuttgart
14:05	Presentation 3 + Q&A	**Push-out tests on stainless steel composite beams** – Rebecca Presswood, University of Southampton
14:25	**Break**	
14:35	Presentation 4 + Q&A	**Web Crippling Behaviour of Web-Perforated Cold-Formed Steel, Stainless Steel and Aluminium Sigma Sections** – Hasini Weerasinghe, University of Sri Jayewardenepura/ Northumbria University
14:50	Presentation 5 + Q&A	**A Hybrid Digital Twin Framework for Real-Time Structural Damage Identification Using Physics-Based Models and Deep Learning** – Shady Adib, University of Newcastle
15:10	**Poll to audience**	Chair: Dr Pete Winslow
15:15	Guest speaker:	**The Wind-Induced Vibration Response of Modular High-Rise Buildings** – Hollie Moore and Dr John Hickey (Trinity College Dublin)
15:30	Guest speaker:	**CalcinX: Development journey from concept to reality for low carbon calcined clay** – Allistair Wilkinson, CEMCOR Ltd
15:45	**Bridging the gap between industry and research: perspectives on future research areas**	Ailsa Roberts, Expedition Engineering
16:00	Certificate, prize giving	Prof John Forth – Head Judge, and Fernando Madrazo-Aguirre – Head Poster Judge
16:15	Closing comments	Chair: Dr Pete Winslow
16:20	**Conference ends**	

To note: the programme is subject to change.

Poster presentations

Flexural behaviour and design rules for modular construction optimised beams with unstiffened circular web openings *(Synopsis 5)*
Jack Lifsey – Northumbria University, UK

Further study on the preparation of a resistance formula for net-tension failure of single and multi-rowed bolted connections of fibre-polymer composites *(Synopsis 14)*
Abdul Mahboob Samsor – Kingston University, UK

Flexural behavior and design rules of cold-formed steel Double sigma sections *(Synopsis 4)*
Drew Gray – Northumbria University, UK

Graphene-Enhanced Fabric Reinforced Cementitious Matrix (FRCM) Composite and Its Effects on Impressed Current Cathodic Protection (ICCP) and Structural Strengthening (SS) for Reinforced Concrete (RC) Beams *(Synopsis 7)*
Xiaoming Zhu – University of Manchester, UK

Particle-based DEM modelling of masonry under compressive loading *(Synopsis 6)*
Kanaeshvarr Devanand – University of Birmingham, UK

Development of Advanced Steel Modular Connections for Sustainable Modular Construction *(Synopsis 13)*
Kajeenthan Kamalaseen – University of Peradiniya, Sri Lanka

Keynote Speakers

Chris Goodier

Chris is a Professor in Construction Engineering and Materials and a member of the Senior Leadership Team for the School of Architecture, Building and Civil Engineering at Loughborough University. He currently leads the NHS-funded RAAC national research project, and is a founder member of the IStructE RAAC Study and the CLC RAAC Industry Response Groups. He has produced RAAC-related CPD webinars for the IStructE, RICS, CIOB and the Concrete Society, and his RAAC work has been featured on the BBC, Sky, and ITV, and in all national newspapers.

Andrew Rolf

Andrew has worked and studied in the field of engineering for the past twenty-seven years. Andrew is Chartered Structural Engineer and a Conservation Registered Engineer (CARES) with significant experience in the restoration and refurbishment of existing buildings. Andrew sits on the Institution of Structural Engineers Reinforced Autoclaved Aerated Concrete (RAAC) study group and risk assessment sub-group. He has presented on RAAC to clients teams, surveyors and engineers.

Research Panel

The Institution of Structural Engineers' Research Panel comprises members from both industry and academia, and has the primary role of supporting, facilitating and directing research in Structural Engineering. The Research Panel, through its members and sponsors, as well as through its links with the local regional groups of the Institution and Institution Liaison Officers in Universities, aims to promote the effective dissemination and application of research, attract young people to research careers and liaise with other organisations with an interest in research. The Research Panel also engages with 'Structures', the Research Journal of the Institution of Structural Engineers, by judging papers for awards.

Through its Research Fund, the Panel are responsible for several research grant, award scheme and competitions, including the assessment of applications, the assignment of funds, the judging of deliverables and the award of prizes. The research grant and award schemes are as follows:

- Undergraduate Research Grant scheme
- MSc Research Grant scheme
- Research Award scheme
- Research into Practice Case Study Competition

The Research Panel has introduced the Industry Focussed Research Challenge which means that research funding, available through the Institution's established schemes, can be focussed on research that is well aligned with the current challenges faced by the profession. Applications through the established schemes that address the priorities of the industry focussed research challenge receive additional credit in the initial selection of grant winners. However, grants can still be awarded to high quality applications on other topics.

The challenge is built around **research themes** that aim to encourage and facilitate collaboration between industry and researchers and are designed to better align research with the needs of industry and should be considered in the broader context of the climate emergency. Full details of current themes are available here and are given below:

- Construction materials
- Loading on buildings
- Global Solutions
- Systems and resilience thinking
- Digital engineering

The Research Panel also suggests to review the climate emergency research and development priorities outlined in Structural engineering innovation for a zero-carbon world: an R&D agenda to match the carbon budget, by Winslow et al.

More information on the Research Fund can be found at: Research Fund - The Institution of Structural Engineers (istructe.org)

The Young Researchers' Conference was instigated by the Research Panel to provide PhD students and young researchers with an opportunity to present their work to an audience of peers and industry professionals, and to exchange ideas and experiences with fellow researchers. The Panel assesses the applications submitted to the conference and judge the presentations on the day.

Dr Pete Winslow
Research Panel Chair

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Conference Team

Presentation Selection Panel:

Dr Rabee Shamass – *Brunel University*
Livia Garcia – *Rail Safety and Standards Board*
Dr Jason Ingham – *University of Auckland*

Judging Panel:

The judging panels are formed from eligible members of the Research Panel.

Prof. John Forth – *University of Leeds*
Dr Donya Hajializadeh – *University of Surrey*
Dr Gary Robinson – *Ridge and Partners LLP*
Dr Ross Johnston – *Amphora Consulting*

Fernando Madrazo-Aguirre – *COWI*
Dr Michaela Gkantou – *Liverpool John Moores University*
Dr Mohammad Mollazadeh – *DeSimone Consulting Engineers*
Zhiquan Ding – *CCCC-FHDI Engineering Co. Ltd*
Dr Matthew Poulton – *COWI*

IStructE Support:

Jane Black – *Head of Technical Secretariat Services*
Rebecca Cohen – *Secretariat Executive*
Zhixi Gu – *Training and Events Coordinator*
Brigette Long – *Digital Marketing Manager*

Research into Practice Case Study Competition 2024 winners

Dr Hollie Moore

Dr Hollie Moore is a Teaching Fellow at Trinity College Dublin, specializing in structural dynamics and modular construction. During her PhD, conducted in collaboration with TCD and Barrett Mahony Consulting Engineers, she focused on bridging the gap between research and practice. Her work involved the in-situ monitoring of Europe's tallest volumetric modular buildings, leading to the first reported damping ratios of high-rise modular structures. At this conference, she will discuss her novel findings and their implications for the future of modular construction.

Dr John Hickey

Dr John Hickey is an Assistant Professor in Structural Engineering at TCD. He completed his PhD at TCD in structural engineering in 2019 under the supervision of Professor Brian Broderick. He then joined the Dynamics and Vibrations research group at the University of Cambridge, where he worked as a Research Associate for three years. He returned to TCD in 2022 as a Teaching Fellow and was appointed Assistant Professor in 2023. He has been conducting research examining the vibration serviceability of tall modular buildings alongside engineers from BMCE since 2018.

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Research Panel members

Dr Pete Winslow

PhD, CEng, MIStructE

Pete obtained his PhD from the University of Cambridge in 2009 and is now a practicing structural engineer and R&D lead, sitting on the executive board of Expedition Engineering and the Useful Simple Trust. He played key roles in designing the pioneering ferrocement solar canopy for the Stavros Niarchos Cultural Centre in Athens and the Stockton Infinity footbridge. He was in the engineering team for the award-winning London 2012 Velodrome and has experience across a range of unusual and special structures: from the acoustically-sculpted Soundforms shells to HS2 Old Oak Station Roof design. Pete is actively involved in a portfolio of R&D programs and innovation consultancy, working with universities, industry and several major infrastructure clients to bring research into practice: seeking to deliver tangible benefits with a particular focus on the climate emergency and carbon reduction.

Professor John Forth (Vice-Chairman)

PhD, CEng, MIStructE

John is the Chair of Concrete Engineering and Structures in the School of Civil Engineering at the University of Leeds and Director of the Neville Centre of Excellence in Cement and Concrete Engineering. He was awarded his first degree, a BEng (Hons) in Civil and Structural Engineering from the University of Sheffield and received his PhD from the University of Leeds. As a Chartered Member of the Institution of Structural Engineers, he is on several Technical Committees (i.e. Eurocodes, fib, RILEM) in the European Union. His research interests include serviceability, durability and the dynamic performance of reinforced concrete and masonry structures.

Dr Jason Ingham

BE(Hons), ME(Dist), PhD, MBA, F.EngENZ, FIStructE

Jason obtained his doctorate from the University of California San Diego in 1995 and is a Professor of Structural Engineering and Deputy Dean in the Faculty of Engineering at the University of Auckland. His research interests are primarily focused on the seismic behaviour of existing masonry and concrete buildings. Jason led the collection of data related to the performance of masonry buildings following the Canterbury earthquakes and has also undertaken post-earthquake building inspections in Sumatra (Indonesia) and in Nepal. He is a past president of the Structural Engineering Society of NZ (SESOC), a past president of the NZ Concrete Society (NZCS), a past member of the management committee of the NZ Society for Earthquake Engineering (NZSEE) and is a Fellow of Engineering New Zealand. Research led by Jason contributed significantly to the development of the New Zealand methodology for detailed seismic assessment of unreinforced masonry buildings.

Fernando Madrazo-Aguirre

PhD, DIC, CEng, MICE

Fernando is an Associate in COWI's London office working in the design and assessment of bridges and special structures. He has contributed to infrastructure projects including the maintenance of West Gate Bridge in Australia and the 1915 Çanakkale Bridge (the new world record suspension bridge with a main span of 2023m) in Turkey, as well as to smaller scale footbridge competitions, and has led engineering teams in projects like High Speed 2. He completed his PhD on under-deck cable-stayed bridges at Imperial College London, where he currently holds the role of Visiting Design Fellow and is involved in undergraduate teaching.

Professor Ahmer Wadee
PhD, ACGI, DIC, CMath, CSci, FIMA, MASCE

Ahmer is Professor of Nonlinear Mechanics at Imperial College London. He is an internationally-leading expert on structural instability and has published some 200 articles in the scientific literature. In 2014, he was listed as one of the UK's top 100 practising scientists by The Science Council. He is Editor of the international journal "Thin-Walled Structures" and also serves on the editorial board of the institution's research journal "Structures". He is a Fellow of the Institute of Mathematics and its Applications, a Chartered Mathematician, a Chartered Scientist, a Member of the American Society of Civil Engineers (ASCE), and served as Chair of the ASCE Engineering Mechanics Institute Stability Committee from 2017-19

Yancheng CAI
PhD, CEng, FICE, MIStructE, MASCE, MHKIE

Dr Yancheng CAI holds the Assistant Professor position in the Department of Construction and Quality Management at Hong Kong Metropolitan University, Hong Kong. He received his PhD degree from The University of Hong Kong in 2013. He then worked in the engineering industry for a few years before he returned to the university in 2016. He is a Chartered Engineer and Fellow of the ICE, member of the IStructE, UK, member of Hong Kong Institution of Engineers (HKIE) and member ofAmerican Society of Civil Engineers. He received the Grand Prize of the HKIE Innovation Awards for Young Members in 2018 and, the "Commendation Merit --- R&D Award by Joint Structural Division of Structural Division of HKIE and the IStructE in 2017. His main research areas include steel structures, structural stability, connections and joints, structural fire resistance and composite structures.

Professor P.A. Muhammed Basheer, CBE FREng
PhD, DSc, FIAE, FICE, FIStructE, FACI, FICT, FIAAM, CEng, FIMMM, FRILEM

Basheer, as he is known, is Chair in Civil Engineering and Executive Dean of the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University, Edinburgh. Formerly he was chair in Structural Engineering and Head of School of Civil Engineering at University of Leeds, UK. He has been an educationalist and researcher in the field of civil (structural) engineering for nearly 40 years. Basheer has secured research income in excess of £19 million, supervised more than 35 PhDs to successful completion and published nearly 440 refereed technical publications. He has received numerous awards/ prizes for his contributions to research, including a lifetime achievement award from the Civil Engineering Research Association of Ireland, CANMET/ACI award for his sustained contributions to the field of concrete technology and the Callendar prize from the Institute of Measurements and Control for developing test apparatus for the construction industry. In 2012, he was elected to be a Fellow of the Irish Academy of Engineering and in 2014 he was elected to be a Fellow of the Royal Academy of Engineering. He is also a Fellow of the Institution of Civil Engineers, Institution of Structural Engineers, American Concrete Institute, Institute of Concrete Technology, Institute of Materials, Minerals and Mining, RILEM and International Association of Advanced Materials. HM King Charles III bestowed him with the Commander of the Order of the British Empire (CBE) in July 2023 for his services to civil engineering.

Eva Gaal
MBA MSc CEng MIStructE

Eva is the Principal Engineer of the Innovation Team at NHBC. She received her MSc degree in Structural Engineering from the Budapest University of Technology and Economics in 2003, and she was awarded an MBA from Oxford Brookes University in 2010. She has been a Chartered Member of the IStructE since 2010. Before joining NHBC in 2016 she worked as a structural design engineer on various industrial, commercial and residential projects. Recognising the need of NHBC to embrace Modern Methods of Construction Eva was key member in setting up the NHBC Accepts service. Under this scheme her team is responsible for assessing Innovative Products and Prefabricated Building Units and assisting Manufacturers and Products Owners to develop and establish innovative

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products and construction methods acceptable to use in the UK construction market. Also her team is working in collaboration with NHBC Foundation to publish research papers for the industry.

Professor Zhenjun Yang
FIStructE, CEng, PhD, BEng

Zhenjun is a Professor in Structural Engineering and Computational Mechanics at Wuhan University, China and a Fellow of IStructE (since 2017). He has over 25 years of academic experience in a few UK (Coventry, Manchester and Liverpool) and China universities (Zhejiang). His main research interest is multiscale experiments and modelling of damage and fracture of concrete, fibre reinforced concrete (FRC) and polymers (FRP), in a view to optimise structural integrity, reliability and sustainability. He has secured over £3m research grants as PI from EPSRC UK and NSFC China etc and published over 120 SCI-indexed journal papers with 5600+ SCI citations and H index=39. He currently serves as an editorial member of 4 international journals (including associate editor of Structures), and has supervised over 30 PhD awardees and PDRAs. He has been listed in Elsevier's Highly Cited Chinese Scholars in Civil Engineering and Stanford University's World Top 2% Scientists, both continuously in last four years (2021-2024).

Professor Brian Uy
BE (Hons 1), PhD, CPEng, CEng, PE, IntPE (Aus), NER (Civil & Structural), FTSE, FRSN, FIEAust, FICE, FIStructE, FASCE, FSEI, FIABSE

Brian Uy is Scientia Professor of Structural Engineering at the University of New South Wales and Honorary Professor of Structural Engineering at the University of Sydney. He is the Chairman of the Standards Australia Committees BD-032 on Composite Structures for Buildings and BD-090-Part 6 on Steel and Composite Structures for Bridges. He is President-Elect and Vice President (Australasia and Southeast Asia) of The Institution of Structural Engineers and Vice President of the International Association of Bridge and Structural Engineering.

Tony Jones
PhD, CEng, FICE, FIStructE

Tony is a Structural Engineer with over 30 years of experience in design, research and investigation of concrete structures. Tony is currently Technical Director at MPA The Concrete Centre. He provides guidance on all aspect of structural concrete design including performance in fire. Tony has been involved with the production of numerous industry guides and has been involved with the development of concrete structural codes for over 20 years. He is currently the UK Head of Delegation on the European design committee, which is responsible for Eurocode 2, Design of Concrete Structures, including the fire part.

Dr Bahman Ghiassi
BSc, MSc, PhD, FHEA, MIStructE, CEng

Dr Ghiassi is an Associate Professor of Sustainable Infrastructure Materials and a Chartered Structural Engineer (MIStructE, CEng) in the School of Engineering at the University of Birmingham. He obtained his PhD in 2013, held two postdoctoral fellowships from 2014 to 2018 (including a Marie Curie Fellowship at the Technical University of Delft), was appointed as Assistant Professor of Structural Engineering at the University of Nottingham in 2018 and then joined the University of Birmingham in 2022 as an Associate Professor. His research centres around sustainable construction materials with the main focus on innovative alternative cements, cement-based composites, masonry and waste-based materials. In 2019, he was awarded the RILEM Gustavo Colonetti medal for his "outstanding scientific contribution to the field of construction materials and structures". Dr. Ghiassi is the author of more than 180 peer-reviewed scientific articles in reputable journals and international conferences. He has given several invited talks and keynote lectures and is an active member of international scientific committees including Chapter lead and Experimental Round Robin Testing Workgroup leader in the RILEM Technical Committee 290-IMC (Durability of inorganic matrix composites used for strengthening of masonry structures). He also sits in the editorial board of a number of journals including the ICE Journal of Construction Materials, Nature Scientific Reports, ASCE Journal of Composites for Constructions and International Masonry Society Journal.

Dr Donya Hajializadeh

BEng (Hons), MEng, PhD, CEng MICE, MIEI, EUR ING, MWES, FHEA

Donya is a Chartered Engineer, Associate Professor and Director of Employability in Civil and Environmental Engineering at the University of Surrey, with over a decade's experience in structural and bridge engineering, specialised in building direct and indirect damage identification and structural health monitoring systems, resilience, risk, reliability (3R) assessment of transport infrastructure, infrastructure interdependency assessment and building performance-based digital twins. Her recent work on a scaled and practice-based feasibility study for an indirect damage detection system received 2022 DfT's Chief Scientific Advisor's 'Innovative Solution'. Donya has contributed to diverse projects, from implementing virtual real-time load and load effect monitoring concepts to developing service life assessment tools for road and rail bridges across Europe.

Dr Rwayda Al-Hamd

B.Sc., M.Sc., PhD, FHEA

Rwayda is a lecturer in civil engineering at Abertay University. Rwayda's research focuses on the resilience of structures. Her research goals are accelerating the building of climate-proof structures and developing sustainable construction materials that meet the current market need for net-zero construction. Her fundamental interest is how structures react to extreme loading conditions like fire and floods: her resilient and sustainable infrastructure research expertise bridges modelling, experimental work, machine learning, and data-driven analysis.

Professor Tai Thai

PhD, FIEAust, CPEng, MIStructE

Tai is an ARC Future Fellow (also former ARC DECRA Fellow) and Professor of Structural Engineering at the University of Melbourne. He is a member of Standards Australia Committees BD23 on structural steel and BD32 on composite structures (responsible for drafting Chapter 5-Design of Composite Joints of composite standard AS/NZS 2327). With a combined expertise in structural engineering and computational mechanics, his research mainly focuses on developing structural systems and computational tools for advanced design of buildings, bridges and other infrastructure with an emphasis of safety, sustainability and resilience.

Michaela Gkantou

Meng, MSc, PhD, CEng, MICE, MIStructE, FHEA

Michaela obtained her PhD from the University of Birmingham in 2017 and is now a Reader in Structural Engineering at Liverpool John Moores University. She is committed to teaching both at undergraduate and postgraduate level. Her research interests are primarily focused on the investigation of the performance and design of structural members through testing and finite element modelling. She has been involved in various UK and European research projects on materials and structures and has co-authored over 40 journal publications, examining the response of high strength steel, stainless steel, aluminium alloy and composite structures. She is a Chartered Member of the Institution of Civil Engineers (ICE) and of the Institution of Structural Engineers (IStructE), a member of the ICE Merseyside Branch Committee, a member of the Technical Chamber of Greece and a member of Women's Engineering Society. She is also a member of the British Standard Committee: CB/203 - Design & execution of steel structures and of B/525/9 - Structural use of aluminium.

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Dr Youyi WEI

BEng, PhD,CEng, MIStructE, MHKIE, BEAM Pro

Dr Youyi WEI is a Structural Engineer of the Development and Construction InnoTech Team at Housing Department, HKSAR. He received his PhD degree from the City University of Hong Kong in 2014 and has more than 10 years of working experience in the engineering industry and research institutions. He dedicated to the R&D and application of cutting-edge technologies and has extensive experience in construction innovation, structural design and project management. He has been responsible for various projects, including the application of drones and AI technology in construction projects, materials and design for product-based Modular Integrated Construction (MiC), smart corrosion monitoring systems for MiC structure, smart construction sites, projects Integrated management and analysis platforms, etc. He now plays a key role in driving innovation and technology development in public housing projects. He is a Chartered Engineer and Member of the Institution of Structural Engineers and Hong Kong Institution of Engineers, and a BEAM Professional of Hong Kong Green Building Council.

Dr Rabee Shamass

BSc, MSc, PhD, FHEA

Dr Shamass is Senior Lecturer in Structural Engineering, College of Engineering, Design and Physical Sciences at Brunel University London. Before joining Brunel, he was a Lecturer and then Senior Lecturer in Structural Engineering at London South Bank University (LSBU). His research experience is in buckling shell structures, stainless steel structures, fibre-reinforced polymers, fatigue performance, reinforced concrete, numerical modelling, sustainable construction materials, composite structures, utilization of construction and industrial waste materials, seismic performance of structures, and the application of machine learning (ML) in structural/civil engineering. His research goal is to propose efficient design guidance and recommendations that can help the engineering community and support our mission to ensure sustainable, cost effective and safe use of construction materials. Currently, he is interested in low-carbon concretes and cementitious materials (e.g. Alkali-activated concretes; calcinated clay cements), carbon sequestration in concrete, and machine learning in interdisciplinary research way.

Livia Garcia

BE(Hons), BA, MA, CEng, MIStructE, FICE, MHKIE, CMEngNZ

Livia is a Principal Civil Engineer currently with Rail Safety and Standards Board (RSSB), UK. She graduated in Engineering from the University of Auckland and has worked in New Zealand, Hong Kong and United Kingdom. Her previous experience includes designing highways viaducts, working as a resident engineer for infrastructure projects, as well as carrying out project engineer assurance roles in the railways. Companies that she has worked for include Beca Carter Hollings and Ferner (New Zealand), Maunsell Consultants (Asia) Ltd (Hong Kong), Network Rail (UK) and so on. Her current role with RSSB is to draft standards and guidance notes for the Great Britain railway industry, mainly on bridge structures related topics such as evaluating excessive dynamic effects in underline bridges . Livia is also involved in research projects managed by the International Union of Railways (UIC), for example derailment mitigation measures and bridge fatigue. In addition, she is currently actively participating in the revision process of the National Annexes for some of the second generation Eurocodes which are relevant to GB railways.

Smail Kechidi

PhD, CEng, MIStructE

Smail is a Lead Engineer at Hadley Industries Holdings Ltd, formerly a Research Associate at the University of Leeds (UK) and the University of Porto (Portugal). He is a chartered structural engineer who provides technical consultancy and research services.

Smail holds a PhD from the University of Porto, focusing on earthquake engineering applied to steel structures. His research over the last 10 years has focused mostly on experimental testing and advanced numerical modelling of structural stability systems and, more recently, on soil-structure interaction as well as integrated seismic risk assessment and loss estimation. He is the author of several articles in top scientific journals. He has recently won multiple IStructE awards.

Dr. Youguang Pan
BSc, MSC, PhD, MIStructE, CEng

Youguang holds two PhDs in structural engineering-related fields: steel-concrete composite construction from Harbin Institute of Technology and concrete repairs from Loughborough University. With over 40 years of experience in structural engineering, he is currently a Chief Engineer at Sir Robert McAlpine. Youguang has authored more than 20 technical publications on composite construction, concrete repairs, and the effects of blast loading on structures. Before joining Sir Robert McAlpine in 2008, he worked with leading design consultancies, including Waterman and AECOM. At Sir Robert McAlpine, he has contributed to numerous complex projects, specializing in value engineering, forensic investigations, and design management across steel and concrete structures, fire engineering, and façades. Notably, in 2010, he led a team designing the ExCeL Exhibition Centre in London, successfully addressing floor vibration challenges in large-span conference floors. He has also served on the CPD panel of the Institution of Structural Engineers (IStructE) in the past.

Dr Martin Walker
MASc, PhD, FHEA, MIMA

Martin is an Assistant Professor in Engineering Design at the Durham University Department of Engineering. His research interests are in structural mechanics, specifically the mechanics of thin plates and shells. Examples include the generation of creases and folds during the collapse of thin-walled structures, the post-buckling behaviour of shells, and the mechanics of origami and kirigami. He is also interested in topics related to blast-resistant design, particularly the development of new energy-dissipating blast protection systems. Martin currently holds an EPSRC New Investigator Award and has been the recipient of over £500k of research funding from sources including the EPSRC and Defence and Security Accelerator. Prior to undertaking his PhD, he worked in industry leading research and development work on new blast protection systems as well as working on more traditional structural engineering consultancy projects.

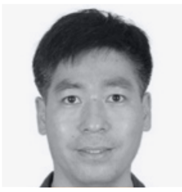
Dr Ross Johnston
MEng (Hons), PhD, CEng, MIStructE, AIFireE, NECReg

Ross is a Director of Amphora Consulting, a specialist Structural, Civil & Conservation Engineering Consultancy. He is a Chartered Structural Engineer with a PhD in Structural Fire Engineering.
He has 15 years' experience delivering Structural, Civil and Fire Engineering design input on complex building and infrastructure projects. He was awarded the IStructE Young Researcher of the Year Award in 2014 and the ICE Palmer Award for Research in 2017.

Ross enjoys implementing innovative structural solutions for both permanent and temporary works, using novel analysis and design approaches. For such projects he has received multiple awards from the NI IStructE Regional Group. In addition to his consultancy work, he has published over a dozen research papers and was an active member on the EU Action TU0904 Integrated Fire Engineering and Response Engineering.

He is proud to be a Guest Lecturer at Queen's University Belfast and is passionate about supporting the development of the next generation of Structural Engineers. Ross' other passions include implementing research methods into industry practice and embedding net-zero principles throughout all stages of the design and construction process.

Zhiquan Ding
BEng, MSc, CEng, MICE, MRICS, LEED AP, Registered Engineers in China, Professor-Level Structural Engineer



Zhiquan joined in CCCC-FHDI Engineering Co., Ltd. (hereinafter referred as FHDI) in 2009 after graduation, and is working as Project Manager and Professor-Level Structural Engineer. He has obtained the Chartered Engineer in UK, a membership of Institution of Civil Engineers (CEng MICE) in UK, a membership of Royal Institution of Chartered Surveyors in UK, LEED AP Credential in US, Registered Investment Consulting Engineer in China, Registered Constructor in China, Register Consultant Engineer in China, etc.

By far, he has finished more than 85 projects, published 12 scientific papers, obtained more than 10 patents, and finished 5 scientific research programs in the consulting industry. His projects also won National and International

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Level Prizes. He worked as the local industrialist for JBM visit to Southwest Jiaotong University in 2023. He is also working as Expert Committee Member in China Steel Construction Society.

He had won titles of Excellent Graduate in 2009 granted by FHDI, the Best Project Manager in 2020 granted by IPMA, Excellent Scientific Researcher in 2020 and in 2023 respectively granted by FHDI and shortlisted one of three FIDIC Future Leaders Award candidates by FIDIC and won the RICS China Construction Professional Awards of the Year in 2023.

Dr Yung-Tsang Chen
BSc, MSc, PhD, AMASCE

Yung-Tsang is the Head of Department of Civil Engineering and an Associate Professor at the University of Nottingham Ningbo China. He was awarded BSc in Civil Engineering and MSc in Structural Engineering from National Chiao Tung University in Taiwan and received a PhD from the University of California, Davis in the U.S. He works in the area of structural and earthquake engineering and has supervised 7 PhDs till competition and published more than 40 journal articles. His research interests include earthquake engineering, structural dynamics, and vibration control for structural damage mitigation.

Dr Gary Robinson
MA, Meng, EngD, CEng, MICE, MIStructE

Gary obtained his doctorate from Loughborough University, following his work assessing the performance of precast building typologies. In addition to this period of industry focussed research, Gary has over 20 years' experience in structural design consultancy, helping to deliver innovative and award-winning structures for both large international firms and small Manchester based start-ups.

Gary is currently an Associate Partner, with Ridge, now working within the Expert Witness team based in Manchester. He specialises in disputes concerning concrete framed structures and has published several journal and conference papers in this area. Gary has also contributed to technical guidance published by the Institution of Civil Engineers (ICE), Concrete Centre and other trade associations.

Gary has lectured various undergraduate courses at Loughborough University, as well as mentoring several final year research projects, and sitting on viva assessment panels. Gary is currently a Supervising Civil Engineer (SCE) for the ICE within Ridge and sits on several panels and committees for the IStructE.

Professor Andrew Yee Tak Leung
DSc, PhD, MSc, CEng, FRICS, FRAeS, MIStructE, FHKIE

Professor Andrew Leung taught Civil and Electrical Engineering at HKU, Aeronautical and Mechanical Engineering at Manchester U, and Building and Construction at City University HK and teaches in Computer and Information Sciences at St Francis University. He is an honorary/guest professor of 15 universities internationally and President of the Asian Institute of Intelligent Buildings and vice-chairman of the Chinese Green Building (HK) Council. He is a Council Member of the Hong Kong Institution of Certified Auditors, an Education Adviser of the Hong Kong Alzheimer's Disease Association, and the Winner of the Hong Kong ICT Awards (HKICT Awards) 2018: ICT Startup (Social Impact) Bronze Award. He published 450 SCI papers having h-Index 43 and is a Top 2% Highly Cited Researchers according to Stanford.

Dr Matthew Poulton
MEng, PhD

Matthew is an Engineer at COWI UK and a specialist in fibre-reinforced polymer (FRP) structures. He obtained his PhD from University College London and has published widely on the topic of FRP bridge design, analysis and testing. His work has fed into the development of national and international guides and standards for the design of FRP structures, including the draft Eurocode CEN/TS 19101. He currently works on the design and assessment of a range of structures including modular highway bridges and the Fehmarnbelt tunnel (the world's longest immersed tunnel). He continues to collaborate with universities and supervise research students on wider topics including sustainability and social value in construction.

Professor Su Taylor

Su Taylor is a Professor of Structural Engineering at Queen's University Belfast and leading research in Structural Health Monitoring (SHM) and low carbon solutions. She is Head of the Intelligent and Sustainable Infrastructure Group and was the first female Professor in Civil Engineering at Queen's. Formerly, Su was the Dean of Research for the Faculty of Engineering and Physical Sciences. Su is Fellow of Institution of Structural Engineers, Fellow of the Institution of Engineers Ireland and was elected as Vice-President of the International Society for Civil Structural Health Monitoring (formerly known as ISHMII) from 2016 to 2022.

Dr. Mohammad Mollazadeh

PhD, CEng, MIStructE

Dr. Mohammad Mollazadeh is a Senior Project Manager at DeSimone Consulting Engineering, based in the London. With over a decade of experience in academia and industry, he has led high-profile projects across residential, commercial, healthcare, and advanced analysis sectors in the UK and internationally.

As a technical lead, Mohammad specializes in high-rise reinforced concrete and steel structures, advanced finite element analysis (FEA), seismic and wind design, concrete-filled steel tubular (CFST) columns, and post-tensioned concrete design. He ensures technical excellence and alignment with UK, European, and US codes.

Mohammad also serves as Lead of Sustainable Design for DeSimone in the UK, collaborating with the University to advance innovative sustainability methods. He holds an MSc and PhD in Structural Engineering from the University of Manchester, with research published in top-tier international journals

Dr Zuhair Namiq

BSc, MSc, PhD

Dr. Zuhair is a Senior Lecturer in the Department of Civil Engineering at Kirkuk University, and the Director of the Design Section at Suren Steel Company. He holds a BSc in Civil Engineering and two master's degrees, an MSc in Civil & Structural Engineering and an MSc in Artificial Intelligence AI at Sheffield Hallam University, UK. He also earned his PhD in Civil & Structural Engineering from the University of Sheffield, UK, specializing in multiaxial fatigue of steel structures.

With over 29 years of experience in structural engineering, Zuhair has worked extensively in steel design for multi-story buildings, complex steel structures, towers, and steel bridges. He has collaborated with leading design consultancies and contributed to numerous complex projects, particularly in steel structures and suspended bridges. His research focuses on the multiaxial fatigue of metallic materials, incorporating advanced numerical finite element modeling. He has authored over 11 peer-reviewed journal and conference papers and, in 2014, presented a novel fatigue evaluation method at an international conference at the University of Seville, Spain.

A hybrid digital twin framework for real-time structural damage identification using physics-based models and deep learning

01 **Dr. Shady Adib**
University of Newcastle

Project objectives and goals

The primary objective of this research is to develop a hybrid digital twin framework that enhances structural health monitoring (SHM) through the integration of physics-based models with machine learning techniques (Adib S. et al., 2023). This framework aims to provide real-time structural damage identification while addressing model uncertainties, enabling accurate and efficient monitoring of infrastructure (Adib S. et al., 2023). Specific goals include:

- Developing a hybrid methodology combining reduced basis (RB) finite element (FE) models with adaptive neural networks (NNs)
- Proposing an approach for optimal sensor placement to improve monitoring precision
- Validating the framework using experimental tests on a truss structure

Description of method and results

The methodology involves three key phases (see Fig 1):

1. Offline phase:
- An RB-FE model simulates the behaviour of linear elastic structures under static loading conditions
- Damage scenarios are modelled as stiffness reductions in structural elements
- Data generated from the RB model train a neural network (NN) capable of detecting deviations from the undamaged state and classifying damage scenarios. The NN also predicts optimal sensor placement for improved accuracy

2. Monitoring phase:
- Sensors are strategically placed on the physical structure based on the NN's predictions
- Real-time data from these sensors feed into the NN to identify potential damage scenarios

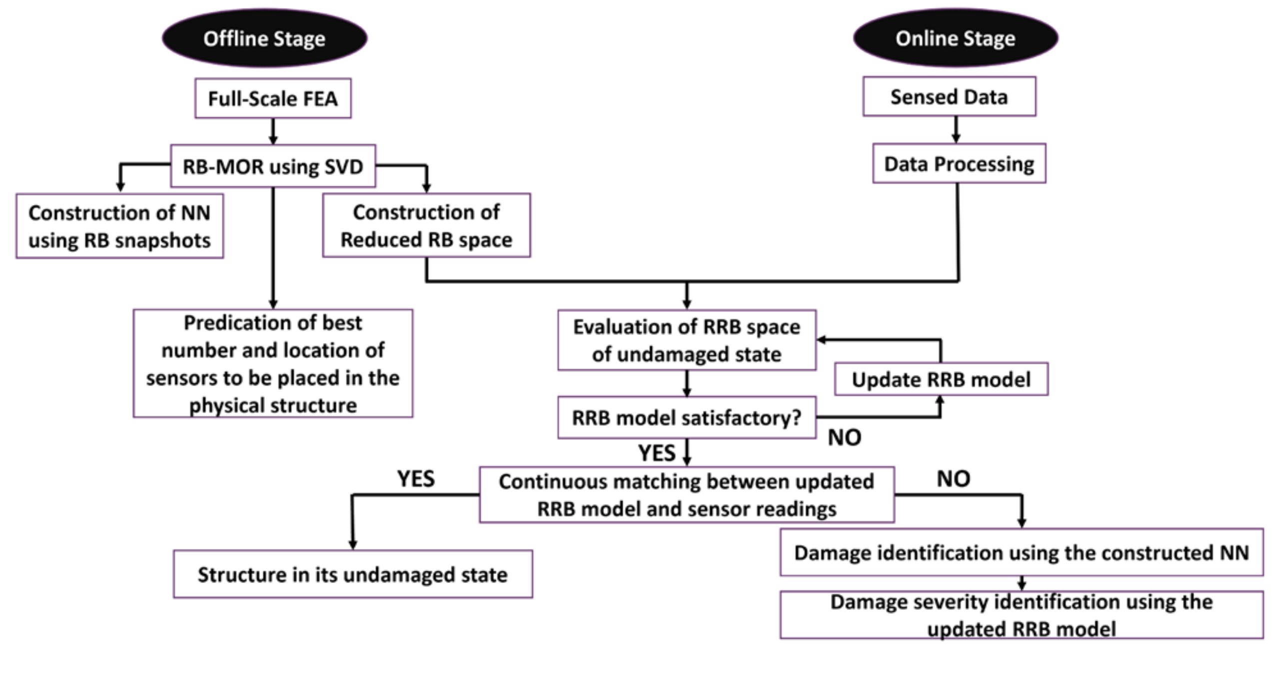

Fig 1 A schematic diagram of the hybrid digital twin framework.

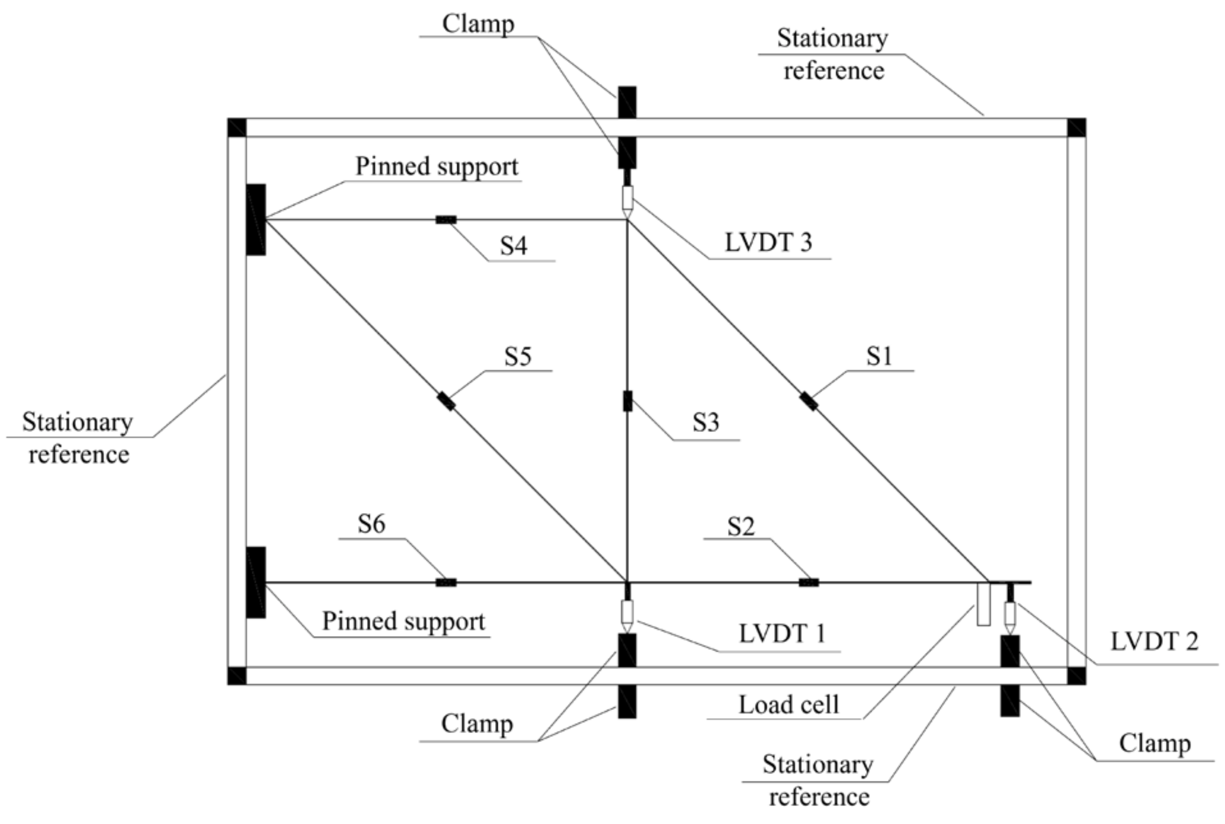

Fig 2 Laboratory-scale truss structure with sensor placements.

- The RB model further assesses the severity of detected damage to provide actionable insights

3. Experimental validation:
- Laboratory tests are conducted on a truss structure subjected to static loading, with artificial damage introduced by reducing cross-sectional areas of selected elements (see Fig 2)
- The digital twin is validated by comparing its predictions with observed physical responses

Key results:
- The NN achieved a high accuracy rate in detecting damage scenarios and predicting optimal sensor placement
- The digital twin demonstrated the capability to provide real-time assessments of structural damage, mirroring the physical system's behaviour accurately
- The approach showed potential for proactive maintenance strategies, improving the lifespan of infrastructure

Potential for application of results

The hybrid digital twin framework offers a transformative approach to SHM by enabling real-time, data-driven damage detection. Key applications include:

- Infrastructure maintenance: Enables proactive decision-making for bridges, buildings, and other critical structures
- Disaster mitigation: Provides real-time monitoring during and after events such as earthquakes
- Cost reduction: Minimises the need for manual inspections and extends infrastructure lifespan through targeted maintenance

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BIM-based integrated assessment of circularity and sustainability in the construction industry

02 **Ihab Al-Qazzaz**
University of Nottingham

Project objectives and goals

The research aim is to investigate how to leverage building information modelling (BIM) to develop an integrated framework for building circularity and sustainability assessment at the early design stage to inform design decisions. The following objectives were set to achieve the aim of this study:

- Identify existing indicators for assessing building circularity and BIM integration approaches
- Design an integrated assessment framework to inform decisions from a technical circularity and sustainability perspective
- Develop a BIM-based prototype tool to implement the proposed framework
- Evaluate the framework by using the prototype in a simulated hypothetical case study

Building circularity assessment (BCA) at the early design stages is crucial for achieving circularity and sustainability objectives, which are often treated separately and can occasionally conflict. Although building information modelling (BIM) has been leveraged to support decision-making, it lacks circularity information, and current BIM-based BCA tools focus mainly on geometry extraction and linking to external databases, not on the inclusion of circularity information in BIM objects (elements and materials). In the case of the addition of information in objects, still, the addition of information in objects is limited only to the elements (thus, not materials), without offering comprehensive decision-making support and no approach simultaneously accounts for circularity and sustainability aspects in decision-making for the trade-off of different aspects and informs design decisions. The need for this integrated assessment and practical tool is emphasized in several studies (Al-Qazzaz et al., 2024a).

Description of method and results

The design science research (DSR) methodology was adopted to develop an artefact to address a problem (Hevner et al., 2004). In DSR, the objectives of the solution are typically expressed in the form of conceptual frameworks, which are subsequently implemented in the form of practical tools. The design and development of a tool based on the conceptual integrated framework initially presented in Al-Qazzaz et al., 2023. As part of the tool design process, requirements were formulated and presented by (Al-Qazzaz et al., 2024b).

A new version of the building circularity indicator (BCI) assessment model has been built upon the best features of the latest and existing assessment models. The new model aims to align with sustainability assessments and requires less data. It predicts and assigns the end-of-life scenario (eg, direct reuse, recycling, disposal) of elements.

The selected indicators in the proposed assessment model were investigated to determine which could be extracted from the BIM model and which needed to be created as custom parameters. Based on the proposed assessment model, a data dictionary for circularity assessment, "Circularity 0.0.1" (Circularity (bSDD), 2024), was developed to enrich the BIM model at three levels: material, element, and building. The system architecture of the developed prototype tool is shown in Fig 1.

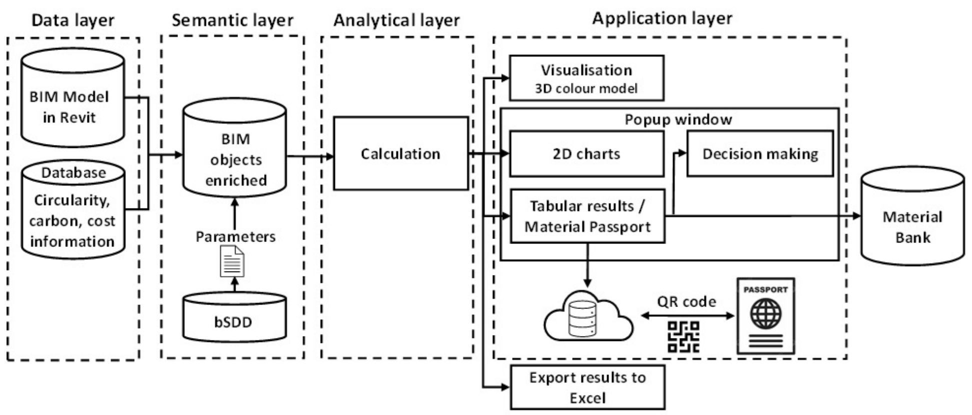

Fig 1 System architecture of the developed prototype tool.

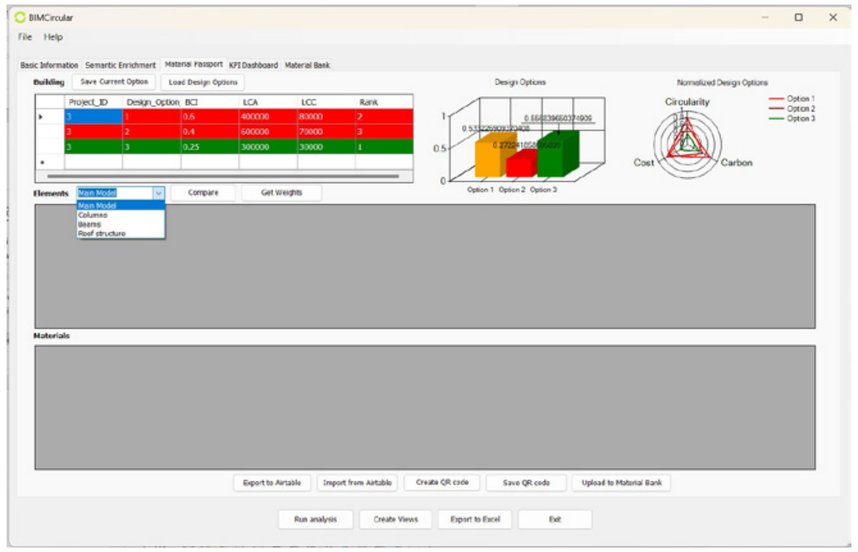

Fig 2 Example of specifying weights based on their preferences and project objectives.

The proposed framework is implemented into a BIM-based prototype tool as an add-in (plugin) within Autodesk Revit using C# programming language and Revit API. MySQL was used to develop the database for semantic enrichment and Airtable was used as a cloud-based database for the material passport. The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) was chosen as a multi-criteria decision analysis method to select the optimal design solution among various design alternatives. The three criteria (circularity, embodied carbon, and cost) can be assigned equal weights of importance, or users can specify weights based on their preferences and project objectives as shown in Fig 2.

The developed prototype tool provides circularity and sustainability insights through various visualisation formats to facilitate decision-making. These include a colour-coded BIM model within BIM (green to red scale), a dashboard with graphical charts for key performance indicators (KPIs), tabular, parameters in elements properties and project information and dynamic quick-response (QR) codes. Additionally, the framework allows data to be documented to a material bank and Microsoft Excel.

Potential for application of results

Implementing the proposed framework and prototype tool will facilitate informed decision-making by identifying the most circular and sustainable materials for buildings, considering both circularity and sustainability indicators. This is hoped to be useful for designers to be more well-informed of the circularity and sustainability insights performance of their alternative design solutions, which will raise awareness about circularity and sustainability among designers. Moreover, it will contribute positively to optimising material use and resources efficiently, the building stocks decarbonisation, and a step toward a twin transition of a sustainable circular economy and digitalisation. Future work will include a demonstration by implementing a case study.

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Probabilistic assessments of load carrying capacity of corroded metallic railway bridges

03 **Ziliang Zhang**
University of Southampton

Project objectives and goals

Accurate estimation of current/future load carrying capacity of railway bridges (characterised on UK railways by means of a route availability number) has prominent practical implications given the key role they play in transport network resilience. However, this can be difficult for historic railway infrastructure, owing to the dual challenges of assessing current condition and potential future rates of degradation. While state-of-the-practice bridge assessments typically do not incorporate degradation as a time-dependent phenomenon, abilities of bridges to safely withstand forces from heavy axle weight (HAW) train referencing various damage mechanisms are likely to deteriorate owing to ageing phenomena, eg corrosion. The problems studied herein thus focus on the exposure of railway bridges to moderate corrosive environments under HAW traffic loads.

Description of method and results

In this work, a probabilistic assessment framework for estimating future route availability (RA) number of ageing metallic railway bridges is proposed (Fig. 1). The methodology is demonstrated with reference to a 37.7 m long, single track, three-span, half-through girder, early steel railway bridge. Nonlinear bridge responses to HAW train loads are evaluated using advanced finite-element models accounting for material plasticity, buckling and potential unstable collapse. Possible failure mechanisms were explored using damage measures related to global and localised performance criteria. Ageing of the metallic bridge was modelled assuming that time-dependent non-uniform corrosion dominates the deterioration process. Various model uncertainties, including those governing corrosion, were explicitly accounted for by sampling multiple realisations from a pre-defined multivariate statistical distribution.

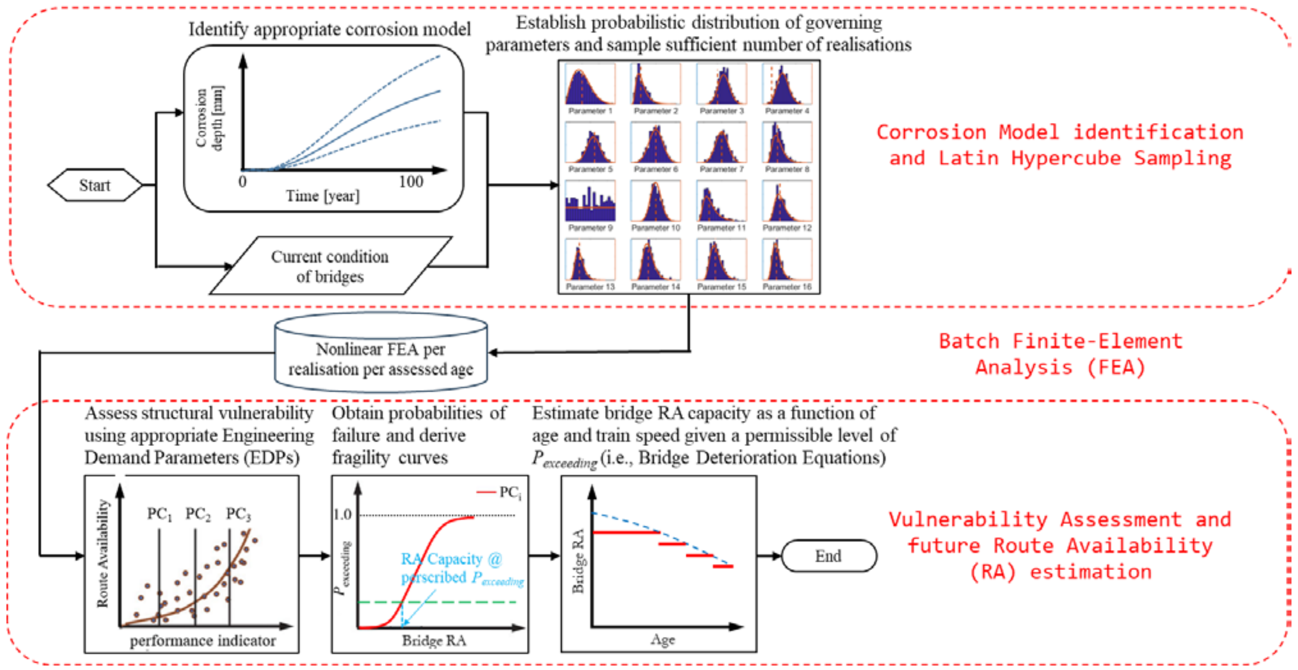

Fig 1 Flowchart of the proposed probabilistic assessment framework for estimating future capacity of ageing metallic railway bridges.

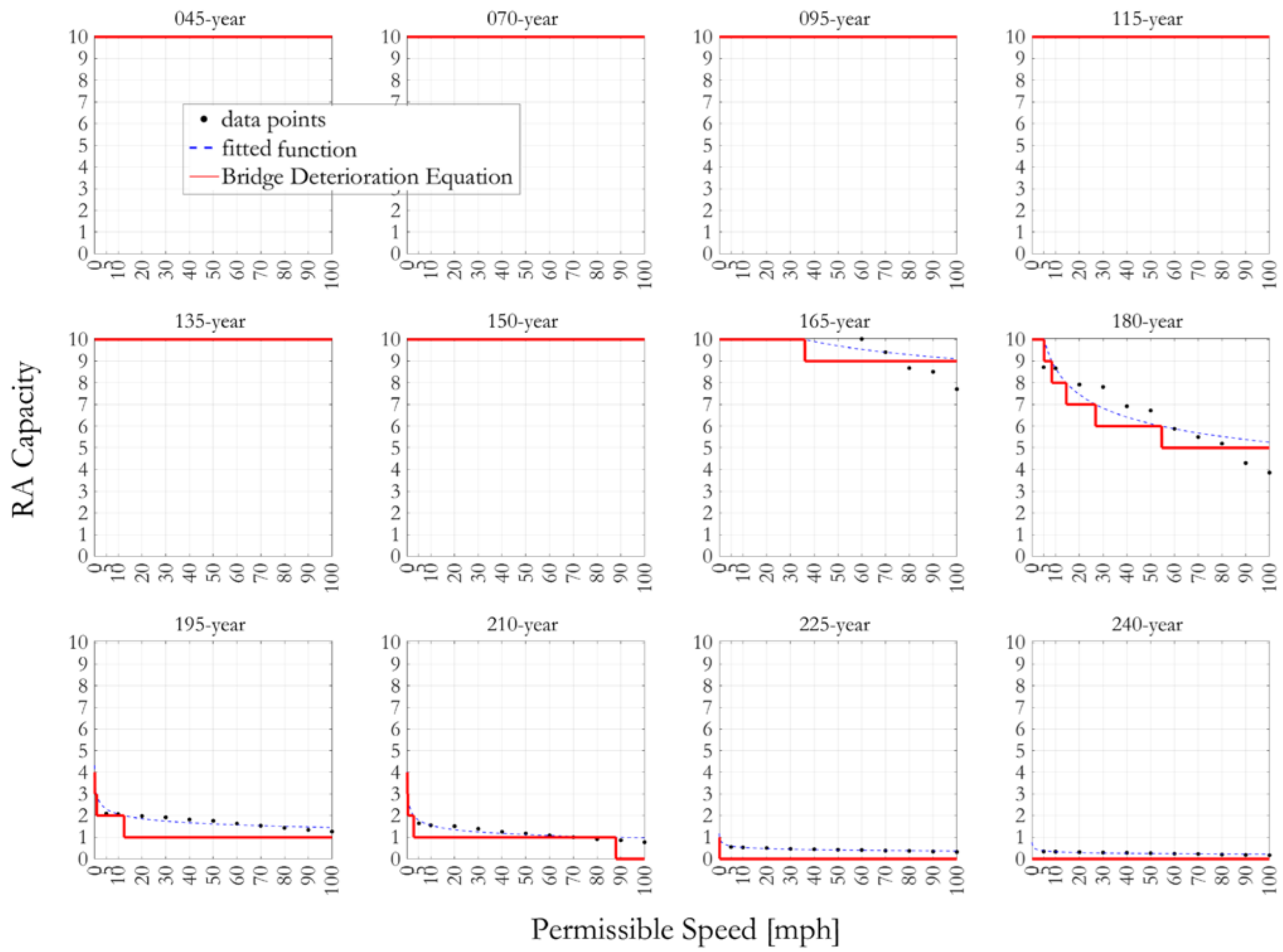

Fig 2 Derived Bridge Deterioration Equations (BDE) of the case study bridge subjected to moving axle load given 95 % confidence level.

Future bridge capacity was quantified in the form of bridge deterioration equations (BDE), ie, bridge RA number as a function of age and train speed (Fig. 2). Derived BDEs suggest that the bridge currently has sufficient capacity, despite nonuniform corrosion to a maximum depth of approximately 3 mm. However, if further deterioration occurs, HAW traffic accessibility could become compromised in three to four decades. An increasingly disproportionate impact of corrosion on RA capacity with respect to age is observed, attributing to: (a) nonlinearity in time-dependent corrosion depth models, (b) dependency of critical buckling load of Kirchhoff thin plates on a cubic term of plate-thickness, and (c) interaction between various failure (especially buckling) modes and their relative criticality in relation to nonuniform random spatial distribution of corrosion depth. The BDE formulation proposed in this paper provides a straightforward piece of information that can be used to support data-driven decision-making processes for both railway infrastructure owners and freight operators. It also contributes to a future scope for ultimately moving towards the development of a machine-learning-based expert tool for quick estimations of future load carrying capacity of railway bridges.

Collaborators

School of Geography and Env. Science, University of Southampton; Rail Safety and Standards Board (RSSB); Network Rail Ltd

Flexural behavior and design rules of cold-formed steel Doublesigma sections

04 Drew Thomas Gray
Northumbria University

Project objectives and goals

The construction industry is becoming increasingly more focused on sustainable construction methods to achieve key sustainability targets. Moreover, innovative sections have been developed in the cold-formed industry, to improve the material efficiency. The Doublesigma section has been introduced in the industry with several advantages including enhanced structural capacity. Fig. 1 shows the cross-section illustration of the Doublesigma section. This research intends to analyze the flexural capacity of cold-formed steel Doublesigma sections to explore the applicability of cold-formed steel Doublesigma sections in modular buildings. Hence the following objectives are set.

- Development of Finite Element models
- Validation of numerical modeling approach
- Parametric plan (Considering a range of slenderness values)
- Development of Design Guidelines

Description of method and results

A numerical approach was selected to investigate the flexural behavior of cold-formed steel Doublesigma section. ABAQUS/CAE (2017) was utilized as a Finite Element (FE) and analysis (FEA) software. Overall two structural elements (1) Doublesigma section and (2) Web side plate were modelled and assembles based on the experimental set-up. The modelling utilized a non-linear analysis to investigate the flexural capacity, this was selected for its proven credibility of being efficient in solving non-linear problems. To check the reliability of the numerical models the verification process was conducted with experimental studies. Hence the studies considered were Pham and Handcock (2010) how explored high strength lipped channel beams (LCB) and Wang and Young (2017) who studied the flexural capacity of web stiffened channel sections including the Sigma section. The numerical models were generated and validated with experimental results. Comparisons indicted the numerical modes were coordinated well with experimental results.

Key parameters such as section depth, thickness and yield strength were selected based on industry requirements. Three section depths (200 mm, 250 mm and 300 mm.), five thicknesses (1 mm, 2 mm, 3 mm, 4 mm and 5 mm) and five yield strengths (300 MPa, 450 MPa, 600MPa, 700 MPa and 800 MPa) were included in the parametric plan, overall 100 numerical models were generated to extensively investigate the flexural behavior of the innovative Doublesigma section.

Parametric study results were obtained from the numerical study which was carried out using ABAQUS/CAE (2017) and results were analysed with key parameters to study their effect on cold-formed steel Doublesigma sections. Fig 2 illustrates the failure pattern of cold-formed steel Doublesigma sections. It was found that the predominate failure mode is that of local buckling.

AS/NZS 4600 (2018) reports 2 design equations for that of predicting the flexural capacity of channel section when their failure mechanism is local bucking. A modified equation (Eqn 1 and 2) was proposed to accurately predict the flexural capacity of Doublesigma sections Table 1 presents the proposed coefficient value

$$Mbl = M_y + (1 - cyl^2)\,(Mp - M_y) \text{ for } \lambda \leq a \quad (1)$$

$$Mbl = [1 - b\,(\frac{\text{Mol}}{\text{Mbe}})^c\,]\,(\,(\frac{\text{Mol}}{\text{Mbe}})^c)\,Mbe \text{ for } \lambda_l > a \quad (2)$$

a	b	c
0.8	0.13	0.38

Table 1: proposed coefficient

Potential for application of results

Cold formed carbon steel sections are one of the best options to be employed in modular construction to provide maximum structural efficiency whilst being light weight. However their flexural capacity nature should be identified to avoid potential failures. Furthermore, the proposed equations become significant to fill the knowledge gap in the design procedure and ensure the design is safer and efficient.

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Standards Australia/Standards New Zealand Australia/New Zealand Standard AS/NZS 4600 Cold-formed steel structures Sydney, Australia, 2018

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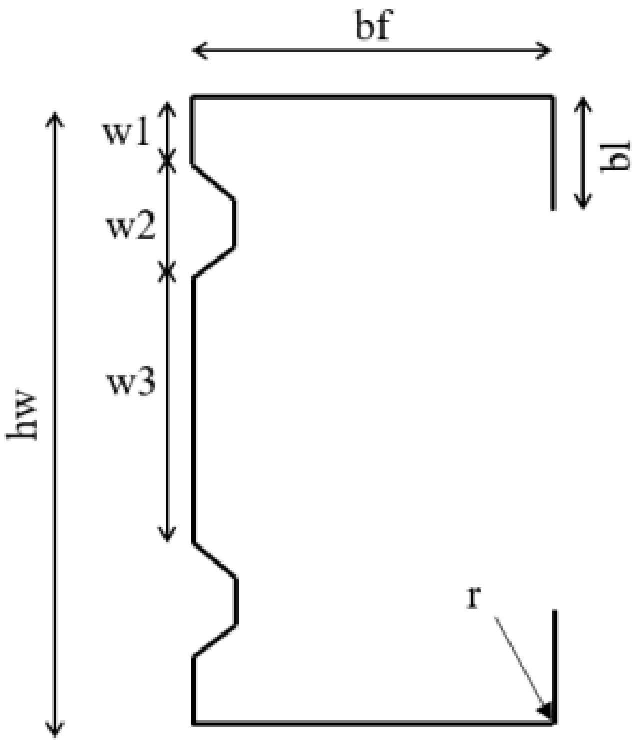

Fig 1 Cross-section illustration of Doublesigma section.

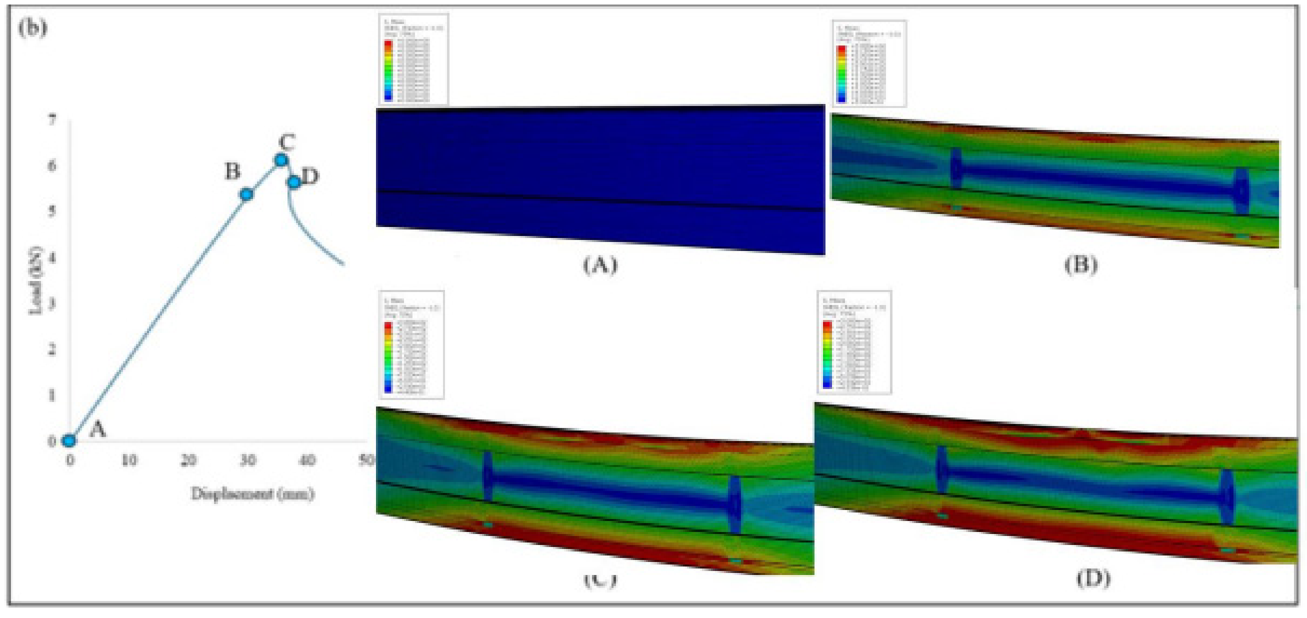

Fig 2 Failure pattern of cold-formed steel Doublesigma section.

Flexural behaviour and design rules for modular construction optimised beams with unstiffened circular web openings

05 Jack William Lifsey
Northumbria University

Project Objectives and Goals:

The demand for structurally efficient, sustainable and cost-effective construction solutions has driven a shift within the industry towards the use of modular construction techniques. This modern method of construction is characterized by prefabricated modules that are assembled on-site to complete the project [1]. This approach offers several advantages over conventional construction methods such as, reduced material waste, enhanced quality control methods and a greatly reduced construction time [2-4]. In parallel with the rise of modular construction, cold-formed steel (CFS) has gained traction do its high strength-to-weight ratio, sustainability and ease of fabrication allowing for the production of complex cross-sections that enhance structural performance [5]. Among innovative CFS sections, hollow-flanges have demonstrated structural performance primarily due to their torsionally rigid hollow flanges, eliminating distortional buckling induced failure modes [6-8].

In the last decade, the modular construction optimised (MCO) beam has been introduced [9] and is displayed within Figure 1. The most significant benefit of the MCO beam, as demonstrated through pilot manufacturing, is the ability to reduce the weight of a modular building floor system by 0.25 kN/m² (18%) over a standard 7.5 m span compared to conventional CFS rectangular hollow sections (RHS) [9]. In addition, the inclusion of web openings offers numerous advantages for the architectural and mechanical, electrical and plumbing (MEP) aspect of a construction project. Web openings allow services to run through floor and ceiling members creating more efficient MEP arrangements and reducing overall floor and ceiling depths, potentially lowering total build cost by over 1% [10]. However, previous studies [11-13], indicate that unstiffened holes in the web compromise the structural capacity of the member. To date, limited research is present around the flexural performance of the MCO beam with unstiffened web openings.

Objective 1: Investigate the flexural behaviour of the MCO beam under local buckling conditions through finite element analysis. Web holes are to be greater than 38% of the clear web height.

Objective 2: Propose design rules for the ultimate section moment capacity of laterally restrained MCO beams with unstiffened circular web holes. Design rules are to be in the form of moment capacity reduction factor and based upon the results from the performed parametric study.

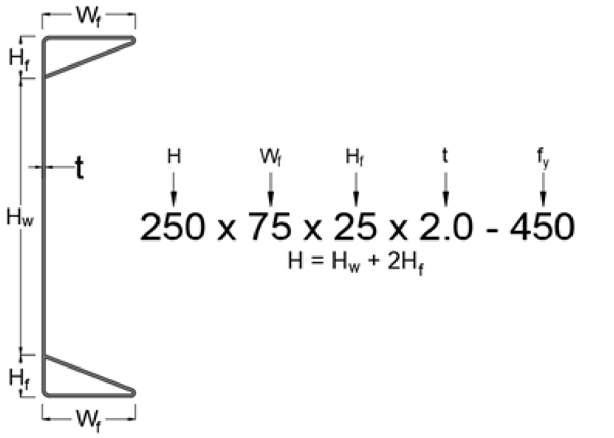

Fig 1 Cross section shape and dimension notation of the MCO beam.

Objective 3: Compare the flexural performance of the MCO beam with and without web holes, against readily available CFS sections commonly found within the construction industry.

Description of method and results

with the goal of achieving the objectives of the research, the methodology can be split up into the following stages:

1. Detailed literature review
To present a strong background surrounding the importance of the research and to identify the gap within research a detailed literature review was performed. The literature review highlighted that hollow-flange CFS beams display improved flexural performance over open channel sections, additionally it was observed that on a regular basis, design rules are typically highly conservative and more accurate design rules are proposed to reduce material costs. Furthermore, the literature review revealed that web openings play a large role in the performance of structural elements in that, where unstiffened, the elastic critical buckling analysis displayed reduced capacities for local and distortional buckling. To conclude the literature review, it was noted that research around the MCO beam with unstiffened web openings extremely limited and there was a clear gap within research that this paper aimed to fill.

2. Develop Finite Elements models to investigate the flexural performance of the MCO beam with unstiffened circular web openings

From previous studies found within the literature review, it was clear that the four point bending was a unified approach to testing the moment capacity of CFS beams, both numerically and experimentally. This method provides pure bending at midspan providing the ultimate moment capacity. For this paper, numerical models were developed and non-linear analysis was performed using ABAQUS [14].

3. Validation of the numerical models using existing experimental data
In order to prove the accuracy of the numerical data, the finite element methodology was validate against existing experimental data. For this paper, two validations were performed, firstly experimental data for plain web hollow-flange beams and secondly, CFS beams with web openings.

4. Conduct a full scale parametric study
To explore the effect of web openings on the flexural performance of the MCO beam and develop reduction factor equations, several parameters were chosen to be studied. A parametric study of 288 FE models was developed, highlighting various MCO section sizes, thicknesses and yield strengths with web holes with diameter 40,60 and 80% of the clear web height. Results from this study revealed that typically, the MCO loses 10% of its ultimate moment capacity when web holes of 80% the clear web height are introduced.

5. Develop new reduction factor equations
From the results of the parametric study, reduction factor equations were developed based upon the results of the parametric study. The reduction factor is to be applied to the ultimate section moment capacity of the corresponding plain web section.

6. Comparison against readily available CFS sections
Two comparisons were performed within this study. Firstly, MCO sections with web holes 80% of the clear web height were compared with plain web LCB sections of same width and depth, where the 80% web holes make up for the increase in coil length. This comparison showed that even with 80% web holes the MCO displays an average increase in flexural strength of 32%. Secondly, a comparison was performed against plain web MCO sections and commercially available LCB sections with equal coil length displaying that an increase of up too 80% in flexural capacity is possible, furthermore, due to the hollow-flanges of the MCO this also leads to a reduction in overall floor depths. It was noted from the results that as slenderness decreases, the increase in flexural capacity also decreases as shown in Figure 2.

Potential for application of results

The design rules developed from this study can be used for predicting the moment capacity of MCO beams with unstiffened circular web openings which have clearly displayed superior flexural performance over commonly used CFS sections. This will improve the exposure of the MCO displaying its benefits to a greater audience and boost its use within modular construction worldwide, helping lower weight of modular units and increase sustainability.

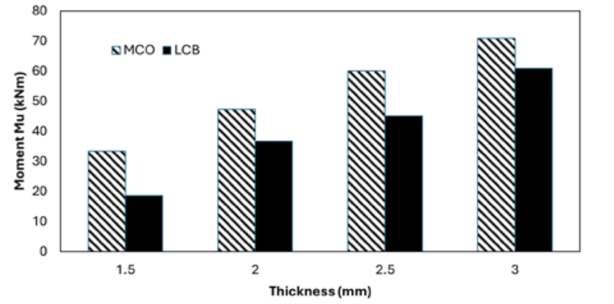

Fig 2 Comparison of Moment Capacity between the MCO and LCB section for the same coil length (514mm) at 600MPa.

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Principle Supervisor: A/Prof Keerthan Poologanathan

Particle-based DEM modelling of masonry under compressive loading

06 **Kanaeshvarr Devanand**
University of Birmingham

Project objectives and goals

Masonry, an ancient construction method, often composed of unit (brick, block, stone) and mortar, remains one of the most popular methods to date (Adaileh et al., 2023). Ageing masonry stock is rising due to its extended life spans with visibly deteriorated masonry still widely in use. As such, behavioural analysis of masonry with minimal destruction is of great importance and masonry modelling solves this issue. A variety of analytical techniques have been used to model masonry but being able to accurately replicate large deformations and intricate crack propagation pathways remains a challenge for most approaches. Additionally, being able to separately model mortar joints and brick-mortar interfaces is advantageous as deterioration can often be seen in loss of interface bonding area between unit and mortar, which is usually regarded as the weakest region in a masonry structure (Ghiassi & Milani, 2019; Pluijm, 1999). The particle-based Discrete Element Method (pbDEM) is an analytical technique which has the potential to model these detailed aspects of masonry behaviour. It is a proven method in brittle deformation analysis and has successful applications in modelling mechanical loading of concrete and rock, whilst using linear parallel bond and linear contact bond methods (Suchorzewski et al., 2018; Xu et al., 2020). Previous applications of pbDEM in masonry are sparse despite positive discussion regarding its accuracy in emulating brittle behaviour and fracture pathway detailing (Azevedo & Lemos, 2022; Rios, 2016; Thavalingam et al., 2001). This study aims to investigate the accuracy of pbDEM in replicating short-term mechanical loading of a masonry prism, subjected to uniaxial compression (see Fig 1).

Description of method and results

A particle-based DEM model of a generic brittle material, using the linear parallel bond method was developed in ITASCA PFC7.0 software, using formulae linking DEM microparameters and material properties, used previously in pbDEM (Xu et al., 2020). These formulae semi-quantitatively linked Ultimate Compressive Strength (FC), Young's Modulus (E) and Poisson's ratio, to DEM microparameters including stiffness ratio (k*), particle and parallel bond elastic moduli (E*) and bond tensile strength (pb_ten). After conducting parametric studies to understand individual DEM microparameter influences on material properties, parameter formulae were modified and also created (shown below as Equations 1-3) and used to validate pbDEM models of individual masonry components, with experimental data referenced from (Oliveira, 2003).

$$v = - (0.0328 (\ln (cf)) + (0.1971 (\ln (k^*)) + 0.093 \quad (1)$$

$$E = 1.9165 (E^*) - 0.6909 (k^*) + 0.7115 (cf) + 0.7714 \quad (2)$$

$$F_c = 2 (pb\_ten) \quad (3)$$

Modified equations (1-2) included friction coefficient (cf) as a new variable. A pbDEM masonry model was developed and validated against physical test data with results compared in Table 1 (Oliveira, 2003). Low error between pbDEM model and physical test provided validation and encouragement to pursue with this method to investigate other aspects of masonry behaviour. A graphical comparison of compression stress-strain response between model and physical test is shown in Fig 2. Results show clear agreement in material stiffness and peak strength value.

	DEM Masonry Prism	Physical Test	Error (%)
Fc (MPa)	28.69	28.50	+0.7
E (GPa)	2.91	2.75	+5.8

Table 1 Comparison between pbDEM masonry model and physical compression test.

Potential for application of results
These findings show that pbDEM can accurately replicate material properties exhibited in small-scale masonry physical tests. This opens the door for future investigations into the influence of design choices in masonry when subjected to different forms of loading.

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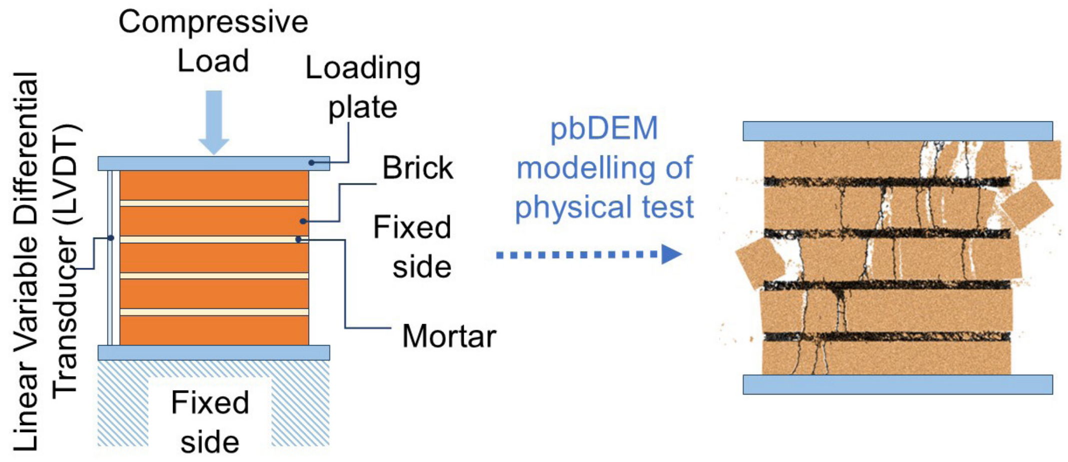

Fig 1 Uniaxial compression of a masonry prism using pbDEM, replicating experiment from (Oliveira, 2003).

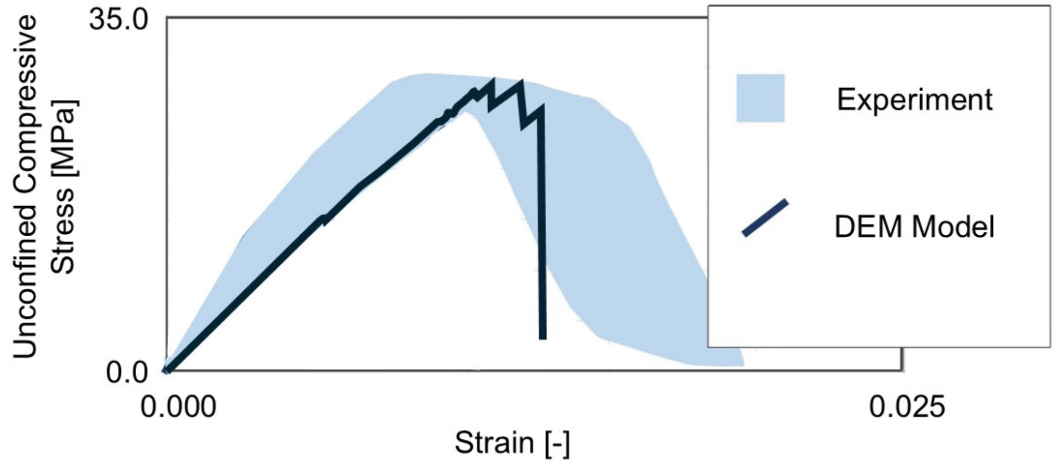

Fig 2 Graphical comparison of compression stress-strain response between pbDEM model and physical test.

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Graphene-Enhanced Fabric Reinforced Cementitious Matrix (FRCM) Composite and Its Effects on Impressed Current Cathodic Protection (ICCP) and Structural Strengthening (SS) for Reinforced Concrete (RC) Beams

07 **Xiaoming Zhu**
University of Manchester

Project objectives and goals

- To understand how graphene affects the behaviour of FRCM composite subject to ICCP in both material and structural level
- To develop a design method for reinforced concrete beams repaired by ICCP-SS with graphene (Fig 1) and predict the extended service life of structure

Description of method and results:

Method

Experimental program, including direct tensile tests, pull-out tests for FRCM composites, and four-point bending tests for 2-year corroded concrete beams intervened by ICCP-SS technique (Fig 2), to understand the effects of graphene, and generate sufficient data for developing the design method.

Numerical and analytical investigations into the tensile and interfacial behaviour of conventional FRCM composites, as well as the flexural behaviour of concrete beams strengthened with FRCM composites for theoretical design (Zhu et al., 2024a and Zhu et al., 2024b).

Results

The inclusion of graphene improves the elastic modulus, the cracking stress, the ultimate tensile stress, the shear strength at the fibre/mortar interface of FRCM composite, enhances the load-bearing capacity of the beam structures.

The incorporation of graphene largely alleviates the degradation of tensile, interfacial properties of FRCM composite, and flexural bearing capacities induced by long-term implementation of ICCP.

The proposed material models for the design of RC beams repaired by ICCP-SS with or without graphene are proven effective under a large database.

Adding a 0.035% dosage of graphene to the FRCM matrix significantly improves the ICCP-SS system's durability, extending the lifespan of RC beams by 55.8% under a 20 mA/m² current density.

Potential for application of results

Eqs. (1)-(4) presents the four material models, mainly referring to effective strain of fibre (ε_{eff}) within FRCM composite, developed from this project, which are essential for RC beam design under different scenarios.

Where ε_{fu} is the fibre tensile strain of dry fibre; β_p and β_L is the nondimensional FRCM bonding width factor and bonding length factors, respectively; f_c' is the specified compressive strength of concrete in MPa; E_f is the elastic modulus of dry fibre in MPa; t_f is the thickness of one layer of fibre in mm; n is the number of layers of fibre mesh, nondimensional; G refers to the graphene dosage in wt% of cement; Q refers to the accumulated charge density for ICCP in the unit of $10^6\ C/m^2$.

FRCM: $$\varepsilon_{eff} = \min\left(0.85\varepsilon_{fu}, 0.735\beta_p\beta_L \frac{f_c'^{0.484}}{E_f^{0.5}t_f^{0.251}n^{0.068}}\right) \quad (1)$$

Gr-FRCM: $$\varepsilon_{eff} = \min\left(0.85\varepsilon_{fu}, 0.735\beta_p\beta_L \frac{f_c'^{0.484}}{E_f^{0.5}t_f^{0.251}n^{0.068}}(e^{3.4G})\right) \quad (2)$$

FRCM under ICCP: $$\varepsilon_{eff} = \min\left(0.85\varepsilon_{fu}(e^{-0.46Q}), 0.735\beta_p\beta_L \frac{f_c'^{0.484}}{E_f^{0.5}t_f^{0.251}n^{0.068}}(e^{-0.21Q})\right) \quad (3)$$

Gr-FRCM under ICCP: $$\varepsilon_{eff} = \min\left(0.85\varepsilon_{fu}(e^{-0.18Q}), 0.735\beta_p\beta_L \frac{f_c'^{0.484}}{E_f^{0.5}t_f^{0.251}n^{0.068}}(e^{-0.16Q})\right) \quad (4)$$

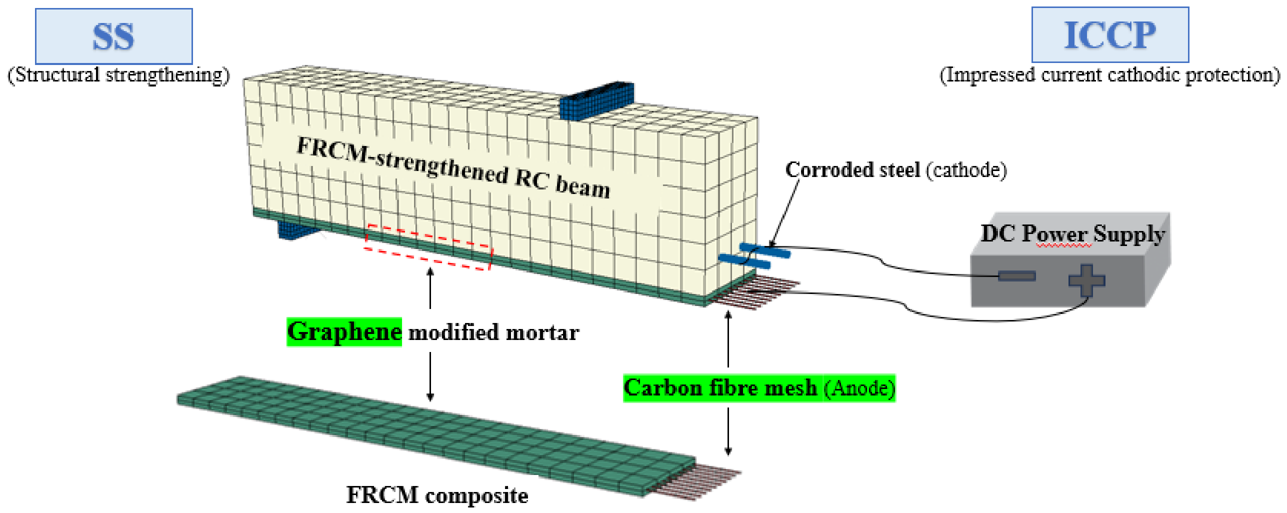

Fig 1 Concrete beams repaired by ICCP-SS using graphene enhanced FRCM composite.

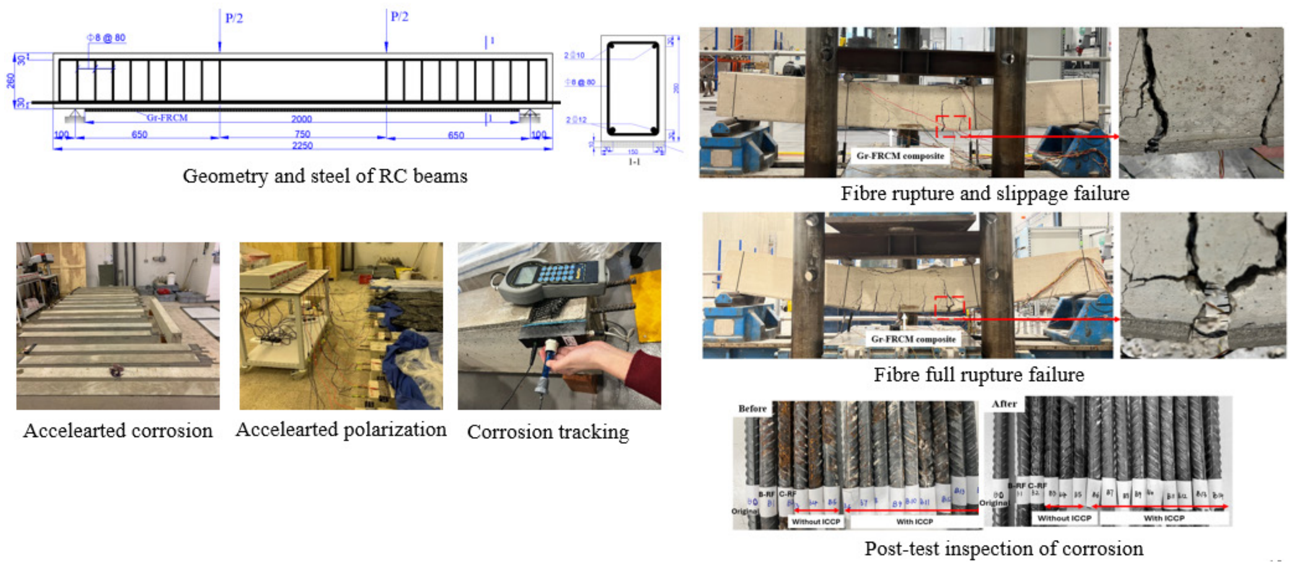

Fig 2 Four-point bending tests for 2-year corroded concrete beams intervened by ICCP-SS technique.

This research highlights graphene's transformative potential in protective technologies for RC structures. By enhancing the performance and durability of ICCP-SS systems, the incorporation of graphene offers promising applications for both new construction and the rehabilitation of aging infrastructure, ensuring improved resilience and longevity of structural elements.

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Design and conceptualization of reusable concrete slab segments

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Project objectives and goals

The reuse of components can significantly reduce the environmental impact of concrete construction. By recovering and later reusing concrete components, it is possible to drastically reduce greenhouse gas emissions, the generation of construction waste, and the primary resource consumption required for new construction (Eberhardt et al. 2019). Technical barriers for reusing concrete components include the integration of the design for reuse in the design process of new structures and reversible connections that allow for future disassembly and reassembly (Rakhshan et al. 2020).

Concrete slabs constitute the largest mass share of conventional concrete buildings and are predominantly cast-in-place monolithic structures, which require extensive mechanical processing to disassemble and recover individual elements. A potential strategy to design concrete slabs for future reuse are prefabricated concrete segments, that allow for disassembly and subsequent reuse (Blandini et al. 2023). The key objectives of the research are reversible connections between the segments and a design method that allows the generation of a stock of segments that can be flexibly reused under various boundary conditions and use scenarios. The investigations are limited to one-way spanning slabs.

The research highlights include:

1. Optimisation algorithm for the segmentation of concrete slabs under the aspect of reuse
2. Conceptualisation and investigations of a reversible connection to join segments
3. Demonstration of the approaches on case studies and scaled segmented concrete beams

Description of method and results

Currently, the design process for newly constructed concrete slabs does not prioritise reuse. Furthermore, neglecting reuse as part of the initial design intent results in structures designed for a specific use scenario. This specificity limits the flexibility and potential applications of components that are recovered after deconstruction.

Therefore, a design method that facilitates the flexible reuse of concrete slab segments has been conceptualised and formulated in a multi-objective optimisation allowing designers to generate a stock of segments that can be used in a prescribed range of span widths, static systems and load conditions.

The input parameters for the multi-objective optimisation comprise a stock of segments characterised by varying lengths, load-bearing capacities and stiffnesses, and static systems with different span widths, boundary conditions and loading conditions. During the optimisation, the segments from the stock are assigned to the supplied static systems under the main objectives to maximise material efficiency, minimize the number of connection points and minimise the number of different segment types.

This enables a quantitative assessment between the choice of more and shorter segments, which generally increases flexibility and material efficiency, and less but longer segments, which minimise the number of connection points. Designers have the ability to influence the relative importance attributed to each objective by the adoption of a linear weighting approach.

The optimisation has been implemented using a branch-and-bound algorithm in *Gurobi* to solve the binary programming problem that was formulated. In order to integrate a finite element analysis into the optimisation, a Simultaneous Analysis and Design (SAND) approach using the Direct Stiffness Method (DSM) was employed.

The application of the design method is illustrated by case studies that demonstrate the approach and impact of design choices as depicted in Fig 1.

To join the individual segments into continuous slabs, a novel reversible connection has been conceptualised. The force transfer between the segments is achieved by contact and interlocking to transfer shear and compressive forces and by locally prestressing a stud bolt to transfer tensile forces. Local grouting is utilised as shown in Fig. 2 to facilitate the compensation of tolerances during the on-site assembly process and to mitigate the occurrence of stress peaks caused by local surface imperfections.

Numerical investigations using the Finite Element Software *Abaqus* and experimental testing on segmented concrete beams have been conducted to validate the concept. The investigations focused on the shear and bending load-bearing capacity, as well as the influence on the level of prestress on the load-bearing behaviour of the connection.

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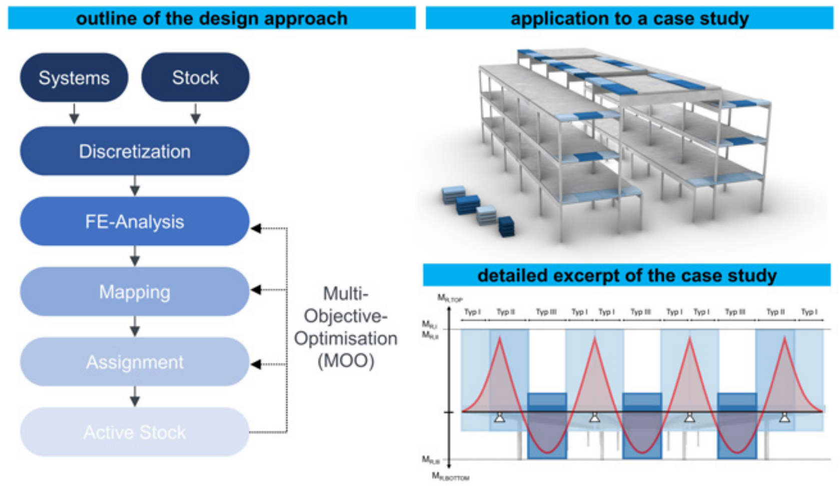

Fig 1 Abstract Design Method.

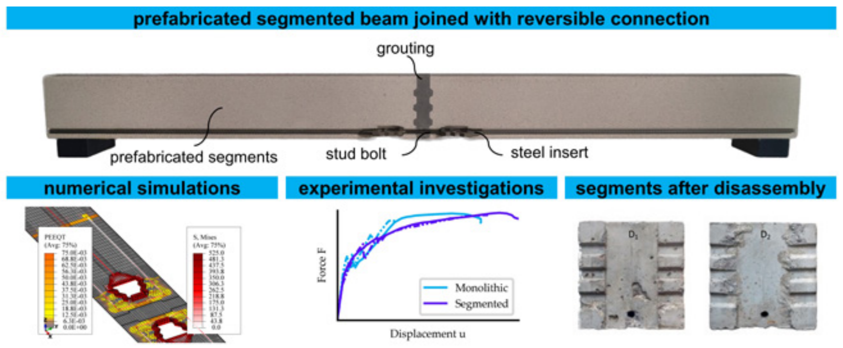

Fig 2 Abstract connection.

An additional series of tests were conducted, in which the assembly, disassembly, and reassembly process was performed in order to simulate the use, recovery, and reuse of segments.

It was demonstrated that the connection presents a potential solution to assemble segments into a continuous structure without compromising the load-bearing capacity or the deformation behaviour. Furthermore, it was shown that the connection enables assembly, disassembly, and subsequent reassembly of the segmented structure (Strahm et al. 2025).

Potential for application of results

The proposed design method for the segmentation of slabs in conjunction with the reversible connection allow for a demountable concrete slab system from which individual segments can be recovered following a selective dismantling of the structure and subsequently be reused elsewhere. The proposed methodology allows to include the Design for Reuse (DfR) and the Design for Disassembly (DfD) in the design process of on-way spanning concrete slabs. Future extensions of the suggested approach may include the application to existing concrete structures increasing the leverage of ecological impacts.

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Structural Performance and Finite Element Analysis of 3D-Printed Concrete Benches

09 **Rui Luo**
National University of Singapore

Project objectives and goals

3D concrete printing (3DCP) offers enhanced design flexibility, material efficiency, and faster production. However, its low tensile strength makes reinforcement essential for improving mechanical performance. Yet, integrating steel reinforcement, although essential for improving mechanical performance, often disrupts the printing path and complicates the process (Gebhard et al., 2021). Hybrid approaches, such as combining 3D-printed layers with pre-installed steel frameworks (Cao et al., 2024), can mitigate interlayer weaknesses but may lead to spatial conflicts in intricate geometries. Precast reinforcement elements, such as cages or meshes, are another option, as noted by Warsi et al. (2024). However, these often involve additional steps, such as grouting core concrete after curing, which reduces production efficiency.

Inadequate interlayer adhesion remains a critical challenge, significantly compromising structural integrity (Zhang et al., 2022). Addressing this issue requires incorporating interlayer bond performance into the ultimate limit state design to improve structural behaviour predictions. Consequently, the potential of 3DCP in load-bearing and complex-shaped structural applications remains underutilised.

The specific objectives include:

- Exploring and evaluating reinforcement strategies for 3D-printed concrete in unconventional geometries, with an emphasis on enhancing load-bearing capacity and durability.
- Investigating the structural performance of reinforced 3D-printed elements through experimental testing and validating the effectiveness of reinforcement placement strategies.
- Establishing a numerical simulation method that accurately considers interlayer bonding and separation, enabling parametric analysis and structural optimisation.

Description of method and results

Park benches were selected as the case study due to their medium-scale dimensions and geometric complexity, as shown in Fig. 1. Three prototypes were developed to explore fabrication strategies: Bench A, a monolithic 3D-printed concrete structure without reinforcement; Bench B, a hybrid design with a 3D-printed outer formwork, midsection steel reinforcement, and grouted core concrete; and Bench C, featuring pre-formed reinforcement placed 20 mm from the bottom edge during printing. A replica of Bench C was installed on campus to demonstrate its practical application.

To reduce embodied carbon, 30% of Ordinary Portland Cement (OPC) was replaced with Ground Granulated Blast Furnace Slag (GGBS). Concrete properties were evaluated through compressive and splitting tensile tests, and three-point bending tests on notched beams, with results of 65 MPa compressive strength, 4.5 MPa splitting tensile strength, and 55 N/m interfacial fracture energy. Experimental testing of the benches utilized roller supports at the bottom and a 30 cm steel plate at the top

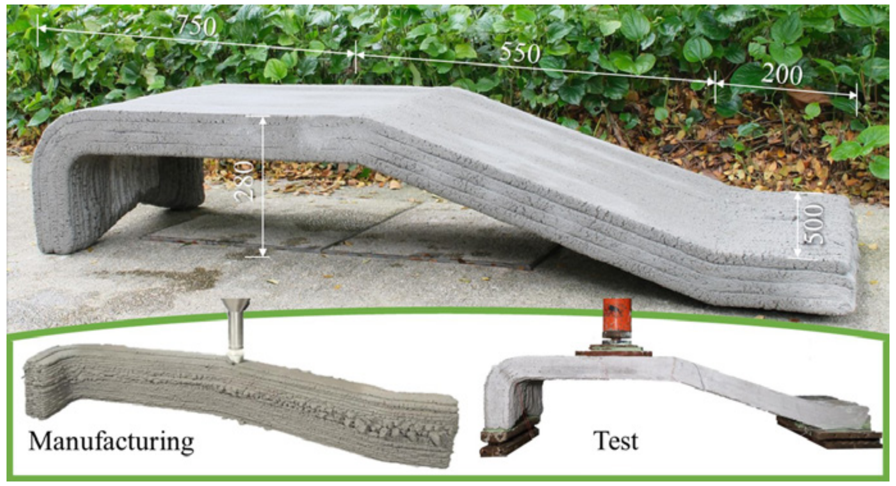

Fig 1 3D-printed concrete bench (unit: mm).

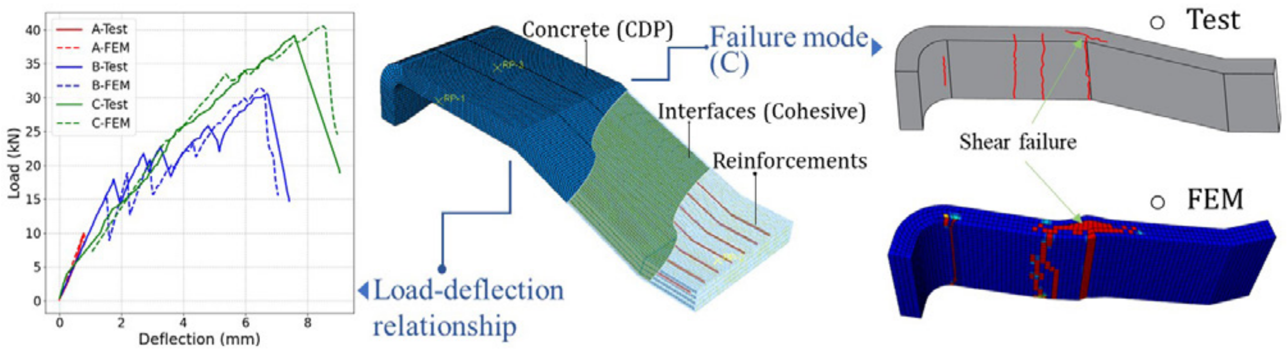

Fig 2 Numerical simulation.

midpoint to ensure uniform load distribution. A 10-ton MTS machine applied force-controlled loading at 20 kN/min until cracking, followed by displacement-controlled loading at 0.5 mm/min. Strain gauges were used for Benches B and C to measure strain distribution.

Finite element analysis (FEA) replicated the experimental loading process to investigate the structural behavior of the benches, as shown in Fig.2. The Concrete Damaged Plasticity (CDP) model was used to simulate cracking and damage evolution in the concrete. Zero-thickness cohesive elements modeled adhesion between layers and at new-old concrete interfaces, applying a traction-separation law based on notched beam fracture test data. Steel reinforcement was embedded in the concrete, with boundary conditions aligned closely with the experimental setup.

The results revealed distinct failure modes. Bench A exhibited brittle failure with abrupt collapse at 9.6 kN. Benches B and C demonstrated ductile failure with progressive cracking and higher ultimate loads (30.2 kN and 39.1 kN, respectively). Bench C's reinforcement placement improved structural performance, achieving smoother load-deflection behaviour and greater ductility compared to Bench B, which exhibited load oscillations due to delayed crack progression.

The numerical simulations effectively replicated the experimental load-deflection relationships, accurately capturing the crack progression and failure mechanisms of Benches B and C caused by shear stress concentrations at the slope corner. Parametric analyses revealed that reducing the reinforcement cover thickness to 20 mm resulted in a wider distribution of flexural cracks and allowed the reinforcement to reach its yield point at maximum load, maximising material efficiency. Increasing the section depth to 60 mm further enhanced load-bearing capacity. These findings underscore the potential of numerical simulations as a practical tool for optimising the structural design of 3D-printed concrete, facilitating efficient load-bearing designs while addressing performance, aesthetic, and practical constraints.

Potential for application of results

This study highlights the potential of combining optimised reinforcement strategies with numerical simulations to enhance the structural performance of 3D-printed concrete. Integrating reinforcement during printing effectively supports load-bearing designs and complex geometries. Future efforts should prioritise automated reinforcement placement to improve bonding and streamline layer-by-layer printing. These advancements could enable practical applications in pedestrian bridges, urban furniture, and architectural facades, promoting greener construction practices with low-carbon materials.

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Web Crippling Behaviour of Web-Perforated Cold-Formed Steel, Stainless Steel and Aluminium Sigma Sections

10 **Hasini Weerasinghe**
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Project objectives and goals

Sigma sections are an innovative Cold-Formed (CF) channel section profile widely used in the light gauge construction industry. With their optimised sectional geometry Sigma sections provide enhanced torsional rigidity, high stiffness, improved load-bearing capacity and economic efficiency compared to conventional lipped channel sections (Thirunavukkarasu et al., 2024). Hence, Sigma sections are often utilized as purlings, floor joists and side rails in thin-walled constructions. Owing to their high industrial demand Sigma sections are often manufactured from an array of materials including carbon steel, stainless steel and aluminium. These sections are often fabricated with web openings to facilitate the easy installation of service lines. However, these web perforations increase the susceptibility of member failure via web crippling, under transverse concentrated loading conditions (Weerasinghe et al., 2022). Nonetheless, no detailed investigations have been conducted on the web crippling response of web-perforated CF Sigma sections (Weerasinghe et al., 2023). Moreover, the existing design standards fail to provide design equations for predicting the web crippling resistance of web-perforated CF Sigma sections. Identifying the existing research gap, the present study aims to investigate the web-bearing resistance of web-perforated cold-formed steel (CFS), stainless steel (CFSS), and aluminium (CFAl) Sigma sections under Interior Two Flange (ITF) loading condition. The specific objectives of the study include:

- Conduct experimental investigations to evaluate the web-bearing resistance of web-perforated CFS, CFSS, and CFAl Sigma sections subjected to ITF load case.
- Develop and validate finite element models (FEM) for simulating the web crippling response of web-perforated CF Sigma sections under ITF loading condition.
- Conduct a comprehensive numerical investigation on the web crippling response of CF Sigma sections under ITF loading condition.
- Develop unified design equations for predicting the ultimate web crippling strength of web-perforated CFS, CFSS, and CFAl Sigma sections under ITF loading condition.

Description of method and results

A detailed experimental study was conducted to evaluate the web crippling response of web-perforated and unperforated CFS, CFSS, and CFAl Sigma sections,

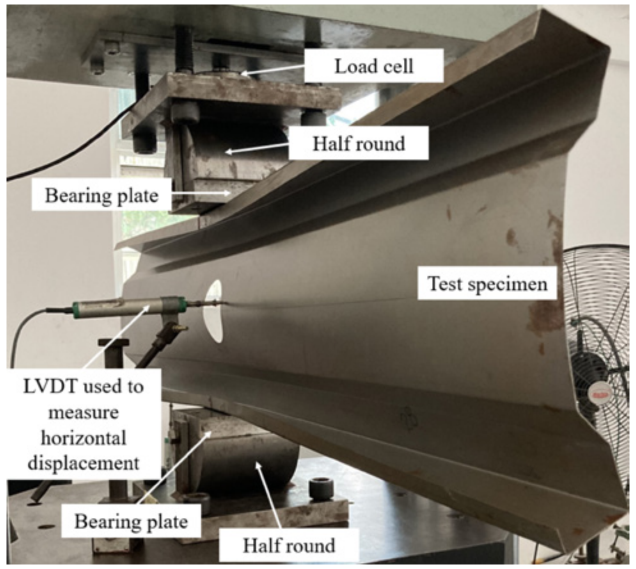

Fig 2 Model validation using load vs displacement plots.

subjected to the ITF load case. Initiating the study, 18 Sigma sections (six sections per material: two unperforated and four perforated sections) were fabricated considering the press brake operation. Subsequently, tensile tests were conducted to identify the mechanical properties of the selected materials. Web crippling tests were conducted adhering to the AISI S909 (AISI S909-17, 2018) test standard (Fig. 1). Further details about the experimental investigation can be found elsewhere (Weerasinghe et al., 2023) The effects of web opening depth and bearing length on web crippling resistance were evaluated by considering three web opening ratios (0, 0.3,0.6) and two bearing lengths (120 mm,150 mm), respectively.

Finite element (FE) models were developed for simulating the web crippling response of web-perforated CF Sigma sections under ITF loading conditions. Numerical simulations were carried out considering the general-purpose finite element software ABAQUS version 6.14 (2014). Experimental results were used to validate the developed FE models. Upon successful validation considering critical loading, load-displacement plots (Fig. 2) and failure modes, developed FE models were used to conduct a detailed parametric study to evaluate the web crippling resistance of web-perforated CFS, CFSS, and CFAl Sigma sections. The present study evaluated the effect of key parameters, including opening diameter, section depth, corner radius, section thickness, bearing length, yield strength and material type, on the web-bearing resistance of cold-formed (CF) Sigma sections. The web crippling strength of web-perforated CF Sigma sections displayed a negative correlation with the section depth, corner radius and opening diameter, while a positive correlation was exhibited with the section thickness, bearing length and yield strength parameters. Web-perforated CFSS Sigma sections displayed the highest web-bearing resistance values, while the lowest values were observed in CFAl sections. This behaviour can be attributed to the strain-hardening behaviour of CFSS sections and low elastic modulus values observed in CFAl sections, respectively. The results of the numerical investigation were compared with the web crippling strength value predictions of the existing design equations. Upon identifying the inadequacies of the existing design equations, a novel unified design equation was proposed under the present study to determine the ultimate web crippling strength of web-perforated CFS, CFSS, and CFAl Sigma sections under the ITF loading condition.

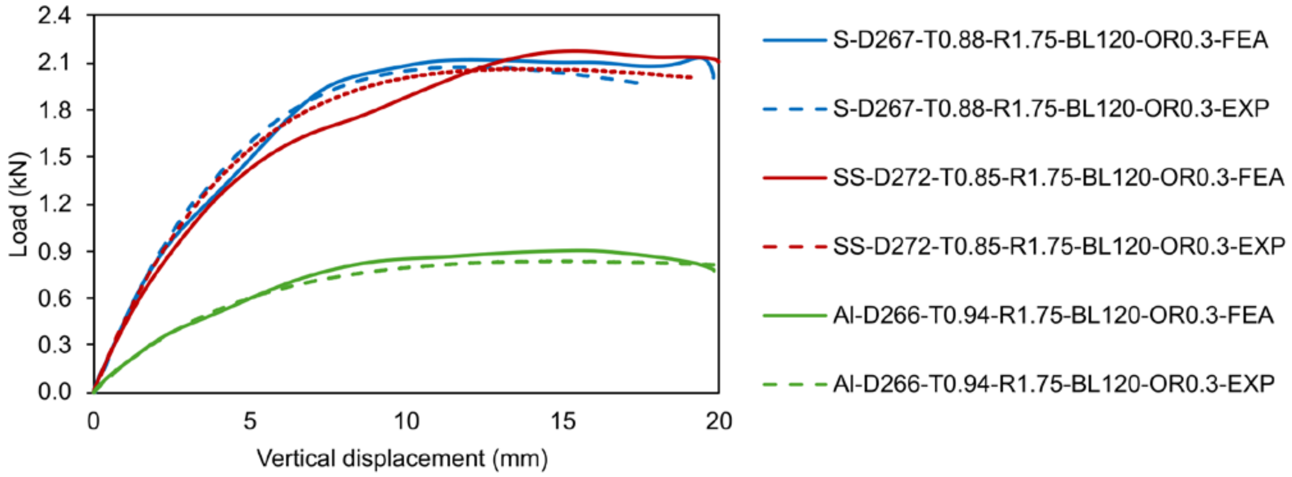

Fig 1 Web crippling test setup.

Potential for application of results

The findings of the present study offer valuable insights regarding the web crippling performance of web-perforated CFS, CFSS, and CFAl Sigma sections. The proposed unified design equation provides a reliable framework for the design of web-perforated CF Sigma sections under the ITF loading conditions, effectively addressing a significant limitation of the existing web crippling design equations. With further validations against a broader set of experimental data, these unified design equations can be integrated into future editions of the existing design guidelines, thereby encouraging the industrial applications of web-perforated CFS, CFSS, and CFAl Sigma sections.

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Innovative Bond-Slip Model for NSM FRP Systems for Concrete Structures

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Project objectives and goals

The primary objective of this research is to develop a robust bond-slip model for Near-Surface Mounted (NSM) Fibre Reinforced Polymer (FRP) systems that utilize cement-based adhesives for concrete structures. The specific goals include:

- Addressing limitations in existing models, particularly those designed for epoxy adhesives, by incorporating the main characteristics of the NSM FRP system using cement-based adhesives
- Employing Artificial Neural Networks (ANNs) to formulate predictive equations for key bond-slip parameters such as maximum bond stress, slip corresponding to maximum bond stress, and fracture energy
- Offering engineers and researchers practical tools to design efficient and sustainable retrofitting solutions for concrete structures using NSM FRP systems

Few models exist to predict bond strength in NSM FRP systems, with most focusing on epoxy adhesives. Seracino et al. (2007) developed an analytical model defining the debonding failure plane, while Zhang et al. (2013-2014) used fracture energy equations and a beam-spring model to estimate bond strength, considering cohesion failure in concrete. The ACI 440.2R (2017) standard suggests a constant bond stress of 6.9 MPa for all NSM FRP systems, regardless of FRP type or groove geometry. However, these models and guidelines consider only limited variables, such as concrete strength and groove dimensions, overlooking critical factors like the adhesive's mechanical properties. Therefore, this study develops a new bond-slip model incorporating mechanical and geometrical properties of cement-based adhesives.

Description of method and results

Methodology in this research is as follows:

1- Data Collection: This research used a database of 153 pull-out tests from existing literature to investigate the bond behavior of NSM FRP systems with cement-based adhesives for concrete structures. The study considered mechanical and geometrical properties of FRP, adhesive, and concrete, along with groove configurations. Key input parameters included:

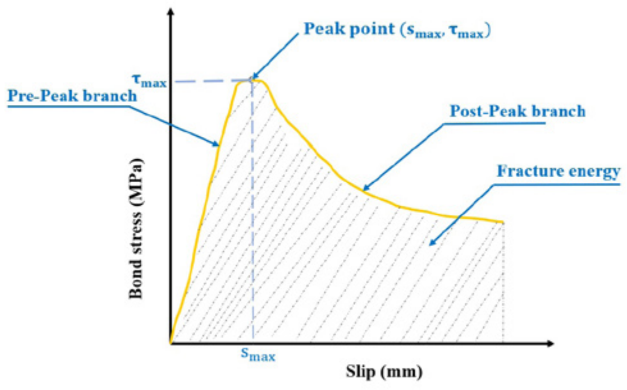

Fig 1 The bond-slip law.

- Concrete compressive strength
- Cement-based adhesive compressive strength
- FRP modulus of elasticity
- Groove dimensions and FRP cross-sectional characteristics

2- Artificial Neural Network (ANN) Development: ANN models with nine input parameters were developed to predict following key outputs as shown in Fig 1:

- Maximum bond stress
- Slip corresponding to maximum bond stress
- Fracture energy
- Pre-peak and post-peak bond-slip relationships

The dataset was split into training (70%), validation (15%), and testing (15%) subsets. A feedforward backpropagation ANN was employed with one hidden layer for simplicity and efficiency.

3- Equation Derivation: Using ANN-derived weights and biases, explicit formulas were developed to replace traditional "black box" ANN predictions.

4- Sensitivity Analysis: Sensitivity analyses were performed to evaluate the influence of each input variable on key outputs.

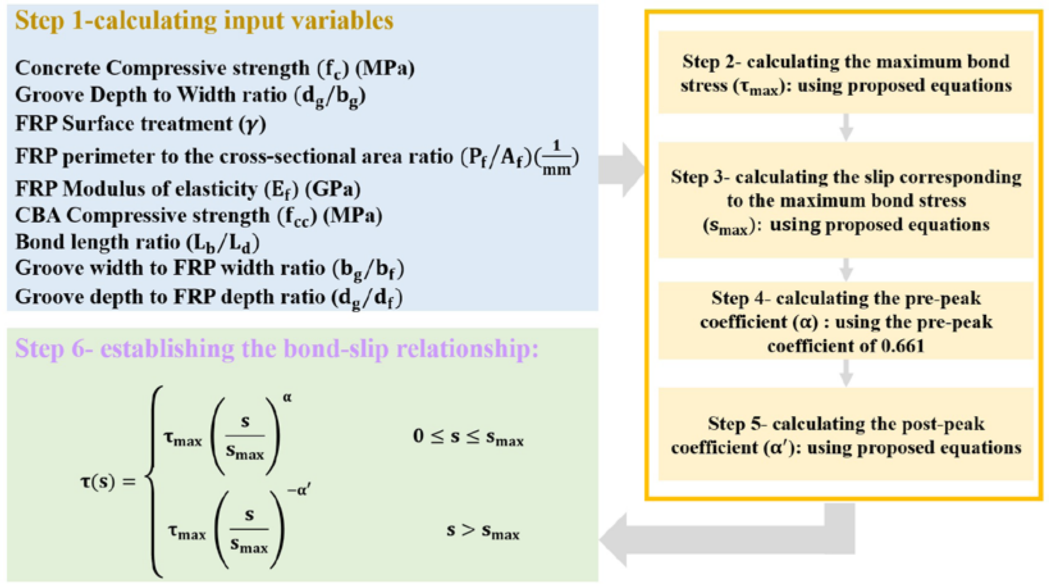

Fig 2 Recommended flowchart outlining the bond-slip law.

Results are as follows:

- The ANN models demonstrated high accuracy in predicting key bond-slip parameters, outperforming existing models such as those calibrated for epoxy adhesives.
- Predictions using proposed ANN models were validated against experimental data, demonstrating reliability across various adhesive properties and geometries for using the NSM FRP system using cement-based adhesives.
- Sensitivity Analysis revealed the relative importance of input parameters. For instance, adhesive compressive strength and groove depth-to-width ratios were identified as critical factors influencing bond behavior.

The model showed strong alignment with experimental data, validating its accuracy. A user-friendly flowchart, as shown in Fig 2, was provided to guide engineers and researchers in applying the developed bond-slip model effectively.

Potential for application of results

This research introduces a groundbreaking approach to designing NSM FRP systems, delivering significant benefits across multiple areas:

- Engineering Practice: Provides user-friendly formulas for accurately predicting bond behavior, enhancing design precision and efficiency.
- Sustainability: Advocates for cement-based adhesives as an eco-friendly alternative to epoxy, offering superior resistance to high temperatures and moisture.
- Standards Integration: Supports the incorporation of the model into structural engineering guidelines, enabling widespread practical adoption.
- Research Advancements: Establishes a foundation for applying AI-driven modeling techniques to advance structural engineering research and innovation.

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Push-out tests on stainless steel composite beams

12 **Rebecca Presswood**
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Project objectives and goals

Steel-concrete composite beams are widely used in bridge construction for their structural efficiency and versatility. The girders are typically formed of carbon steel, which is prone to corrosion, requiring coating and ongoing maintenance to prevent deterioration, which can have a significant impact on the life-cycle cost of the bridge. Corrosion is more critical for bridges near coastal areas or where de-icing salts are used.

Stainless steel girders offer a solution to the corrosion problem of composite beams in harsh environments. However, their design is outside the scope of current international design standards due to limited experimental data. Two options may be considered for providing the shear connection for composite action: stainless steel shear connectors, or carbon steel shear connectors, which are a cheaper alternative and would be protected from corrosion by the surrounding concrete slab. Limited tests have been carried out on stainless steel composite beams by Zhou *et al.* (2021), and the reliability of existing design equations for predicting stud resistance needs to be verified against stainless steel shear connectors. No tests have been carried out on carbon steel shear studs welded to stainless steel beams and the quality of the weld between the dissimilar metals must be assessed.

This research aims to investigate the structural behaviour of austenitic EN 1.4301 stainless steel SD3 and carbon steel SD1 shear studs welded to lean duplex EN 1.4162 I-section beams, focusing on the strength, ductility and weld quality of the studs. This will be achieved by:

- Testing the tensile strength and weld quality of austenitic EN 1.4301 stainless steel and carbon steel shear studs welded to lean duplex EN 1.4162 plates
- Conducting push-out tests on austenitic EN 1.4301 stainless steel and carbon steel shear studs welded to lean duplex EN 1.4162 beams
- Assessing the applicability of international design code stud resistance predictions for stainless steel composite beams

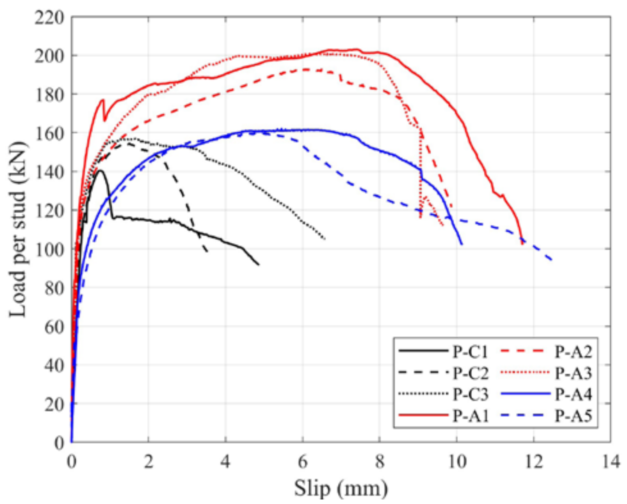

Fig 1 Load-slip response of push-out tests: P-C indicates carbon steel studs in C100 concrete, P-A1 to P-A3 indicate austenitic EN 1.4301 stainless steel studs in C100 concrete and P-A4 and P-A5 indicate austenitic EN 1.4301 stainless steel studs in C50 concrete.

Description of method and results

Tensile tests on welded studs were carried out to investigate any deterioration of mechanical properties arising from the welding process; five carbon steel studs and five austenitic EN 1.4301 stainless steel studs were arc stud-welded to lean duplex EN 1.4162 stainless steel T-sections and tested under tension until failure. X-ray computerised tomography (CT) scanning was used to observe the cross-sectional quality of the welds and microstructure analysis of the welds was carried out via etching.

Eight push-out tests according to Eurocode 4 were conducted on lean duplex EN 1.4162 composite specimens: three with carbon steel studs in C100 concrete, three with austenitic EN 1.4301 studs in C100 concrete, and two with austenitic EN 1.4301 studs in C50 concrete. Further detail on the tests can be found in Presswood *et al.* (2024). The results of the push-out tests are shown in Fig 1. The shear resistances obtained from the tests were compared to the predicted resistance by several international design codes, and to the resistances from push-out tests on carbon steel studs welded to carbon steel beams collected from the literature (Fig 2).

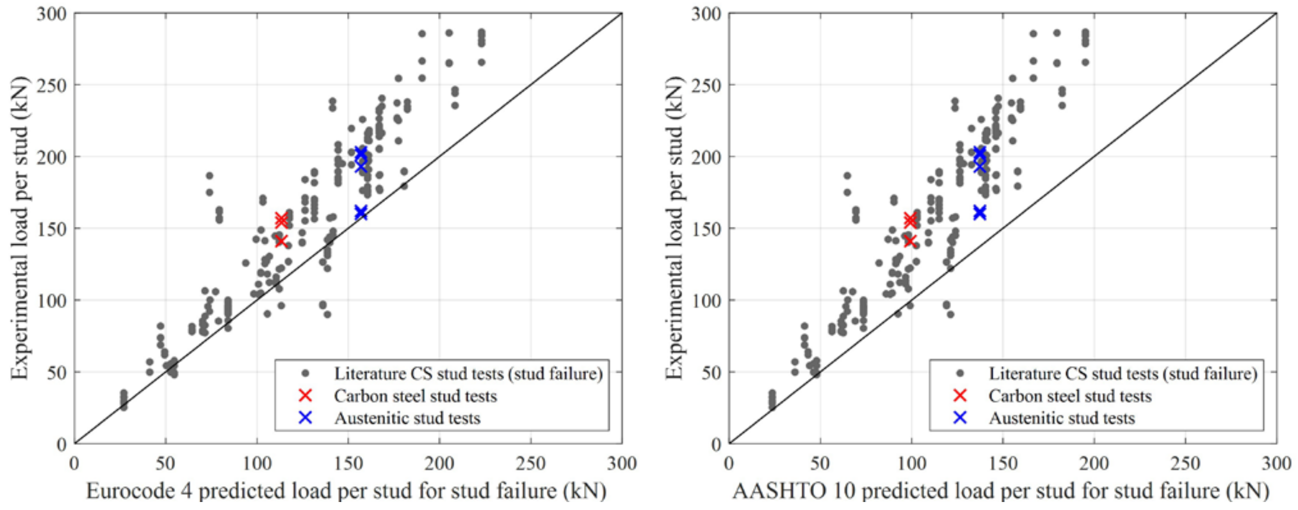

Fig 2 Comparison of test results with Eurocode 4 and AASHTO 10 predicted stud resistance for carbon steel stud push-out tests reported in the literature and push-out tests from this study.

Key findings include:

- The carbon steel studs welded to lean duplex EN 1.4162 plates demonstrated premature brittle failure in tension.
- The carbon steel stud welds contained large voids whereas the austenitic stud welds were more uniform.
- Excessive brittle martensite was present in the weld and heat-affected zone (HAZ) of the carbon steel specimens. The austenitic stainless steel stud welds contained a mixture of austenite and duplex in their microstructure.
- In push-out tests, austenitic stainless steel studs achieved significantly larger capacity and ductility than carbon steel studs, and met the Eurocode 4 ductility requirements.
- Carbon steel studs did not meet the Eurocode 4 ductility requirements. This was attributed to poor weld quality, which suggests that carbon steel studs should not be used in composite beams with lean duplex stainless steel sections.
- Stud resistance equations in Eurocode 4 and AASHTO 10 provide safe-sided predictions, with austenitic studs performing comparably to carbon steel studs from literature.

Potential for application of results

Life-cycle cost studies have shown that stainless steel girders can lead to a more economical solution than carbon steel girders in composite beams, especially in harsh environments, due to avoidance of repainting the steelwork (Schedin and Backhouse, 2019; Meza and Baddoo, 2023). No design codes currently exist for the design of stainless steel composite bridge structures; carbon steel design guidance is generally conservative when applied to stainless steels. The raw material cost of stainless steel grades is higher than that of carbon steel, and it is important to optimise design to reduce material consumption, which improves economic and environmental sustainability. These results will assist in the development of new design guidance, ensuring optimal and efficient design of sustainable stainless steel composite bridges.

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Development of Advanced Steel Modular Connections for Sustainable Modular Construction

13 **Kajeenthan Kamalaseelan**
University of Peradeniya

Project objectives and goals

The growing emphasis on sustainability within the construction industry has placed modular construction at the forefront of innovative solutions for the built environment. With its inherent advantages in efficiency, reduced waste, adaptability, and resource optimization, modular construction is increasingly being adopted as a sustainable alternative to traditional building methods (Lawson et al., 2012; Kamali & Hewage, 2016). A pivotal component of modular construction is the performance of steel modular connections, which serve as the critical elements for ensuring structural integrity, facilitating rapid assembly/disassembly, and meeting the demands of modern construction practices for resilience, adaptability, and sustainability. Despite the extensive research conducted on modular construction, the optimization of steel modular connections to enhance their mechanical performance, sustainability, and adaptability remains underexplored. Existing challenges include achieving superior structural efficiency while minimizing environmental impacts and addressing the increasing complexity of computational methods used in the design and validation of these systems.

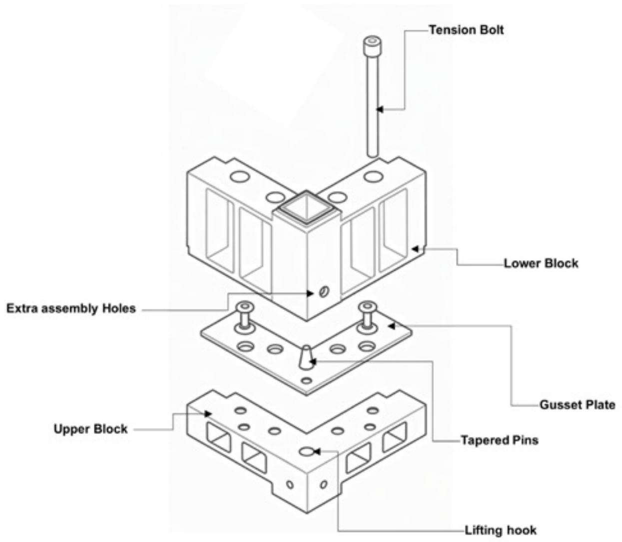

Fig 1 Proposed innovative steel modular connection.

The primary focus of this research is to develop and validate advanced steel modular connections that enhance performance, minimize environmental impact, and integrate cutting-edge computational methods. The specific objectives include:

- Employ advanced optimization techniques to enhance the strength, stiffness, and durability of steel modular connections, ensuring seamless assembly and disassembly for reuse or repurposing
- Conduct testing to evaluate the mechanical performance and failure mechanisms of modular connections under various loading conditions.
- Utilize parametric designs to explore and refine modular connection geometries for improved adaptability and functionality.
- Develop high-fidelity finite element models to simulate connection behaviour, providing detailed insights into stress distribution, deformation, and failure mechanisms.
- Incorporate sustainable practices by selecting eco-friendly materials, optimizing resource usage, and promoting reusability and recyclability.
- Leverage machine learning techniques to predict performance outcomes and guide the optimization of modular connection designs.

Description of Method and Results

This research aims to investigate the behaviour of advanced steel modular connections under various loading conditions, including axial, shear, and bending, to develop performance-based design guidelines for modular construction. The research adopts a comprehensive numerical approach, employing advanced computational methods to enhance the understanding of connection performance and address sustainability challenges in modular construction (Lawson & Ogden, 2020; Farmer, 2016). A critical component of the study involves finite element (FE) modelling, performed using ABAQUS/CAE (2017), renowned for its robust capabilities in analysing complex structural problems . The FE models are developed to simulate the behaviour of modular connections, providing detailed insights into stress distribution, deformation, and failure mechanisms under diverse loading conditions. These simulations facilitate the refinement of connection geometries, ensuring their strength, stiffness, and durability meet the demands of modern construction practices, as illustrated in Fig-1: Proposed innovative modular connector.

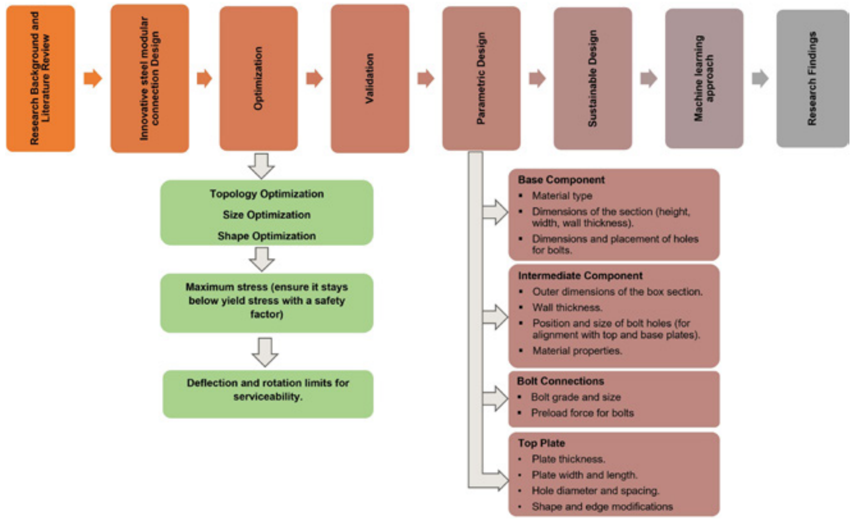

Fig 2 Proposed methodology of the research.

The research also incorporates advanced optimisation techniques, including topology, size, and shape optimisation, to achieve superior structural efficiency while minimising material usage and environmental impact (Gibb & Isack, 2023). The optimisation process ensures that maximum stress remains below the yield stress with a safety factor, and serviceability criteria such as deflection and rotation limits are satisfied.

In addition to numerical modelling and optimisation, the study explores parametric design approaches to refine modular connection geometries, enhancing their adaptability and functionality. Parametric design enables the systematic evaluation of design variables, such as material type, dimensions of components, and bolt configurations, to achieve optimal performance. Testing and validation of the modular connections are conducted to evaluate their mechanical performance and failure mechanisms under varying conditions, ensuring the reliability of the proposed designs (Lawson, Ogden & Bergin, 2022). The overall process is systematically detailed in Fig-2: Proposed research methodology.

A significant innovation in this research is the integration of sustainable practices, such as the use of eco-friendly materials, resource optimisation, and promotion of reusability and recyclability in modular construction (Kadir et al., 2019). Machine learning techniques are also leveraged to predict performance outcomes, providing a data-driven approach to guide the optimisation and design of modular connections.By addressing the interplay of structural performance, sustainability, and adaptability, the expected outcomes of this research include the development of high-performance steel modular connections that align with the principles of sustainable construction, offering innovative solutions to the challenges of modern construction practices. These advancements are expected to contribute significantly to the efficiency, resilience, and environmental sustainability of modular construction systems.

Potential for Application of Results

Advanced steel modular connections represent an excellent solution for achieving high structural capacity with efficient material usage in sustainable modular construction. However, the performance of these connections under various loading conditions must be thoroughly understood to prevent failures, particularly under dynamic and cyclic loading scenarios. The proposed design guidelines and optimization strategies are crucial for addressing this gap in the current design framework. By integrating the optimized design parameters and performance predictions, these results ensure that modular steel connections can be implemented with enhanced safety, reliability, and efficiency in the construction of sustainable modular buildings.

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Further study on the preparation of a resistance formula for net-tension failure of single and multi-rowed bolted connections of fibre-polymer composites

14 **Abdul Mahboob Samsor**
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Introduction & Objective

This study focuses on developing a reliable resistance formula for net-tension failure in bolted connections of fibre-polymer composites, particularly addressing the 4×4 bolting configuration. Using experimental testing and analytical modelling, the research evaluates stress concentration factors as per the CEN/TS 19101:2022 standards. The experiments involved tensile testing of precision-machined specimens to determine the stress concentration factor (k_{tc}), for the 4×4 configuration. These findings advance the design options for bolted connections in fibre-polymer composites and contribute to standardizing design procedures under the Eurocode framework. The study enhances understanding of multi-row bolted configurations, aiding structural integrity and safety in composite applications.

Methodology

The study utilized an olive-green, 1500 Series ¼ in. (6.4 mm) thick pultruded flat sheet, manufactured by Creative Pultrusion Inc. (now Creative Composite Group). Specimens for the 4×4 bolted connections, as shown in Figure 1, were prepared per the geometric requirements in Table 11.1 and guidelines in sub-clause 12.2.3.1 of the TS standard (CEN/TS 19101:2022), focusing on net-tension failure and resistance calculations. High-precision fabrication was achieved using a CNC machine, maintaining cut length tolerances within ±0.2 mm, squareness of cuts within ±1°, and hole location tolerances within ±0.01 mm. The symmetrical connection geometry featured four rows and columns of bolts, tested in a double-lap shear joint to minimize out-of-plane deformations. The pultruded plate, placed between two 10 mm S355 steel plates, was fastened using M10 grade 8.8 steel bolts and 2.2 mm thick washers, with 11.6 mm bolt holes providing a clearance of 1.6 mm. Bolts were centrally positioned within oversized holes and tightened to low torque for uniform load distribution, while minimum end and edge distances of 2d and bolt spacing of 4d were maintained. Tensile tests on five specimens, conducted using a hydraulic testing machine at a constant stroke rate of 0.01 mm/s, revealed net-tension failure in the first row of bolts, as shown in Figure 1.

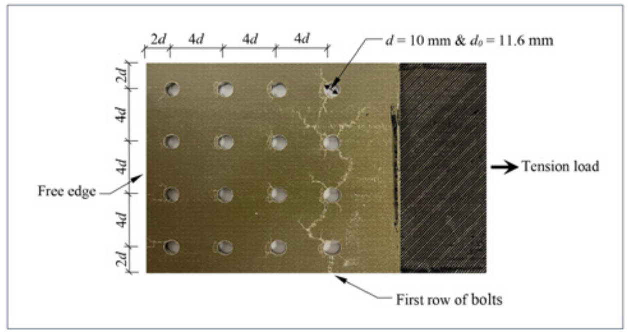

Fig 1 Photograph of 4×4 bolted connection post-tensile testing, exhibiting the net-tension mode of failure at the bolts first row.

Key Findings and Conclusion

To use a design procedure for single and multi-bolted connections in the European CEN Technical Specification CEN/TS 19101:2022, it is necessary to have experimental test results to determine a stress concentration factor for each bolted connection configuration. Currently, the TS presents nine stress concentration factors but does not scope the configuration having four rows of four bolts, which is referred to as the 4×4 configuration. In this paper, new experimental-derived test results that satisfy the requirements of the TS (in Clauses 11 and 12) are reported. Analysis of these results finds that for this 4×4 bolt connection, the stress concentration factor is 1.3. This is a very encouraging outcome because 1.3 is found to be identical to the mean stress concentration factor for 3×3 bolted connections of pultruded materials. Finally, the authors recommend that the 4×4 configuration could be introduced into the TS by specifying that its stress concentration factor is 1.5, which is identical to its value for the 3×3 case. The proposed 1.5 is half the stress concentration factor recommended in TS for this configuration.

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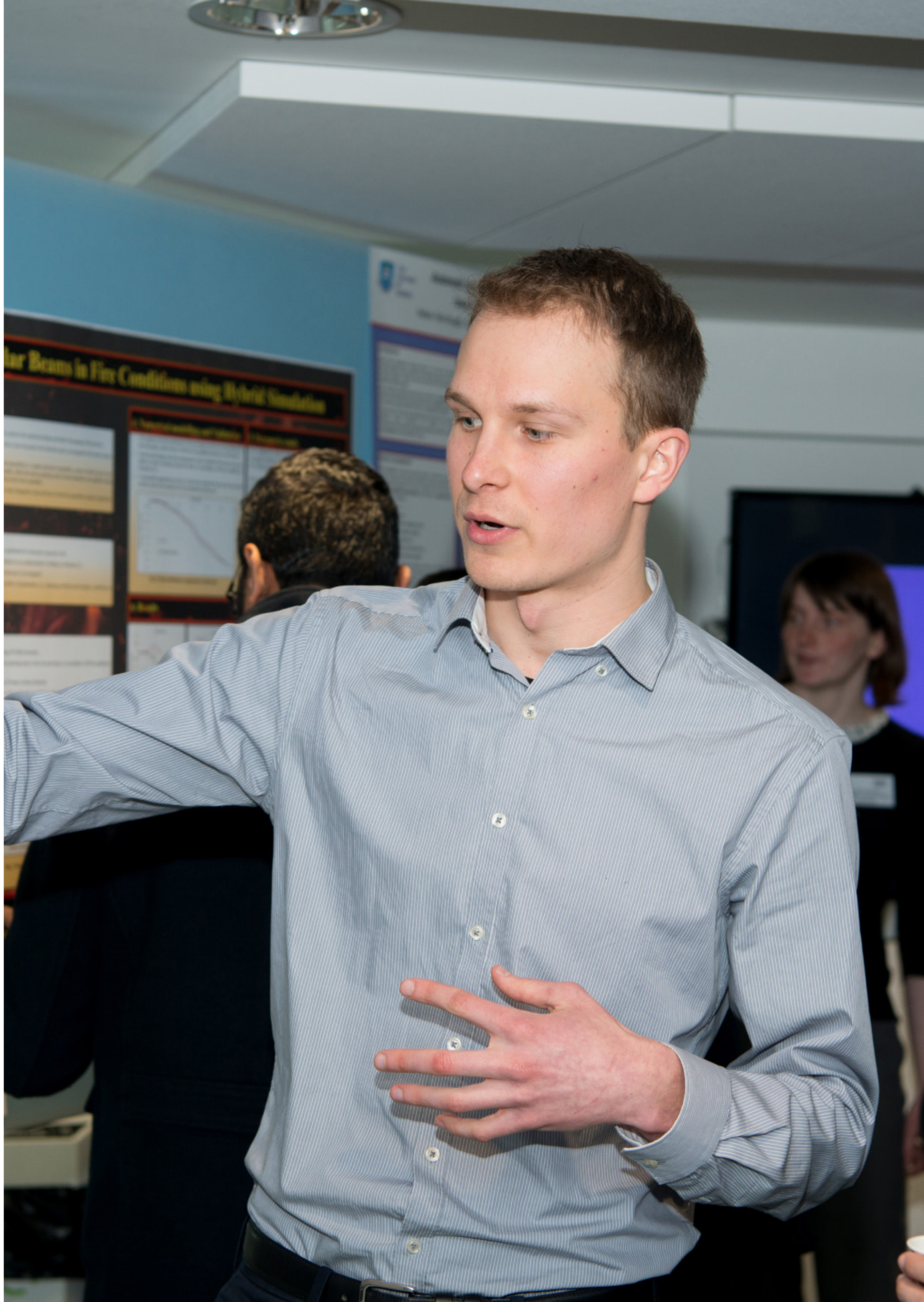

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