

Proceedings of the

# 28<sup>th</sup> Young Researchers Conference

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19 March 2026

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## Conference sponsor



### Arup

Arup is a global collective of designers, engineers, and consultants, working across the built and natural environment. Independent and purpose-driven, we bring imagination, rigour, and care to complex challenges – shaping sustainable, resilient places, infrastructure and systems that improve lives and help shape a better world for clients, communities and future generations.

[www.arup.com](http://www.arup.com)



### IABSE (British Group)

IABSE (International Association for Bridge and Structural Engineering) is a long established and well-respected international association dedicated to developing, sharing and disseminating structural engineering knowledge and expertise among its members. The British Group comprises those members currently working in the UK and organises a variety of events and meetings in the UK.

[www.iabse.org.uk](http://www.iabse.org.uk)

## Conference Programme – 19 March 2026

09:30	Registration and networking
<b>Conference starts</b>	
10:00	<b>Chair's welcome</b> Peter Winslow
10:10	Keynote address: <b>Beyond the Paper: Scaling innovation to create the future you want to see</b> with Q&A Pippa Horton, Co-Founder and Chief Growth Officer, Reclinker
10:40	Judging panel introduction
<b>Session 1</b>	
10:45	Research presentation 1: <b>Elastic buckling formulae for web crippling of square and rectangular hollow sections under concentrated transverse forces</b> with Q&A Ruikai Dai, Imperial College London
11:05	Research presentation 2: <b>Seismic performance of modular steel structure with a self-centering connection system</b> with Q&A Yan Yang, University of Bristol
11:25	Break
<b>Session 2</b>	
11:45	Research presentation 3: <b>Hybrid T-joints featuring 3D printed details: optimisation and experimental verification</b> with Q&A Tong Hu, Imperial College London
12:05	Research presentation 4: <b>From paper cuts to earthquake protection: Kirigami as a seismic damper</b> with Q&A Sahand Khalilzadeh Tabrizi, University of Surrey
12:25	Research presentation 5: <b>Load introduction mechanism in CFST columns with blind-bolted shear connections</b> with Q&A Weijie Ning, Hong Kong Polytechnic
12:45	Lunch break
<b>Session 3</b>	
13:45	Research presentation 6: <b>Experimental investigation of two-side fastened roof diaphragms made of trapezoidal sheets</b> with Q&A Barnabas-Attila Lorincz, Technical University of Cluj-Napoca
14:05	Research presentation 7: <b>Utilisation of pumice for low carbon lightweight structural concrete</b> with Q&A Gaurav Kirti Patel, University of East London
14:25	Research presentation 8: <b>Experimental investigation of corrosion effects on the structural performance of reinforced concrete slabs incorporating distributed fibre optic sensing</b> with Q&A Saba Ghassemi, University of Southampton
14:45	Audience poll
14:55	Break
<b>Session 4</b>	
15:15	Guest speaker: <b>Combining thrust line masonry theory with finite element analysis to investigate low carbon recycled concrete floorplate systems</b> with Q&A Sam Gardiner, Structural Engineer, Arup
15:35	Certificates and prizegiving
15:45	Chair's closing comments
15:55	Conference ends

**To note:** the programme is subject to change.

## Poster presentations

**A novel scissor-assisted active tuned mass damper inerter: Design and performance evaluation**

(Synopsis 3)  
Yuqiu Wei – University of Nottingham Ningbo

**Developing green ecological concrete with porous sponge technology**

(Synopsis 5)  
Yasir Al-Okbi – University of Florida

**Buckling behaviour of composite concrete-filled tubular flange beam**

(Synopsis 6)  
Rana Al-Dujele – Brunel University

**RGB filter analysis for fatigue damage in high-strength reinforcement**

(Synopsis 10)  
Jorge Egger – University of Chile

**Appraisal of split pylon cable-supported bridges subjected to gravity loads**

(Synopsis 11)  
Wenchao Li – University of Sheffield

**Bio-inspired cold-formed steel built-up section members using an interlocking design: concept and behaviour**

(Synopsis 12)  
Ke-Jiang Zhan – Hong Kong Polytechnic University

**Analysis of the delamination mechanisms of mass timber products**

(Synopsis 13)  
Liliana Mladenova – Abertay University

**Experimental investigation of lightweight cold-formed steel frames with semi-rigid connections**

(Synopsis 15)  
Ansuman Panda – Imperial College London

**Enhancement of recycled cementitious materials by accelerated carbonation**

(Synopsis 16)  
Henrique Comba Gomes – University of Plymouth

**Robustness-based design of precast concrete structures**

(Synopsis 19)  
Sepideh Akbari – Imperial College London

**Numerical simulation of anisotropic plastic compressive behaviour and failure mechanisms of timber for TCC applications**

(Synopsis 21)  
Thilakshi Hiyare Gamage – University of East London

## Keynote Speaker



### Pippa Horton

Pippa is Co-Founder and Chief Growth Officer of Reclinker, leading the commercialisation of breakthrough low-carbon cement technology to decarbonise one of the world's most carbon-intensive industries. She has supported three University of Cambridge spin-outs – Deepform, Structural PANDA and Reclinker – and previously worked in Clean Energy & Climate Investment at Legal & General. Pippa focuses on scaling innovation and accelerating the transition to a low-carbon built environment.

## 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

## Conference Team

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

### Presentation Selection Panel:

**Dr Rabee Shamass** – Brunel University  
**Prof. Jason Ingham** – University of Auckland  
**Tony Jones** – MPA The Concrete Centre  
**Dr Yung-Tsang Chen** – University of Nottingham Ningbo  
**Dr Martin Walker** – University of Durham  
**Dr Matthew Poulton** – COWI

### Conference Judging Panel:

**Prof. John Forth** – University of Leeds  
**Dr Michaela Gkantou** – Liverpool John Moores University  
**Fernando Madrazo-Aguirre** – COWI  
**Dr Youguang Pan** – Sir Robert McAlpine

### Poster Presentation Judging Panel:

**Dr Ross Johnston** – Amphora Consulting  
**Dr Donya Hajializadeh** – University of Surrey  
**Dr Matthew Poulton** – COWI  
**Dr Luke Lapira** – UCL  
**Prof. Su Taylor** – Queen's University Belfast  
**Dr Ilanildo Dias** – M & P Gadsden  
**Dr Gary Robinson** – Ridge & Partners LLP  
**Dr Allin Azerbakht** – AtkinsRealis

### IStructE Support:

**Jane Black** – Head of Technical Committee Services  
**Rebecca Cohen** – Technical Committee Executive  
**Olga Žarnicka** – Training and Events Executive

## Guest presenter



### Sam Gardiner

Sam is a chartered structural engineer in one of Arup's London Buildings teams. He has experience in navigating the complexities of constrained central London developments, both for new-build and retrofit construction. Sam is passionate about architecturally driven projects and for the last two years has worked on detailed design development of the Glory Facade at Sagrada Familia, where his digital skills are enabling the team to overcome complex design and analysis challenges. Sam is also committed to harnessing innovative digital workflows to design and construct sustainable structures that meet the demands of the future.

**Presentation title: Combining thrust line masonry theory with finite element analysis to investigate low carbon recycled concrete floorplate systems**

The speaker will be presenting advanced masonry design methods developed by Arup, which are now being used to investigate the feasibility of salvaged concrete block and mortar floor systems. This research aims to address the significant challenge associated with reinforced concrete end of life, by opening up opportunities for re-use through innovative design. Combining classical thrust-line and plastic theory with Eurocode 6 and bespoke finite-element modelling has enabled the team to explore range of vaulted geometries, ultimately aspiring towards a low carbon floorplate for use in everyday commercial office applications. This research is currently being funded by Arup and Innovate UK, and the team are in the process of building a full-scale prototype.

## 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.

### Professor Jason Ingham

BE(Hons), ME(Dist), PhD, MBA, FEngENZ, FStructE



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 P.A. Muhammed Basheer, CBE FREng

PhD, DSc, FIAE, FICE, FStructE, 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 MStructE



Eva is the Principal Engineer of the System Review 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 for NHBC to support Modern Methods of Construction Eva was key member in setting up the NHBC System Review service. Under this scheme her team is responsible for assessing Innovative Systems and Prefabricated Building Units and assisting Manufacturers and Products Owners to develop and establish innovative systems and construction methods acceptable to use in

the UK construction market. Her team is also working in collaboration with NHBC Foundation to publish research papers for the industry.

## Tony Jones

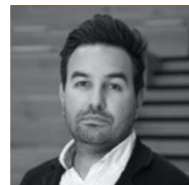
PhD, CEng, FICE, FStructE



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, MStructE, CEng



Dr Ghiassi is an Associate Professor of Sustainable Infrastructure Materials and a Chartered Structural Engineer (MStructE, 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

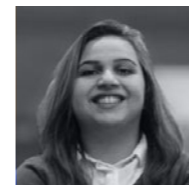
BEng (Hons), MEng, PhD, CEng MICE, MIEI, EUR ING, MWES, FHEA



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

BSc, MSc, PhD, FHEA



Rwayda is a Dame Kathleen Ollerenshaw Fellow at The University of Manchester. Rwayda's research focuses on the resilience of structures. Her research goals are accelerating the building of climateproof 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, MStructE



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, MStructE, 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.

## Dr Youyi WEI

BEng, PhD, CEng, MStructE, 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, FStructE, FICE, MHKIE, CEngNZ**



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, MStructE**



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, MStructE, 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

competition and published more than 40 journal articles.

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, MStructE, 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.

## 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, MStructE**



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, MStructE, 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

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**MEng, PhD**



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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

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**PhD, CEng, MStructE**



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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.

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Makonnen is a Principal Engineer and Lead Technical Authority at Transport for London with over 25 years of post doctoral experience in railway and multidisciplinary transportation infrastructure. He is a Fellow of both IStructE and CIHT and has led major

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Anil is a Principal Engineer and the Lead Technical Authority for Surface Assets at Transport for London (TfL), providing strategic technical leadership in the design, management, and assurance of bridges, structures, and tunnels across the network. With more

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He served as the Technical Authority and Structures Lead on the Silvertown Tunnel project in East London. Recognised as TfL's Subject Matter Expert for structural assets, he drives innovation, best practice, and robust technical governance to enhance the safety, climate change resilience, and performance of London's transport infrastructure.

## Dr Luke Lapira

**PhD, DIC, MSc, BE&A (Hons), Perit FHEA**



Luke is a Lecturer in Structural Engineering and Design in the Department of Civil, Environmental and Geomatic Engineering at University College London. He obtained his PhD in Structural Engineering from Imperial College London, where he investigated

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His research focuses on structural instabilities of steel and stainless steel structures, with particular interests in their structural health assessment and performance in fire scenarios. Luke's work combines advanced nonlinear finite element analysis with experimental work, with a focus on deriving practical guidance for researchers and structural designers. Luke has several years of professional design experience in Malta as an architect and structural engineer, which he brings into his research and teaching.

## Dr Nicola Chieffo

**BSc, MSc, PhD, FHEA, GStructE**



Dr Nicola Chieffo is a Lecturer in Civil Engineering at the University of Huddersfield. His research lies at the intersection of structural engineering, disaster risk reduction, and the resilience of existing and historic masonry buildings in hazard-prone

urban environments. He is a member of the CERU – European Centre of Urban Risk and Risk KAN – Vulnerability Dynamics in (Multi-)Hazard Risk Research. He has collaborated with ReLUIS (the University Network of

Seismic Engineering Laboratories) and the Italian Civil Protection Department on assessing the seismic vulnerability of masonry buildings across Italian municipalities, carrying out urban-scale vulnerability and risk analyses. His expertise includes the development of stage-damage curves, loss estimation methodologies, and disaster risk management strategies. His current research further explores climate adaptation for cultural heritage, integrating AI-based approaches and satellite data for hazard modelling, vulnerability assessment, and flood analysis, as well as leveraging digital technologies to support evidence-based decision-making for resilience planning and humanitarian response.

## Dr Allin (Alireza) Azarbakht

**PhD, CEng, MStructE, FHEA**



Dr Allin (Alireza) Azarbakht is a Principal Structural Engineer at AtkinsRéalis with more than twenty years of combined academic, research, and industry experience in earthquake engineering, advanced structural dynamics, and the design of safety-critical infrastructure.

His work blends rigorous research expertise with the delivery of major international projects in nuclear, seismic, and high-rise structural engineering.

Allin has held several former academic appointments, including serving as an Associate Professor in structural engineering, alongside roles as a Research Fellow in Earthquake Engineering at the University of Strathclyde and Lecturer in Structural Engineering at the University of Greenwich. Across these posts he taught extensively in structural analysis, seismic engineering, finite-element modelling and reinforced-concrete design, while supervising numerous postgraduate research projects, leading curriculum development, and contributing to knowledge-exchange and programme accreditation. As co-leader of Work Package 3 in the €8M EU Horizon TURNkey project, he advanced methodologies in operational earthquake forecasting, early-warning systems, and rapid seismic-response strategies.

In industry, Allin is the technical lead and asset manager for the TG Set Substructure design on EDF's EPR2 nuclear programme. His portfolio also includes leading seismic design for the British Embassy redevelopment in New Delhi, and guiding performance-based seismic assessment for the 170-m Mirage Tower within the NEOM Trojena MVC CAT III programme.

A Chartered Structural Engineer and Fellow of the Higher Education Academy, Allin has published extensively on seismic hazard, nonlinear structural response, and resilience of critical infrastructure.

# Elastic buckling formulae for web crippling of square and rectangular hollow sections under concentrated transverse forces

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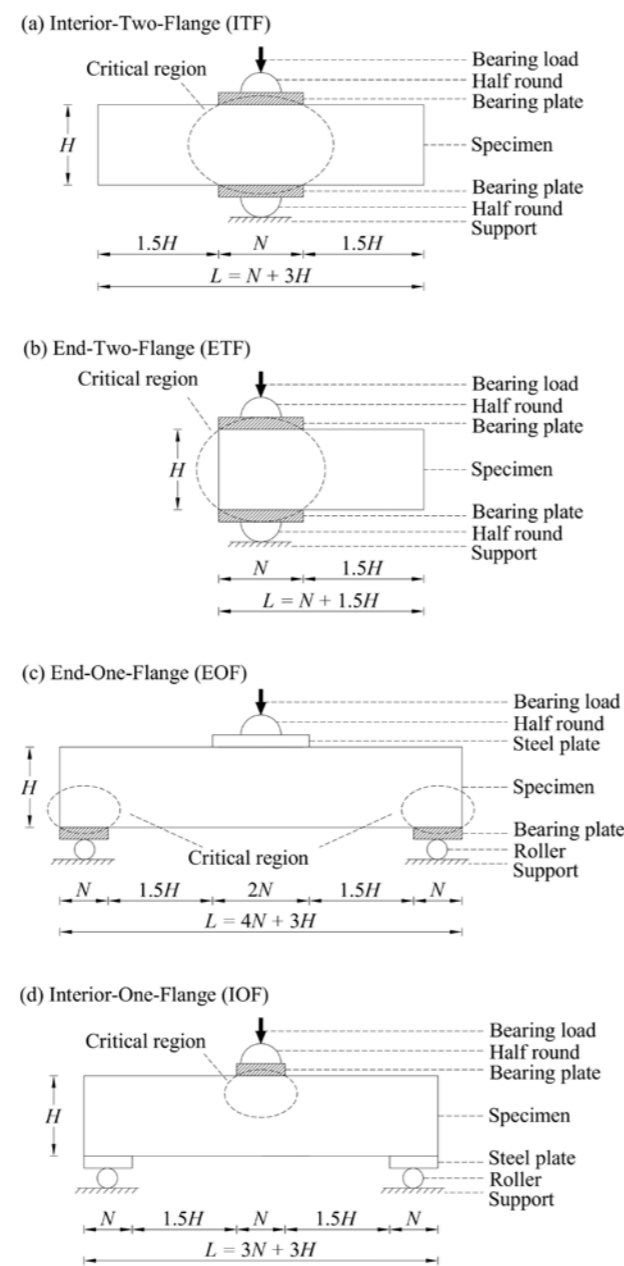
## Project objectives and goals

Structural steel members subjected to concentrated transverse forces are known to be susceptible to web crippling failure, particularly if the influenced region is unstiffened. Stiffening of tubular members is inconvenient and uneconomical. Hence, these sections are particularly vulnerable to web crippling failure and thus require suitable design provisions. The principal focus of existing investigations have been on the web crippling ultimate resistance under four standard loading conditions specified in the North American Specification (NAS, 2016) and Australian/New Zealand Standard (AS/NZS, 2018), namely the Interior-Two-Flange (ITF), End-Two-Flange (ETF), Interior-One-Flange (IOF) and End-One-Flange (EOF) loading conditions, as demonstrated in Fig 1.

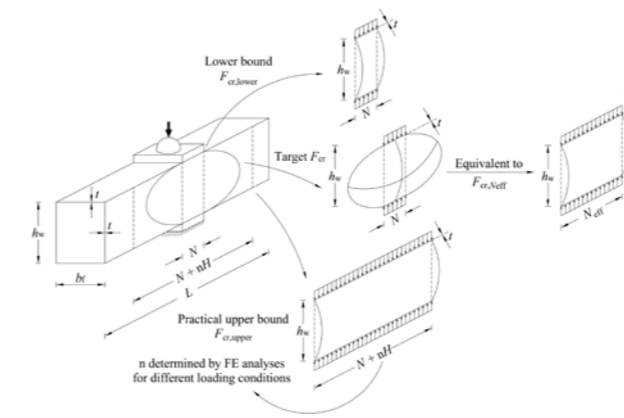
Structural instability phenomena are typically treated in international design standards using strength curves, formulated on the basis of the normalised slenderness of the element. This has not, thus far, been the case for web crippling design, revealing inconsistencies. Within the calculation procedure, the elastic buckling load for web crippling is inherently required, for which existing investigations are scarce. Hence, the current study aims to bridge this gap by developing formulae for predicting the elastic buckling load for web crippling of SHS and RHS members under concentrated transverse forces, covering the four standard loading conditions specified in NAS and AS/NZS and their transitional cases.

## Description of method and results

The underlying general concept for the currently developed approach, as illustrated in Fig 2, is that the elastic buckling load for web crippling of SHS and RHS members, denoted as  $F_{cr}$ , is between a theoretical lower bound  $F_{cr,lower}$ , where no adjacent region beyond the bearing length is mobilised, and a practical upper bound  $F_{cr,upper}$ , where the adjacent region is mobilised to its maximum extent. The theoretical lower bound  $F_{cr,lower}$  is the elastic buckling load of a wide plate with cross-sectional dimensions  $N \times t$  and length  $h_w$  with partially restrained boundary conditions along the loaded edges (arising from the rotational restraint afforded by the flanges) and free boundary conditions along the unloaded edges. A practical upper bound for the maximum influenced length, generally formulated as  $N+nH$ , is proposed based on finite element (FE) analysis results for different loading conditions (i.e.,  $n = 2$  for ITF and  $n = 0.5$  for ETF). Where the target elastic buckling load for web crippling  $F_{cr}$  lies between these two bounds is expressed



**Fig 1 Demonstration of the (a) Interior-Two-Flange (ITF) (b) End-Two-Flange (ETF) (c) End-One-Flange (EOF) and (d) Interior-One-Flange (IOF) loading conditions defined in the NAS and AS/NZS design provisions**



**Fig 2 Demonstration of the general concept of the lower and upper bounds to the target elastic buckling load of an RHS member subject to concentrated transverse loading**

through the mobilisation coefficient  $\zeta$ , which ranges from 0, for no mobilisation, to 1, for maximum mobilisation. Hence, the target elastic buckling load can be expressed in a general form thus:

$$F_{cr} = F_{cr,lower} + \zeta (F_{cr,upper} - F_{cr,lower}) \quad \text{where } 0 \leq \zeta \leq 1. \quad (1)$$

Numerical models have been developed within the commercial package ABAQUS to simulate the web crippling behaviour of SHS and RHS members. The 4-noded 'S4R' shell element was employed, with a general mesh size of approximately 5 mm and a refined mesh size of approximately 2.5 mm in the curved regions of the rounded corners and in the vicinity of the bearing loads and supports. A Young's modulus  $E = 210,000 \text{ N/mm}^2$  and a Poisson's ratio  $\nu = 0.3$  were assumed throughout the study; the proposed formulae do however apply to all isotropic materials. Instead of modelling the bearing and support plates explicitly, the loads transferred into the structural member are modelled through uniformly distributed loads directly applied to the contacting nodes; these nodes should lie along the intersections between the flanges and the corner radii, and within the bearing and support plate lengths. With this modelling technique, the load eccentricity to the webs owing to the corner radii is also reflected. The boundary conditions employed in the FE models vary with different loading arrangements, as described by Dai et al. (2025). The linear bifurcation analyses (LBA) were conducted with unit loads, such that the elastic critical buckling loads were directly linked to the output eigenvalues. The developed numerical models were validated against known analytical results and were subsequently employed to conduct a comprehensive parametric study that encompasses the four standard loading conditions specified in NAS and AS/NZS and their transitional cases.

The general equation is rearranged to develop predictive formulae for the mobilisation coefficient  $\zeta$ , where the target elastic buckling load for web crippling  $F_{cr}$  in Eq. (1) is substituted with the FE results. The functions for  $\zeta$  are first developed and assessed for the standard ITF and ETF loading conditions; the transitional case between the ITF

and ETF loading conditions is subsequently considered, featuring the influence of the clear distance from the edge of the bearing forces to the free end. After the general two-flange loading cases are resolved, the transitional cases from ETF to EOF loading conditions, and from ITF to IOF loading conditions, are considered, respectively. For these transitional cases, the critical buckling mode is not always web crippling dominant, but can also be bending or shear dominant, owing to the inevitable coexistence of bending and shear inherent within the loading setup. Hence, the cases where web crippling is dominant or at least influential are considered herein to avoid the excessive unfavourable side effects from coexisting bending and shear. Overall, the developed formulae are shown to provide accurate and safe sided predictions that are typically within 5% of the numerical values.

## Potential for application of results

The developed formulae can be employed as a convenient alternative to numerical methods to predict the elastic buckling loads for web crippling of SHS and RHS members subjected to concentrated transverse forces. The adopted functions and required calculations are straightforward and explicit, which lend themselves to programming and tabulation in engineering design practices. The proposed elastic buckling formulae constitute an important part in the ongoing development of a novel design approach for web crippling resistance that is consistent with those for other general structural instability phenomena in international design provisions.

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# Seismic performance of modular steel structure with a self-centering connection system

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## Project objectives and goals

Modular steel structures have garnered widespread attention in the construction industry, as they effectively address the growing demands of urbanisation while promoting eco-friendliness and sustainable building practices. This construction method involves the off-site fabrication of volumetric modules in a factory-controlled environment, followed by on-site assembly to form a complete building. Inter-module connections are used to assemble the modular units into a complete structure. Various inter-module connections have been developed to improve structural performance of modular structures. Research has shown that modular units can act as discrete energy-absorbing systems to protect the building under seismic load, especially when connected via advanced joint mechanisms such as friction-slip connections, bolted semi-rigid joints, or damping-based connectors. Additionally, rocking systems have long been recognized as an effective approach to mitigating structural damage in buildings subjected to strong earthquakes. However, such systems are prone to high-mode effects, which may induce excessive shear stresses at the base of the structure (Wiebe et al., 2013). Building upon insights from previous studies, this research aims to develop an innovative self-centering system incorporating post-tensioned (PT) cables and controllable rocking connections to enhance the seismic performance of modular steel structures. Unlike conventional base-rocking systems, in which rocking occurs only at the base, the proposed controllable rocking connections enable distributed rocking along the building height. This arrangement has been shown to alleviate the adverse effects associated with high-mode responses (Wiebe et al., 2009).

## Description of method and results

Time-history analyses were performed using the commercial finite element (FE) software ABAQUS to investigate the seismic performance of modular steel structures assembled with the proposed connection method. The structure of the FE model is shown in Fig 1. Beams and columns were modelled with B21 beam elements, while T2D2 truss elements were employed to simulate the cables. The cables were connected to the top and bottom of the frames through coupling constraints. To simulate the anchorage conditions, both horizontal and vertical degrees of freedom ( $U_1 = U_2 = 0$ ) were constrained at the cable ends, whereas only the horizontal degree of freedom ( $U_1 = 0$ ) was restrained at the cable midpoints. For the controllable rocking connections, the horizontal

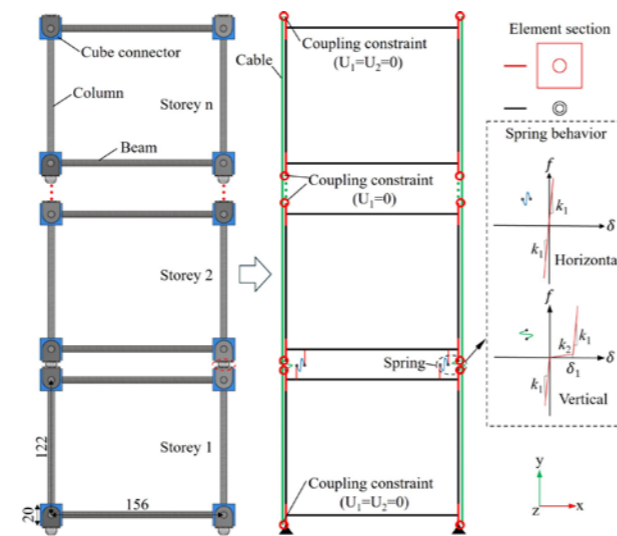


Fig 1 Diagram of FE model

displacement was restricted using high-stiffness springs ( $k_1$ ), while a bilinear spring element was adopted to simulate the vertical behaviour, with  $\delta_1$  controlling the maximum gap-opening displacement. In addition, the post-tensioning force in the cables was applied using the "initial stress" option in ABAQUS.

Because rigid connections are commonly used in modular structures and base rocking systems have been recognized as an effective technique for protecting buildings during strong earthquakes, FE models of modular structures with rigid connections and base rocking systems were also established in ABAQUS for comparison. Although the Rayleigh damping model can provide an accurate damping ratio at specific modes, it tends to overdamp the structure in the frequency ranges outside these target modes. Considering that the rocking behaviour of modular structures can alter their natural frequencies, the Maxwell damping model was adopted in this study. This model can provide a constant damping ratio across a relatively wide frequency range (Cheng, 2022).

Six artificial ground motions were generated, matching the same target response spectrum, and were applied to the three structural configurations. To better reflect practical

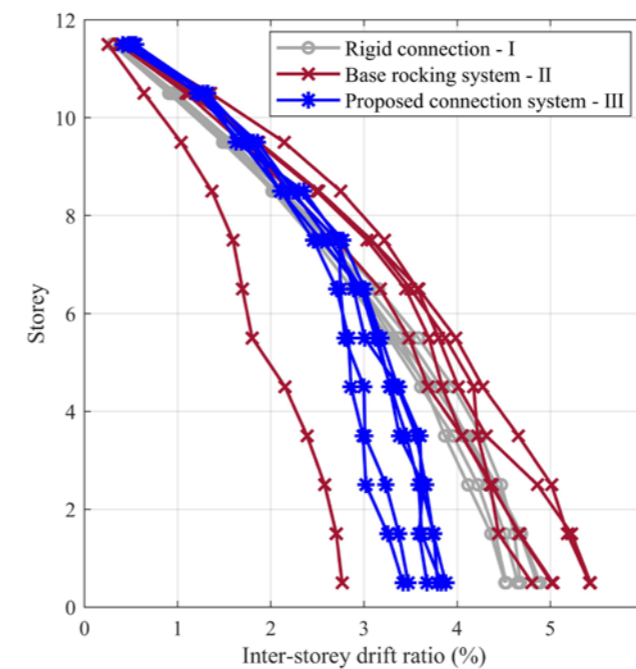


Fig 2 Inter-storey drift ratio of three types of structures

design conditions, the fundamental periods of the three structural models were set to be identical and located on the descending branch of the response spectrum. The maximum inter-storey drift ratios of the three structures under the generated ground motions are compared in Fig 2. Because the inter-storey drift ratio reflects the distortion level of each storey, it serves as an indicator of the shear demand in that storey. For the base-rocking system, a noticeable sensitivity to the input ground motions was observed. Among the six ground motions considered, the base-rocking system generally exhibited inferior seismic performance compared with the structure employing rigid connections; however, in one case, it showed better performance. In contrast, the proposed connection system demonstrated more stable and consistent seismic responses. Although the stories above the ninth-floor experienced larger inter-storey drift ratios, the maximum values consistently occurred at the ground floor and were always lower than those of the rigid connection structure, indicating the proposed system's potential to enhance seismic performance.

## Potential for application of results

The FE results demonstrated that assembling modular units using the proposed controllable rocking connection can effectively protect modular buildings during strong earthquakes. Based on these findings, the vertical and horizontal mechanical properties simulated in the FE simulations will be carefully incorporated into the detailed design of the controllable rocking connection. To facilitate practical implementation, a series of experimental programs including axial, shear, and cyclic loading tests will be conducted to evaluate the connection's mechanical behaviour. Subsequently, large-scale experimental tests will be carried out to investigate the seismic performance of modular steel structures assembled with the proposed connection system.

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# A novel scissor-assisted active tuned mass damper inerter: design and performance evaluation

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## Project objectives and goals

In the field of structural vibration control, there are three primary control strategies: active, semi-active, and passive. The tuned mass damper (TMD) is one of the most common passive control devices (Frahm, 1911). With advances in industry, Smith (2002) proposed a mechanical element called an inerter, which can generate an inertial force equivalent to that of a mass several hundred times greater than its own. Marian and Giaralis (2014) integrated the inerter with the TMD to introduce the tuned mass damper inerter (TMDI), a device that requires less mass than the traditional TMD. Recently, the active tuned mass damper inerter (ATMDI) has been introduced in response to needs for higher control performance (Sadeghian et al., 2025; Gai et al., 2025). However, studies on active inerter-based devices are still quite limited. Furthermore, better control performance corresponds to greater control demands (in terms of control force and power), which places bigger demands on actuators, consequently making the control strategy unfeasible in practical applications.

The specific goals of the study are:

1. To propose a novel active inerter-based damper, termed scissor-assisted active tuned mass damper inerter (SATMDI), designed to achieve excellent vibration control performance and concurrently has lower control demands
2. To develop a design procedure for the SATMDI that is capable of simultaneous and non-simultaneous parameter tuning
3. To evaluate the effectiveness of the proposed device, explore the differences between the SATMDI and ATMDI, and investigate the impact of using different design approaches

## Description of method and results

Fig 1 illustrates the analytical model and the design procedure of the SATMDI. The SATMDI consists of five main components: an actuator (generating control force  $f(t)$ ), a spring (with stiffness  $k_d$ ), a damper (with coefficient  $c_d$ ), a mass block ( $m_d$ ), and a scissor-inerter ( $\theta, b$ ). The actuator, spring, and damper are connected in parallel, forming one assembly that is attached to the primary structure at one end and to the damper mass at the other. The scissor-inerter is connected between the damper mass and the ground. The inertial force of an inerter is proportional to the relative acceleration between its two terminals (1 and 2). To amplify relative acceleration, a scissor structure is integrated at both ends of the inerter,

as shown in the schematic diagram in Fig 1. When configured within a specific angle range, this structure effectively magnifies the relative acceleration across the inerter. The resulting amplification factor (Bian et al., 2025), which depends on the scissor angle ( $\alpha = \cot^2(\theta)$ ), leads to a significant enhancement of the inertial force.

The design flowchart in Fig 1 outlines the design procedure of the SATMDI. Design starts with the selection of initial values for the damper mass  $m_d$  and inertance  $b$ . The scissor angle  $\theta$  ranges from 0 to  $\pi/4$ , resulting in an amplification factor  $\alpha \geq 1$ . In the special case where  $\alpha = 1$ , the system simplifies to an ATMDI. Furthermore, two design approaches are used to get optimal parameters: simultaneous and non-simultaneous parameters adjustment. The former entails the concurrent optimisation of the stiffness, damping coefficient, and active control force weighting. The latter approach, however, first determines the stiffness and damping coefficient from existing TMDI closed-form solutions (Marian and Giaralis, 2014) and then adjusts the active control force weighting.

Time history analysis of the benchmark model was conducted under the 1940 El Centro earthquake ground motion to evaluate the performance of the SATMDI in vibration control. The response displacement reduction and normalized control demands are shown in Fig 2. As illustrated in Fig 2(a), under the same active control force weighting, the performance index of both devices first increases with  $k_d$  and then decreases, peaking when  $c_d$  approaches zero. The SATMDI demonstrates superior performance, yielding a higher displacement reduction percentage than the ATMDI.

By adjusting the active control force weighting to ensure identical displacement reduction performance across all configurations, a consistent baseline is established for a direct comparison of their control demands. The four configurations are labelled as follows: S-SATMDI and S-ATMDI for the simultaneous adjustment strategy, and NS-SATMDI and NS-ATMDI for the non-simultaneous one. Fig 2(b) presents the corresponding control force and power demands for these four configurations. The results indicate that the simultaneous strategy yields lower control demands. This finding confirms that optimising the TMDI prior to applying control forces does not necessarily result in an optimal SATMDI or ATMDI design. Furthermore, regardless of the design approach (simultaneous or non-simultaneous), the SATMDI exhibits reduced control demands compared to the ATMDI.

## Potential for application of results

The SATMDI proposed in this study can be employed for seismic vibration control in buildings, significantly reducing structural displacements. Compared to the ATMDI, SATMDI lowers the demands on actuators, which enhances the feasibility of such vibration control schemes and allows for the selection of more cost-effective actuators in practical engineering applications.

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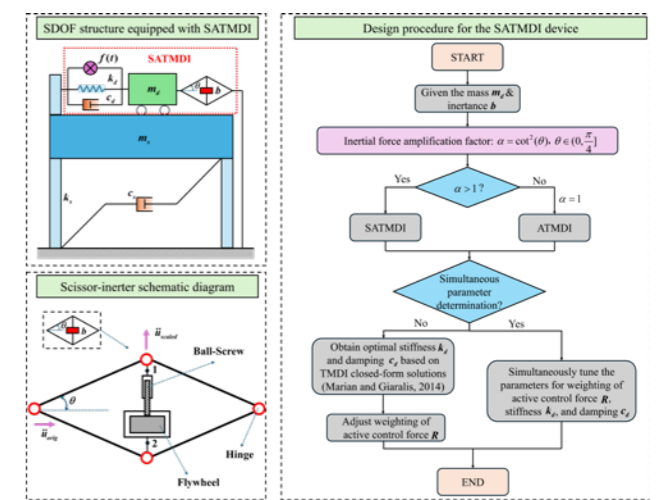


Fig 1 Schematic of SDOF structure equipped with SATMDI and design procedure

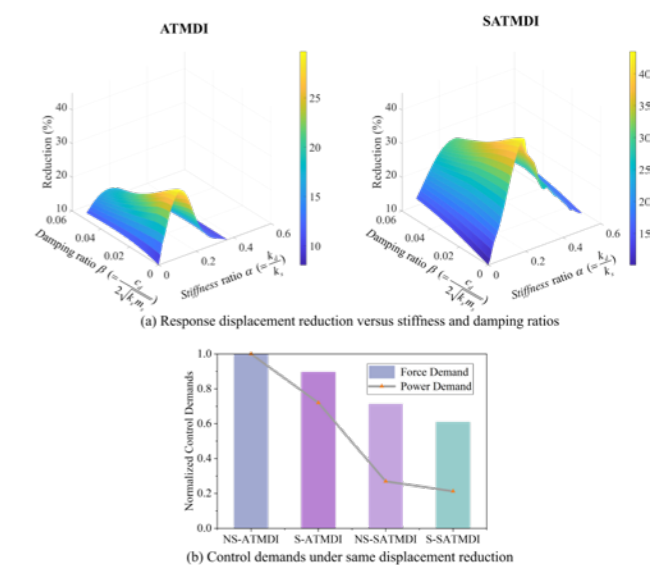


Fig 2 Comparison of performance for SATMDI and ATMDI systems

# Hybrid T-joints featuring 3D printed details: optimisation and experimental verification

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## Project objectives and goals

Wire arc additive manufacturing (WAAM), a method of metal 3D printing, has begun to gain traction in structural applications due to its geometric freedom and robotic automation (Gardner, 2023). However, when applied to entire structures, WAAM remains slower and more costly than conventional steel production methods such as hot-rolling or cold-forming, limiting its widespread adoption.

To address this challenge, a hybrid strategy is proposed in which primary structural components are fabricated conventionally and WAAM is applied only where complex geometry or enhanced performance is required (Meng and Gardner, 2025). This leverages the geometric flexibility of WAAM without compromising the productivity or cost-efficiency of standard steelwork. In addition, WAAM enables optimised structural designs that further reduce material use and production time.

This project aims to demonstrate the feasibility and benefits of integrating topology optimisation within a hybrid WAAM workflow for structural connections. Topology optimisation identifies efficient load paths, and WAAM material is placed only along these regions, creating geometries that improve load transfer while reducing material use and manual fabrication. In this study, hybrid tubular T-joints featuring WAAM components are, for the first time, optimised, manufactured and tested.

Specific goals:

1. Establish a transferable workflow for structural connections, from optimisation to fabrication
2. Examine the geometry and material properties of the WAAM components
3. Verify the hybrid WAAM strategy through full-scale structural testing and quantify performance improvements

## Description of method and results

The methodology covers the conceptualisation, manufacture and experimental verification of hybrid T-joints featuring topology-optimised WAAM details. Four conventionally welded square hollow section (SHS) T-joint configurations were designed as benchmarks, with brace widths of 100-260 mm and chord widths of 200-300 mm selected to represent typical failure modes under brace compression. Topology optimisation was performed on the brace-to-chord junction while maintaining the chord continuity, followed by post-processing to ensure

printability under WAAM-specific constraints. Nonlinear finite element (FE) analysis was then performed and guided the selection of seven optimised hybrid T-joints and four benchmark counterparts for fabrication and experimental verification.

A density-based solid isotropic material with penalisation (SIMP) method was used for topology optimisation, implemented through the TOSCA module in ABAQUS. Certain optimised features fell below WAAM's minimum printable size. To preserve the optimised geometry while ensuring printability, the solid models were converted into shell forms by expanding the iso-surface, creating hollow components with practical wall thicknesses of 2.5-6.5 mm. These shell components were refined iteratively based on the stress distributions obtained from nonlinear FE analysis, with low-stress regions selectively removed to reduce material use while maintaining the stiffness and strength of the optimised T-joints.

The experimental programme comprised (1) 3D laser scanning to examine the geometric properties of the WAAM components, (2) tensile coupon tests to characterise the mechanical properties of the WAAM steels, and (3) full-scale structural tests on the T-joints under brace compression. A typical hybrid T-joint and the geometric deviation of its WAAM component relative to the design is shown in Fig 1. The out-of-plane deformation fields of the T-joints and the surface strain fields of the corresponding WAAM components were captured during the tests using a stereo digital image correlation (DIC) system, with a representative example illustrated in Fig 2.

Test results revealed that the hybrid T-joints achieved significantly improved structural performance over the corresponding conventional welded joints, driven by two key mechanisms: (1) redistribution of load from the chord face toward the SHS chord sidewalls, and (2) extension of the effective loading length along the chord, through the optimised WAAM components. These observed behaviours during the tests are consistent with the intended optimisation objectives.

Furthermore, the structural performance gains of the tested hybrid T-joints were quantified, relative to their conventionally welded benchmarks. The greatest gains were observed in joints whose benchmarks exhibited chord face failure and had high chord cross-sectional slenderness, with initial stiffness increases of up to around

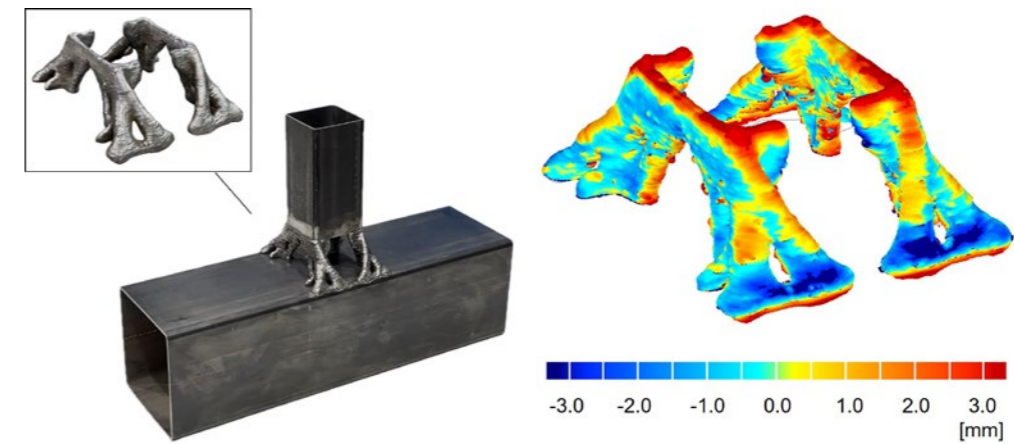


Fig 1 Typical hybrid T-joint specimen and the geometric deviation of its WAAM component

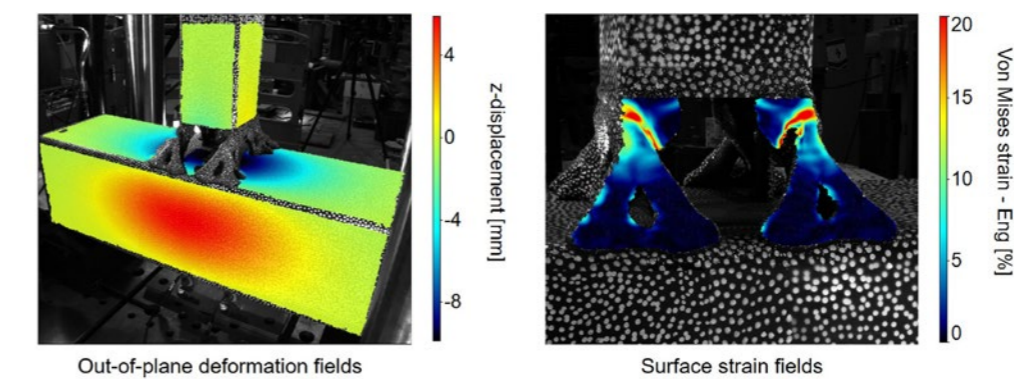


Fig 2 Out-of-plane deformation fields of a typical hybrid T-joint specimen and the surface strain fields of its WAAM component captured at failure load during testing

2000% and capacity increases of up to almost 500%. Across all configurations, the optimised hybrid T-joints demonstrated substantial improvements not only in structural performance but also in structural efficiency, with stiffness-based efficiency increasing by more than 1000% and capacity-based efficiency increasing by up to 165%.

These results highlight the strong potential of WAAM-enabled topology optimisation to enhance both structural performance and efficiency of SHS T-joints.

## Potential for application of results

The project demonstrates that integrating topology optimisation with hybrid 3D printing can significantly enhance the structural performance of steel structures, while enabling greater fabrication automation without compromising the cost-effectiveness of conventional steelwork. The hybrid WAAM strategy is transferable across a wide range of structural systems and offers a scalable pathway for the wider adoption of sustainable, optimisation-informed structural solutions.

Beyond performance gains, the hybrid WAAM strategy opens new opportunities for expressive structural design, allowing geometry to follow structural logic more directly and enabling forms that unite efficiency with architectural expression.

The developed workflow has already progressed beyond the component scale. It has been implemented in a world-

first, 10-metre-span hybrid WAAM 3D truss, designed using layout optimisation and featuring conventionally produced members connected by WAAM nodes. This structural demonstrator is currently undergoing fabrication and testing at Imperial College London, demonstrating that the hybrid WAAM strategy is not merely conceptual, but a practical and deployable approach for future steel construction.

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MX3D

# Developing green ecological concrete with porous sponge technology

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## Project objectives and goals

- Green ecological concrete (GEC) using porous sponge technology (PST) is an alternative to normal concrete materials. In this paper, the behaviour of environmental concrete is investigated using orthogonal experiments to satisfy the requirements of sponge city building, which is based on the design approach of mix proportion. The findings in this study indicate that the specimens' compressive strength peaked at a 0.95% sponge admixture; according to the ideal sponge admixture, the specimens' compressive strength peaked at a 13.2% mineral powder admixture; In contrast to normal concrete, (GEC) with porous sponges has twice the water-retaining capacity of standard concrete, while maintaining the same external temperature, as well as good permeability and minimal evaporation
- The main techniques for controlling the alkaline environment in porous eco-concrete for slope protection were examined in this work using microscopic mechanism analysis, durability testing, and biogenic energy. Enhancing the performance of porous eco-concrete would encourage the use of "green-sustainable" eco-concrete in engineering projects for slope protection

## Description of method and results

Sand, blast-fired mixed mineral powder, water, stones (coarse components), normal Portland cement, and polymer fibre components which are subsequently referred to as sponge, are the ingredients of green porous sponge eco-concrete. Compared to regular concrete, ecological concrete has much less strength. The bonding action of cementations materials and the interlocking effect between aggregates are the primary sources of its strength. Strengthening ecological concrete was facilitated by high cement strength. A strength grade of 42.5 MPa silicate cement was utilised.

Tables 1 and 2 display the physical and mechanical characteristics as well as the chemical composition and content of cement. The ideal ratio of combinations has been established using the filling hypothesis, which is displayed in Table 3; after that, the sponge was added directly, and the ideal admixture of the sponge was established through a series test.

At California University, laboratory tests are used to determine the sandstone's grain diameter. As seen in Fig. 1, select three distinct grain diameters. There are three distinct groups for the range of grain diameter: 9.2–12.5 mm, 12.5–15.5 mm, and 15.5–19 mm.

Table 1 The chemical makeup and contents of cement %

Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	SO <sub>3</sub>
3.02	6.12	1.32	3.10	18.97	2.95

Table 2 Physical and mechanical characteristics of cement

Standard consist of Water/%	Time setting (min)		Compressive strength (MPa)			Flexural strength (MPa)		
	Initial	Final	3 day	7 day	28 day	3 day	7 day	28 day
29	205	325	29.7	45.9	60.2	5.6	7.5	9.1

Table 3 The ratios of the porous, eco-friendly concrete mixture

Type	Concrete aggregate	Cement	Water
Quantity per volume unit (kg/m <sup>3</sup> )	1220	316	143



Fig 1 Various coarse aggregate grain diameters: (a) 10 mm, (b) 14 mm, and (c) 18 mm

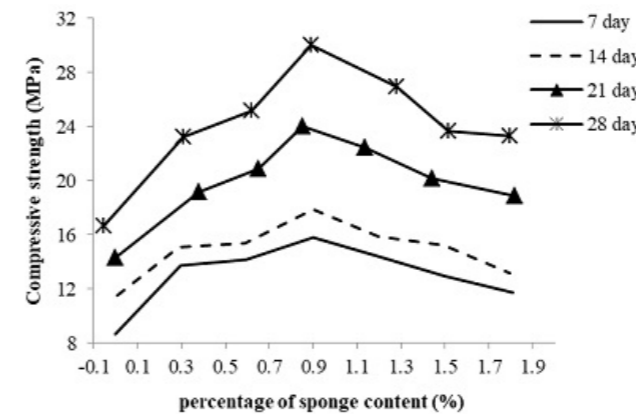


Fig 2a Compressive strength of concrete the specimen on days 7, 14, 21 and 28 with varying sponge contents

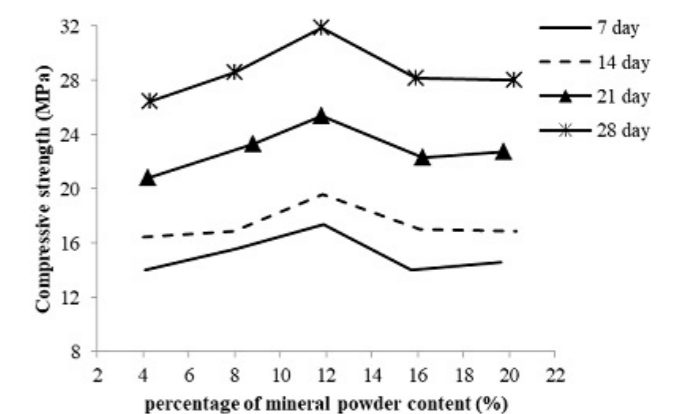


Fig 2b Compressive strength of concrete the specimen on days 7, 14, 21 and 28 with varying mineral powder contents

The following section offers a thorough explanation of the test procedures for the environmentally conscious porous sponge environmental concrete's water retention, porosity for water, and loss of water as well as the compressive strength test method in compliance with relevant standards.

## Potential for application of results

This experiment looked at the compressive strength of green porous sponge eco-concrete in regard to three periods of time (7, 14, 21, and 28 days) and varying sponge particle concentrations. During the test, the final measured value was determined by taking the average arithmetic score across the three samples in the entire group. In the event when the median and one of the measurements differ by more than 15%, the median value will be considered the measured value. This group's test data will be invalid and subjected to independent testing if it was more than 16% of the standard deviation value. Fig. 2 displays the outcomes of the assessment.

A specific correlation between the quantity of sponge used and the specimen's compressive strength may be observed from the data in the figure. As the quantity of sponge was initially raised, the compressive strength of environmentally friendly porous sponge that was green improved in tandem considering the quantity of sponge; however, as the quantity of sponge went beyond a specific point, a decrease in compressive strength would occur.

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# Buckling behaviour of composite concrete-filled tubular flange beam

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## Project objectives and goals

This project is focussed on investigating the buckling behaviour of beam composite concrete-filled tubular flange numerically. This type of composite beam is evaluated in simple support with a lateral unconstrained concentrated load in mid-section in order to examine the beam's stability performance (Wassef et al, 1997; Kim et al, 2005). The finite element (FE) model of this kind of composite beams is established by using ABAQUS software. Specimens with different cross section forms are designed using (FE) modelling. Concrete is effectively constrained by steel tubes, which reinforces the deformation capacity of concrete. Based on buckling analysis of eigenvalue member, buckling load is extracted. The changing rules of buckling load with section form, member length, and concrete strength grade, yield strength of steel and stiffening ribs are investigated, and the design. The results from the numerical analysis are compared to available test data. A good agreement was shown between the experimental and numerical data, thus validating the numerical model which has been developed.

The research project has the following objectives:

- Reasonable stiffening ribs can greatly improve the complete stability and strength of this type composite beam

- The buckling load increase of the component which decreases with rising concrete strength grade
- Provides initial defect morphology by using linear stability (Ding et al, 2009)
- The web depth is reduced when compared to an I-shaped girder of the same total depth, leads to reduce web slenderness effects

## Description of method and results

The specimen details incorporated in the FE model are based on the rectangular tubular flange girder which was examined in the test programme of Wang et al. (2009). Accordingly, the primary defined characteristics are the steel yield strength ( $f_y$ ), concrete compression strength ( $f_c$ ), web thickness ( $t_w$ ), steel tube flange thickness ( $t_f$ ), hole to web height proportion ( $a/h_w$ ), and space to web height ratio ( $s/h_w$ ). Stiffeners are used in honeycomb steel webs to stop local buckling of the beam. Each specimen has a length ( $L$ ) of 3200 mm and a sectional dimension ( $B \times H$ ) of 200 mm  $\times$  700 mm. To avoid localised bearing failure, two 6 mm transverse stiffener plates were welded to both endpoints of the beams. Steel has the same strength as beams and steel tubes, and each pair of 6 mm transverse stiffeners are evenly spaced all throughout the entire length of the sample at 1/4, 1/2, and 3/4 spans to avoid local buckling of the web and eliminate web distortion.

Table 1 Dimensions of the CFTFG cross-section

H (mm)	$t_f$ (mm)	$h_w$ (mm)	$t_w$ (mm)	B (mm)	$h_f$ (mm)	$t_{stiffener}$ (mm)
700	15	400	6	200	150	12

Table 2 Details of the material properties

Steel (Wang et al, 2008)				Concrete	
Yield stress, $f_y$ (N/mm <sup>2</sup> )	Ultimate stress, $f_u$ (N/mm <sup>2</sup> )	Young's modulus, E (N/mm <sup>2</sup> )	Poisson's ratio	Compressive cylinder strength of concrete, $f_c$ (MPa)	Poisson's ratio
236.8	377.2	200000	0.3	42.5	0.20

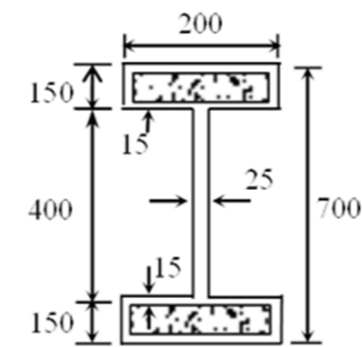


Fig 1 Cross-section of a composite beam with a concrete filled tubular flange (all units in mm)

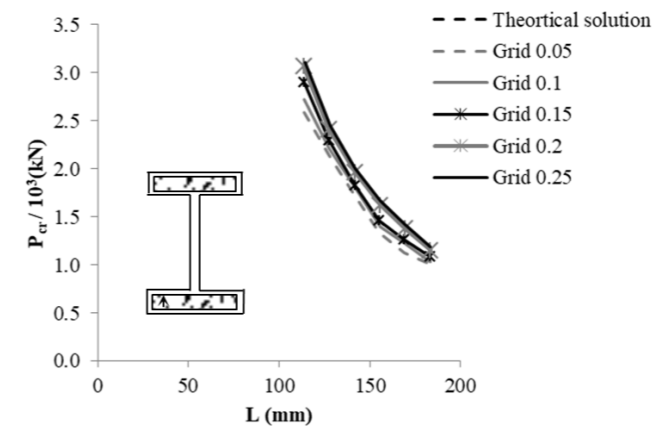


Fig 2 Buckling of specimen with various mesh divisions: numerical and theoretical solutions using finite elements

## Potential for application of results

- The effects of concrete strength grade, member length, and section shape on the buckling load are investigated
- The buckling load can be increased by adding stiffening ribs perpendicular to the web direction in the steel tube of the I-shaped composite steel beam. The buckling stress is raised when the stiffening ribs are positioned in the flange steel tube of the beam component perpendicular to the web direction. The rise in component buckling load is decreasing as the concrete strength grade increases
- A composite beam with a rectangular steel tube concrete flange may significantly increase the beam's bearing capacity and overall stability in both directions

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# Load introduction mechanism in CFST columns with blind-bolted shear connections

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## Project objectives and goals

Concrete-filled steel tubular (CFST) columns are widely adopted in modern construction due to their high strength, stiffness, and constructional efficiency. In practice, CFST columns are integrated into structural frames primarily through beam-to-column connections, and the manner in which load is introduced through these connections governs the development of composite action within the column.

For welded connections, load transfer relies largely on bond interaction at the steel-concrete interface, which is sensitive to interface conditions and often insufficient to mobilise the concrete core (Uy et al., 2012). Existing studies on load transfer in welded CFST columns (Mollazadeh and Wang, 2016; Xu et al., 2021) have shown that the actual load transfer region differs from that assumed in current design standards, and these works highlight the strong influence of column length as well as the inherent limitations of bond-governed transfer.

Bolted connections offer a more direct load transfer mechanism through bearing, and blind-bolted systems effectively overcome the installation limitation of conventional bolts in hollow sections. Extended blind-bolts have also been developed to achieve deeper anchorage and improved engagement with the concrete core (Debnath et al., 2025). However, existing studies on blind-bolted systems are mainly limited to isolated connection tests, and member-scale investigations on their load introduction behaviour remain scarce.

Therefore, a systematic understanding of how blind bolts introduce load into CFST columns, and how structural parameters influence this process, is required. Accordingly, this research aims to clarify the load introduction mechanism in CFST columns with blind-bolted shear connections. The specific objectives are:

- To assess blind-bolted connections as an efficient load-transfer mechanism through direct bearing
- To quantify the effects of key parameters on load transfer through experimental and numerical studies
- To characterise the load introduction region in blind-bolted CFST columns
- To evaluate existing design approaches and propose recommendations for structural applications

## Description of method and results

The research adopts a combined experimental and numerical approach to investigate the load introduction mechanism in CFST columns with blind-bolted shear connections. A series of large-scale tests was conducted to quantify the load transfer behaviour under connection loading conditions. The test setup is shown in Fig 1, where the CFST column is connected to a solid loading column and a stiffened loading frame through blind-bolted beam connections. This configuration ensures uniform load introduction into both connections, and the high stiffness and strength of the loading assembly prevent extraneous deformation, enabling the specimen to govern the overall structural response. Instrumentation was arranged along the steel tube and concrete core to capture local deformation and assess the development of load transfer. In parallel, finite element models were developed and validated against the experimental results, allowing the influence of key parameters to be examined beyond the scope of testing.

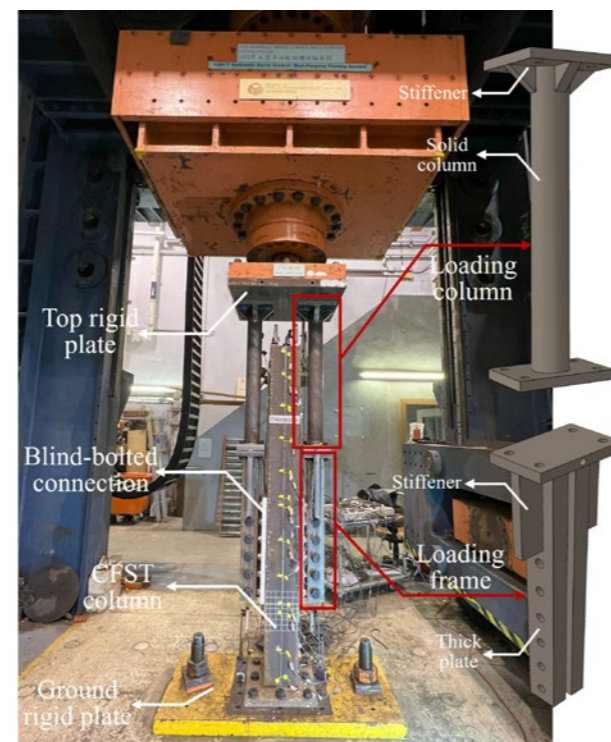


Fig 1 Experimental setup for load transfer tests

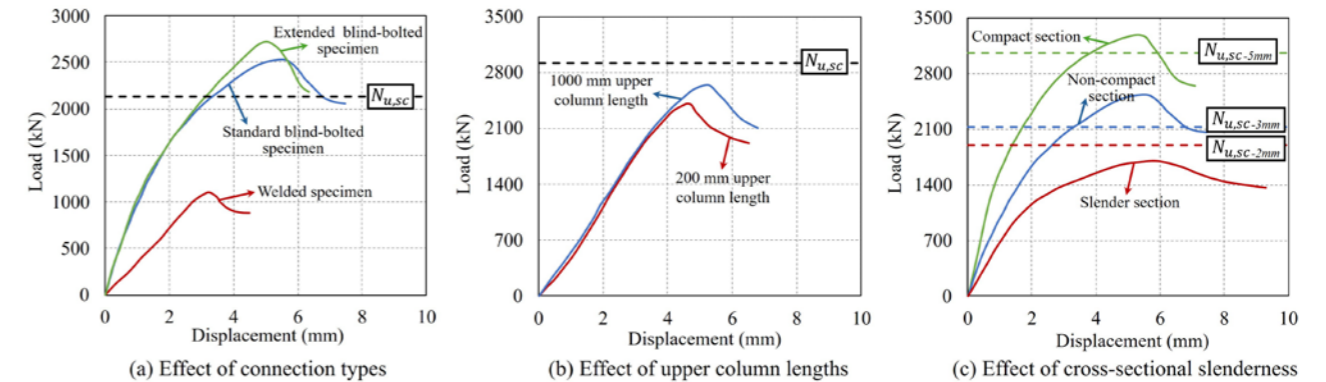


Fig 2 Load-displacement behaviour under different test parameters

The results show that the load introduction mechanism in CFST columns is significantly influenced by connection type, upper column length, and cross-sectional slenderness. As illustrated in Fig 2(a), blind-bolted specimens exhibit markedly higher load transfer efficiency compared with welded specimens. This enhancement is especially pronounced for extended blind-bolts due to their deeper anchorage, which promotes a more effective bearing mechanism and reduces the reliance on steel-concrete bond interaction. Fig 2(b) indicates that increasing the upper column length provides a longer internal load transfer path, allowing more concrete to be mobilised and facilitating the development of composite action. Furthermore, Fig 2(c) shows that blind-bolted connections enable both compact and non-compact sections to achieve their full composite strengths even with relatively short upper column lengths. In contrast, slender sections fail to reach complete composite action because insufficient confinement leads to premature local buckling and suppressed concrete mobilisation. Comparison with predictions from existing design approaches reveals that current methods, which typically assume uniform end bearing and full composite action, do not adequately capture the load transfer behaviour observed in CFST columns. The discrepancy highlights the need for an improved design framework that explicitly incorporates load transfer efficiency and the influence of anchorage depth, cross-sectional slenderness, and column length.

## Potential for application of results

The findings from this study provide a clearer understanding of how loads are introduced through blind-bolted shear connections into CFST columns and offer direct implications for structural design practice. By quantifying the influence of anchorage depth, column length, and cross-sectional slenderness, the results enable more informed selection and detailing of blind-bolted

systems in composite construction. Furthermore, the observed discrepancies between test results and current design predictions highlight the need for improved design provisions that account for the different mechanisms governing load transfer. The proposed insights support the development of more accurate design models for CFST members with beam connections, contributing to safer and more efficient structural systems. These outcomes are expected to benefit the design and optimisation of composite frames.

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# Performance of self-healing micro-concrete composites with silane-treated fibres and epoxy microcapsules

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## Project objectives and goals

Concrete is one of the most widely used construction materials globally, yet its long-term durability is significantly constrained by cracking, low tensile capacity, and progressive deterioration under environmental exposure. Micro-cracks allow the ingress of water, chlorides, sulphates, and harmful ions, accelerating structural degradation and leading to costly maintenance interventions. Fibre reinforcement and self-healing technologies offer promising pathways to address these long-standing limitations. Fibre reinforcement enhances toughness and distributes stresses more evenly, while self-healing mechanisms can restore mechanical integrity without human intervention.

This study aims to develop and evaluate a micro-concrete composite capable of enhanced strength and autonomous crack healing using polyvinyl alcohol (PVA) fibres, basalt fibres, silane surface treatment, and microencapsulated DGEBA epoxy resin. The overarching objective is to create a more durable, resilient cementitious material that combines improved mechanical behaviour with the capacity for self-repair.

The specific goals of the project are:

1. To investigate the influence of untreated PVA and basalt fibres on the mechanical performance of mortar, including compressive, flexural, and tensile strength.
2. To examine how silane treatment using GPTMS modifies fibre-matrix bonding and enhances mechanical properties compared to untreated fibres.
3. To fabricate DGEBA epoxy microcapsules and integrate them into fibre-reinforced mortar to enable autonomous self-healing.
4. To assess crack development, microstructural behaviour, and healing potential in mortar mixes containing fibres and microcapsules.
5. To provide a comparative evaluation across untreated fibres, silane-treated fibres, and microcapsule-enhanced systems, establishing a foundation for future self-healing performance and strength recovery studies.

These objectives collectively support the long-term aim of advancing cementitious materials capable of both enhanced performance and reduced whole-life maintenance demands.

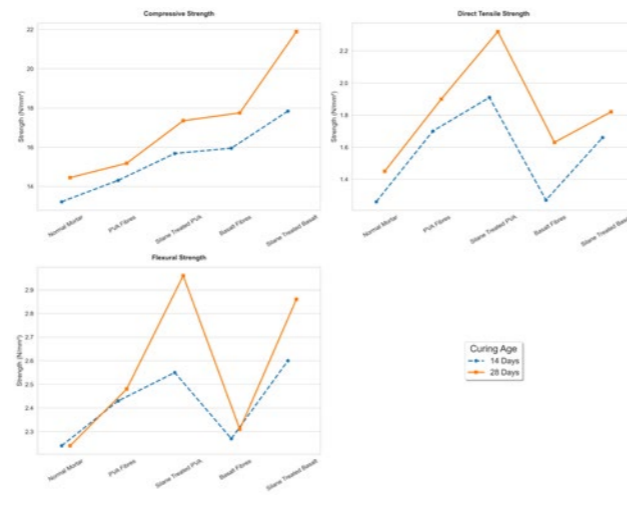


Fig 1 Mechanical Strength of Various Mixes of Micro-Concrete Samples

## Description of method and results

### Materials and mix design

The study uses cement, red building sand sieved to 600 µm, PVA fibres (12 mm), basalt fibres (24 mm), GPTMS silane coupling agent, and laboratory-fabricated DGEBA epoxy microcapsules. The base mortar mix followed a 1:3 cement-to-sand ratio with a water-to-cement ratio of 0.50. A series of mixes were prepared across three experimental phases: (1) untreated fibre-reinforced mortar, (2) silane-treated fibre-reinforced mortar, and (3) fibre-microcapsule mixes designed for self-healing evaluation. Although the full healing experiments are ongoing, the materials preparation and preliminary cracking methodology have been completed.

### Phase 1: Mechanical performance of untreated fibres

In Phase 1, PVA- and basalt-reinforced mortar samples were cast and tested at 14 and 28 days for compressive, flexural, and tensile strength. Results demonstrated that both fibres increased post-cracking toughness and improved resistance to brittle failure compared to control mortar. Basalt fibres provided greater strength enhancements due to their higher tensile capacity, while PVA fibres improved crack control efficiency because of their hydrophilic nature and strong bonding to the cement matrix. These findings established a baseline for assessing the effect of fibre treatment and healing agents.

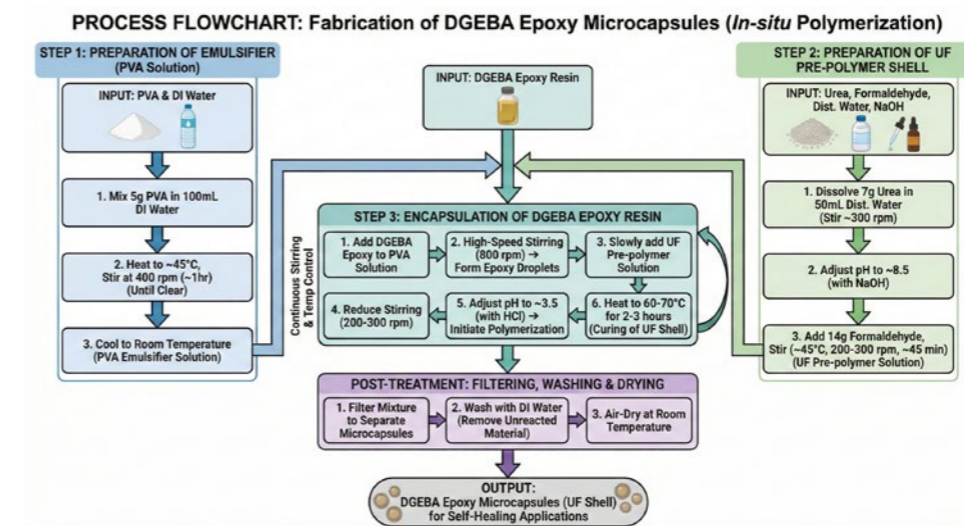


Fig 2 Experimental Procedure for preparation of DGEBA Epoxy Microcapsules

## Phase 2: Effect of silane-treated fibres

In Phase 2, fibres were surface treated using GPTMS to enhance chemical compatibility with the cementitious matrix (C.Zhao et al., 2023). SEM-EDS analysis confirmed successful silane coating, showing improved surface roughness and the presence of epoxy functional groups. Mechanical testing indicated enhanced performance across all strength categories (Fig 1). Silane-treated fibres demonstrated superior load transfer and improved durability potential, validating the importance of chemical modification in fibre-reinforced mortar systems.

## Phase 3: Self-healing preparation and crack evaluation

The self-healing stage of the project includes the fabrication of DGEBA microcapsules (Fig 2) using urea-formaldehyde shell formation (S.R. White et al., 2001), preparation of fibre-microcapsule composite mixes, and implementation of controlled cracking procedures. Capsules were successfully synthesised and observed to possess stable spherical morphology suitable for embedding into mortar (T.Gupta et al., 2017). Preparatory work on controlled shrinkage cracking and micro-crack observation has been completed, establishing the methodology for subsequent strength-recovery and healing-efficiency assessments.

Although quantitative healing results are not yet available, the methodological framework includes crack width measurement, microscopic imaging, and post-healing mechanical retesting. The integrated healing system is expected to demonstrate a combination of fibre bridging, epoxy release upon capsule rupture, and improved fibre-matrix bonding due to silane treatment. These synergistic effects form the basis for the future evaluation of healing efficiency, crack closure, and strength recovery.

## Potential for application of results

The development of self-healing fibre-reinforced cementitious composites offers significant potential for modern infrastructure. By reducing the frequency and severity of cracking, these materials can substantially lower maintenance costs and extend service life in applications such as bridges, pavements, tunnels, retaining

structures, and marine environments. Fibre reinforcement provides immediate enhancement to toughness and crack resistance, while microcapsule-based healing introduces a long-term, autonomous repair capability that responds to damage as it occurs.

Silane-treated fibres contribute additional durability by strengthening the fibre-matrix interface, reducing water penetration pathways, and enhancing structural cohesion. When combined with epoxy microcapsules, the resulting composite may offer both mechanical resilience and intelligent self-repair, making it suitable for structures exposed to cyclic loading, chemical attack, or difficult maintenance conditions.

This research forms a foundational step toward the development of robust, intelligent concretes capable of improving sustainability and resilience in the built environment. The experimental Phase 3 results, currently in progress, will further quantify the healing performance and mechanical recovery, enabling practical recommendations for large-scale implementation.

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# From paper cuts to earthquake protection: Kirigami as a seismic damper

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## Abstract

Kirigami, the traditional Japanese art of paper cutting, offers a framework for transforming flat two-dimensional sheets into complex three-dimensional geometries. When applied to engineering materials, Kirigami patterns can introduce extraordinary stretchability, even for materials such as aluminium which typically fail at relatively small strains. This remarkable extensibility makes Kirigami an attractive candidate for energy dissipation applications such as seismic dampers.

In this study, kirigami principles are used to develop metallic yielding dampers for the seismic protection of structures. A comprehensive investigation is carried using a combination of reduced-order analytical modelling, finite element analysis, and experimental validation to examine the mechanical response and energy dissipation characteristics of metallic Kirigami structures. The reduced-order kinematic model serves as the foundation for a design approach enabling the energy dissipation behaviour to easily be customised for particular structures. Kirigami-based metallic yielding dampers offer an inexpensive but highly customisable approach for the seismic protection of structures.

## Introduction

Kirigami, derived from the Japanese art of cutting paper, has evolved into a powerful method for engineering structures with large, programmable deformations. The main advantages of Kirigami lie in its ease of fabrication and implementation across a wide range of thin, material-based plates, as well as its compatibility with common cutting techniques—such as laser cutting—which streamline the manufacturing process. Moreover, a diverse variety of cut patterns can be readily produced. Kirigami's diverse pattern families—ranging from simple ribbon cuts to more complex closed-loop geometries—enable significant out-of-plane motion and tuneable mechanical responses (Sun et al., 2021). These characteristics have led to applications in areas such as soft robotics (Rafsanjani et al., 2019; Walker, 2024), wearable sensing (Li Wang, Li and Xu, 2023), and adaptive architectural systems (Yi et al., 2018). In the field of energy dissipation, Kirigami-inspired structures have been explored for improving stability and reducing peak loads in sandwich cores and crushed tubular systems (Ma et al., 2021). However, most prior work has focused on compressive or shear loading. Our previous study on a metallic Kirigami shock absorbers (Khalilzadehtabrizi et al., 2025) demonstrated its potential under tensile actions.

Building on this direction, the present study investigates macro-scale metallic Kirigami structures and adapts them for structural energy dissipation under bidirectional cyclic loading. The proposed device consists of parallel Kirigami plates with identical cut patterns (Fig 1), enabling stable out-of-plane yielding. Energy dissipation is governed by localised plastic bending along cut pattern-controlled yield lines. Combining analytical models, finite-element simulations, and experimental testing, we establish the deformation mechanics and provide a practical design methodology for kirigami-based metallic yielding dampers. The findings show that metallic Kirigami offer a simple, tuneable, and efficient platform for next-generation yielding dampers.

## Methodology

As shown in Fig. 1, the damper consists of a series of plates arranged in parallel. The behaviour of the damper can be characterised by the cut parameters of the plates. Each plate has a cut length  $L$ , width  $W$ , and thickness  $t$ . The material properties assume an elastic perfectly plastic material model with a Young's modulus,  $E$ , and yield stress,  $f_y$ .

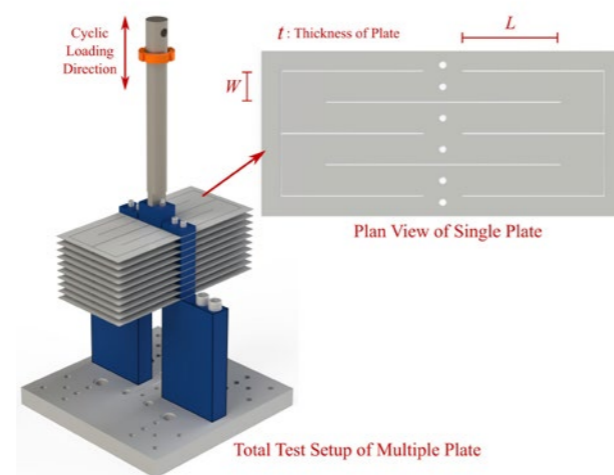


Fig 1 Experimental apparatus and kirigami plate geometry

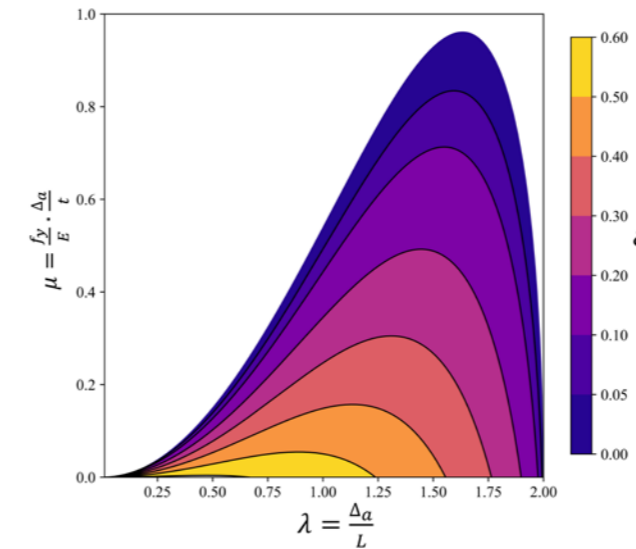


Fig 2 Variation of damping ratio,  $\xi$ , as a function of  $\mu$  and  $\lambda$

Three complementary approaches—experimental testing, finite element modelling (FEM), and an analytical kinematic model—were employed. Experimental testing utilised an Instron 2580 universal testing machine with the test fixture shown in Fig. 1. Test specimens, both individual plates and assemblies, were fabricated from aluminium 1050 and tested under displacement-controlled cyclic deformations over a range of amplitudes. To supplement the experiments, finite element modelling was performed using ABAQUS and validated against the experimental tests. A finite element analysis based parametric study was then performed to fully explore the behaviour. Finally, a reduced-order model consisting of rigid facets connected by perfectly-plastic yield lines was derived. This model was then used to develop a simple design protocol for the dampers.

Given that the proposed device operates as a damper under cyclic loading, it is essential to establish a method for calculating its damping ratio. A simple analytical prediction for the damping ratio was obtained using the reduced order model. For a prescribed displacement amplitude  $\Delta a$ , expressed in terms of the principal non-dimensional parameters,  $\mu = \frac{f_y}{E} \cdot \frac{\Delta a}{t}$  and  $\lambda = \frac{\Delta a}{L}$ , the damping ratio  $\xi$  is estimated using Eq. 1.

$$\xi = \frac{2}{\pi} \left( \sqrt{1 - \frac{\lambda^2}{4}} - \frac{8\mu}{\lambda} \right) \quad (1)$$

Fig. 2 illustrates the variation of the damping ratio,  $\xi$ , as a function of the dimensionless parameters  $\mu$  and  $\lambda$ , providing a framework for design.

## Conclusion

This study demonstrates that metallic Kirigami structures provide a simple, efficient, and highly adaptable platform for energy-dissipating devices under cyclic loading. Experimental, numerical, and analytical analyses show strong agreement, validating the design approach. The results highlight the critical influence of geometric and material parameters on energy dissipation and damping performance, and the developed design protocol offers a practical framework for tailoring Kirigami-based dampers for particular structures.

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# RGB filter analysis for fatigue damage in high-strength reinforcement

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## Project objectives and goals

The research aim is to investigate the high-strength reinforcement that is being used for one of the most important civil engineering projects in South America: The Chacao Bridge in Chile. This suspension bridge will be the largest of its kind on the continent, with a length of 2.5 km in a seismic zone. The following objectives were set to achieve the aim of this study:

- To analyse the low-cycle fatigue performance of this type of reinforcement (ASTM A706 Grade 80). This requires testing several specimens with different slenderness ratios (5, 10, and 15) and total strain amplitudes (1% to 5%).
- To use digital RGB filter analysis to measure strains under cyclic fatigue with greater accuracy. This aims to reduce the computational cost that some photogrammetry programs generate for experimental analysis through a simple algorithm that converts images into pixels and then into a matrix with points defined in coordinates.

## Description of method and results

The methodology involves three key phases.

- Application of photogrammetry:  
The RGB colour space consists of three main components, which are based on the intensity of the primary colours of light: red, green and blue. The basic element in an image is the pixel, which is expressed as a point in  $(R, G, B)$  coordinate. This allows describing the position of a pixel over time, where each image recorded during the test can be filtered through ranges of specific RGB colours (Egger et al., 2021). Orange marks are applied on the upper head and lower surface of the rebar. The purpose of placing marks is to track the centre of these orange points,  $(px_1, py_1)$  at the top and  $(px_2, py_2)$  at the bottom, to obtain the overall longitudinal strain along the clear span (see Fig 1). It is possible in MATLAB to represent each pixel with coordinates  $(x, y)$  including its  $(R, G, B)$  colour space values. Therefore, it is only necessary to filter the orange marks using appropriate ranges of  $(R, G, B)$ , and then plot the filtered pixels in a binary matrix  $b$  using the function  $spy(b)$ . Once the filter has been applied, the centre of each mark can be tracked over time, using Eqn 1 and 2, to finally obtain the axial strain.

$$L(t) = py_2(t) - py_1(t) \quad (1)$$

$$\epsilon_{RGB}(t) = \frac{L(t) - L(t_1)}{L(t_1)} \quad (2)$$

Where  $L(t)$  is the relative buckling length, and  $\epsilon_{RGB}(t)$  is the axial strain obtained by RGB filter.

- Accuracy and sensitivity of photogrammetry:  
The accuracy depends directly on the number of pixels available in the image, since the smallest measurable distance in an image corresponds to the distance between two pixels. If the scale is 5 mm/pixel, the minimum observed distance is 5 mm. This implies that increasing the zoom on the rebar provides more pixels over the same surface, allowing strains to be captured with greater detail. Vibrations or minor disturbances in the laboratory can cause slight shifts in the detected centre of the filtered mark, however, these sensitivities are generally less critical than the following sources of variation. The first relates to the selected coordinate ranges used to filter each image. Inaccuracies in defining these ranges may result in inconsistent detection of the marks. The second issue concerns the measured buckling length, which depends on the camera resolution. When a shorter buckling length is recorded, fewer pixels are captured, reducing the level of detail available for measurements. Nevertheless, higher resolution cameras could mitigate the shortcoming.
- Results:  
Experimental results from the low-cycle fatigue tests on Grade 80 bars are obtained (see Fig 2), and fatigue life models are developed to relate the key parameters, the total strain amplitude  $\epsilon_a$ , the total energy dissipated  $W_{fT}$ , and the number of cycles to failure  $N_f$ .

$$\epsilon_a = M(2N_f)^m \quad (3)$$

$$W_{fT} = W_a(\epsilon_a)^p \quad (4)$$

The results obtained showed failure patterns consistent with those reported in the literature (Tripathi et al., 2018, Massone and Herrera, 2019). Fig 2 presents that the fatigue life curve decreases as the slenderness ratio increases, since longer buckling lengths make the specimens more susceptible to earlier failure, and

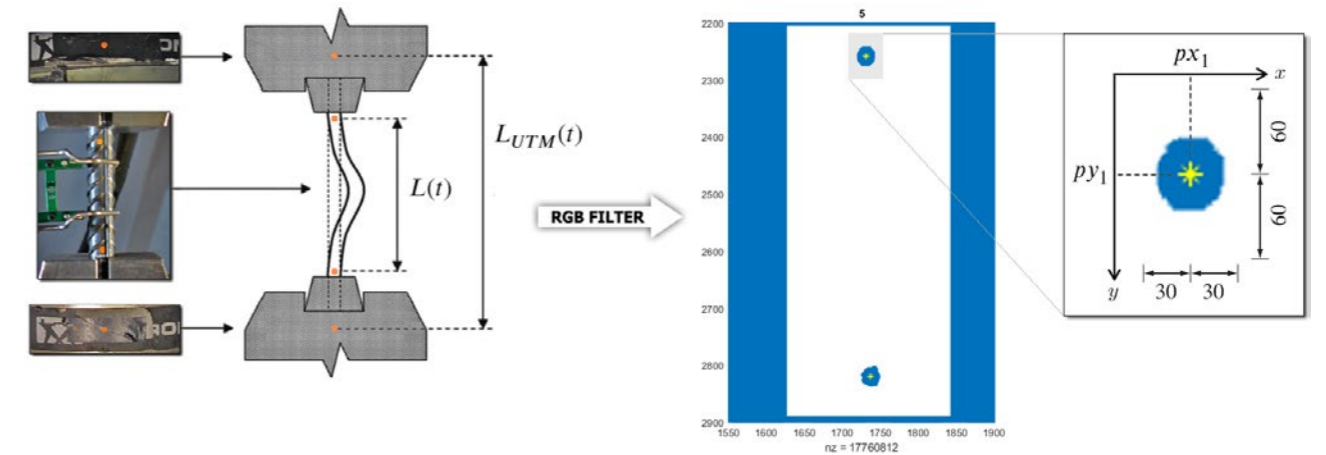


Fig 1 Filtered image using orange marks represented by binary matrix

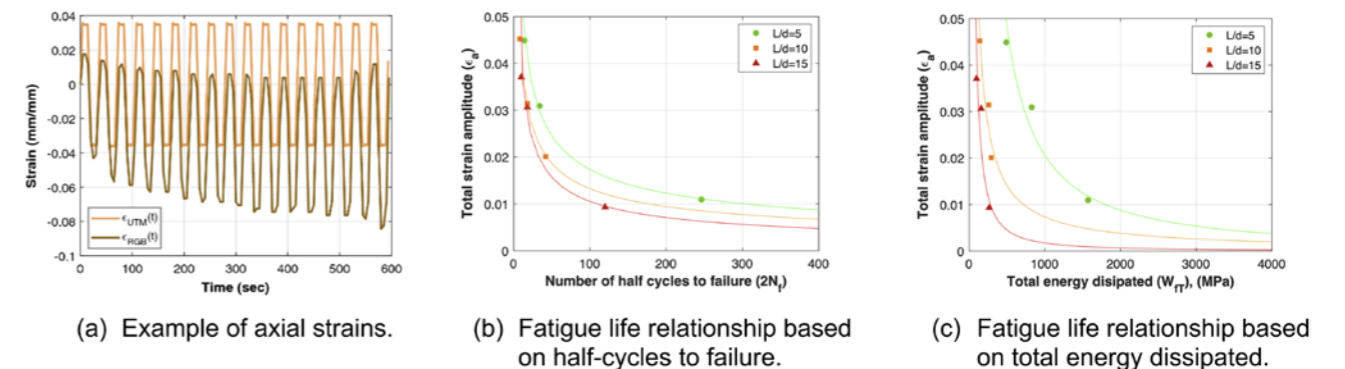


Fig 2 Axial strains and fatigue life curves

can lead to a significant reduction in the dissipated toughness. Additionally, when the total strain amplitude increases, all cycled rebars exhibit a shorter fatigue life because the specimens reach the plastic range and exhaust their available energy faster. Ensuring sufficient ductility in the reinforcement for projects in Chile is essential due to its potential implications during seismic events (Egger et al., 2023).

## Potential for application of results

The methodology developed in this study can be used to measure strains for multiple experimental tests at a lower computational cost, since unlike other methodologies that track every pixel in high-resolution images, the RGB filter analyses only the pixels of interest. The importance of this method is to measure strains as accurate as possible, since traditional equipment is unable to detect secondary effects, such as possible plastic lengthening of the bar, slippage inside the clamps, or rotations in embedment.

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# Appraisal of split pylon cable-supported bridges subjected to gravity loads

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## Project objectives and goals

The bridge engineering industry faces new challenges in developing sustainable and eco-friendly infrastructure. With the expansion of the global economy, the demand for cross-sea bridges has grown significantly. Currently, two main types of long-span bridges dominate practice: cable-stayed bridges and suspension bridges. Several innovative designs for cable-stayed bridges have been proposed. Gimsing and Georgakis (2011) introduced a V-shaped pylon design, while Starossek (1996) compared split and vertical pylons, identifying potential cost reductions for inclined pylons. Fairclough et al. (2018) applied layout optimization, obtaining results consistent with the split pylon form. These studies highlight the split design's potential advantages and developmental prospects. However, there remains a lack of comparative analysis between split pylon cable-stayed bridges and conventional cable-stayed bridges. Therefore, a comparison of their initial forms can provide valuable insights and serve as a reference for the study and development of this emerging bridge type.

## Description of method and results

The zero displacement method was first applied by Wang et al. (1993). This method can make the girder deflection approach zero under the dead load case through simple iterative calculation of the initial strains. Therefore, the advantage of this method is that when the girders have the

same size, the structure can reach a similar initial shape by adjusting the cable force. In this way, the characteristics of the cables under different pylon inclination angles can be explained by comparing the forces on the cables and other components. Wang and Yang (1996) pointed out that for the initial shape analysis of a cable-stayed bridge, a linear analysis should be sufficient. Therefore, the models are all linear elastic analyses involving self-weight loading, with nonlinearity not considered.



Fig 1 Illustrative split pylon cable-stayed bridge rendering with schematic, non-final geometry

Table 1 Comparison of key parameters

Parameters	Vertical	Split_60	Split_70	Split_80
Force volume of cables	100.00%	123.68%	110.00%	102.45%
Percent difference		+23.68%	+10.00%	+2.45%
Force volume of pylons	100.00%	69.23%	63.81%	60.82%
Percent difference		-30.77%	-36.19%	-39.18%
Force volume of girder	100.00%	78.70%	83.03%	89.97%
Percent difference		-21.30%	-16.97%	-10.03%
Percent difference of total force volume		-25.38%	-26.86%	-25.73%
Percent difference of total embodied carbon		-12.74%	-17.40%	-18.55%
Percent difference of total strain energy		-11.39%	-16.29%	-12.26%

**Note.** Percent difference is calculated using the conventional cable-stayed bridge as a reference. 'Split\_70' refers to a split-pylon cable-stayed bridge with a pylon inclined at 70° to the horizontal.

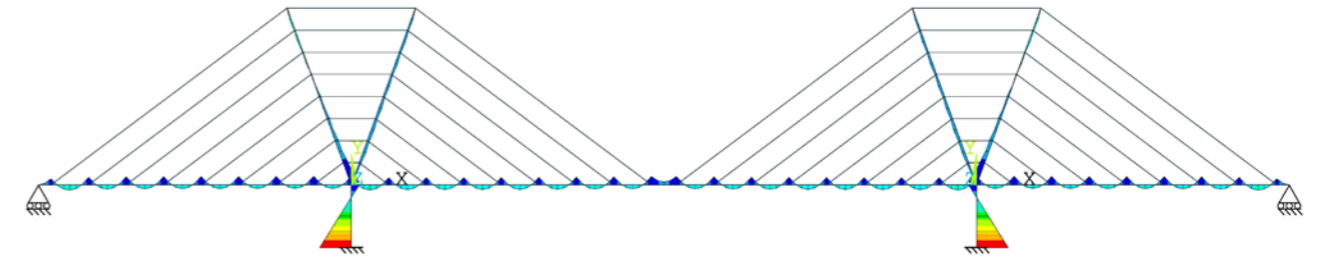


Fig 2 Bending moment diagram of split-70 configuration with boundary conditions

To carry out the proper comparison, the product of force and length, which is a measure of the structural economy proposed by Croll (1997), was adapted. Jutila et al. (2021) applied the force-length method to compare the different schemes of cable-stayed bridges in terms of costs. Here we refer to this as 'Force volume'.

Table 1 summarises the analysis results for a representative 1,200 m cable-stayed bridge with a 600 m main span and two 300 m side spans. The bridge adopts a double-pylon, self-anchored system with a harp-type cable layout, and Fig 1 provides an illustrative rendering. Owing to structural symmetry, only half of the bridge was analysed using a fishbone model. Except for the pylon configuration, all geometric parameters were kept identical to allow direct comparison. After the FEA converged, the bending moment diagram in Fig 2 confirmed that a reasonable completion state was achieved. As shown in Table 1, the split-pylon bridge exhibits clear differences in the force distribution among the main superstructure components compared with the conventional vertical-pylon design. The only increase occurs in the cable force volume, which mainly results from the longer cable lengths rather than higher forces. Overall, all split pylon configurations achieve more than a 26% reduction in total force volume and up to 18.55% lower embodied carbon. The Split-70 form performs best, combining high stiffness (-16.29% strain energy) with efficient material use, demonstrating superior overall structural performance.

To further assess the scalability and general applicability of these benefits, additional analyses were conducted for main-span lengths of 100 m, 300 m, 600 m, 1200 m, and 2000 m. In all cases, the pylon height was proportionally scaled to the span, and material properties were held constant to isolate geometric effects. Across the full span range, split-pylon bridges consistently showed improved material efficiency and lower embodied carbon relative to the conventional design. Among the studied forms, Split\_70 form provided the most balanced structural and environmental performance, confirming its advantages across varying span scales.

## Potential for application of results

The results of this study provide guidance for the preliminary design and optimization of cable-stayed bridges. By clarifying the structural behaviour and efficiency of split-pylon configurations relative to conventional vertical pylons, the findings support more economical, material-efficient, and lower-carbon design choices. These insights also offer a basis for future research on innovative bridge geometries and the wider application of split-pylon systems in long-span projects.

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# Bio-inspired cold-formed steel built-up section members using an interlocking design: concept and behaviour

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## Project objectives and goals

In response to the global trend towards low-carbon economies, there is an increasing emphasis on promoting green buildings and transforming traditional construction industries, with a particular focus on enhancing the reusability and demountability to minimise carbon emission and maximise resource efficiency (Selvaraj and Chan, 2024). Cold-formed steel (CFS) built-up section members have gained growing popularity as a more environmentally friendly alternative in modern building systems owing to their numerous advantages, including superior strength-to-weight ratio, ease of fabrication, recyclability, design flexibility and material efficiency (Yu, 2000; Li and Young, 2022).

The current technology for assembling CFS built-up section members predominantly involves the use of discrete connectors, such as welds, bolts, or screws, along the longitudinal direction. Each of these traditional connection techniques offers distinct advantages and drawbacks. Welding, for instance, provides strong and permanent joints but poses significant challenges for disassembly and modification once completed. On the other hand, bolts and screws allow for assembly and disassembly but typically require precise alignment and can be time-consuming to install and remove. These limitations highlight the need for improvements in the reusability and demountability of

connection methods in practical engineering applications. Consequently, there is a pressing need to develop an innovative connection technique that enhances both reusability and demountability, thereby addressing the shortcomings of traditional methods and meeting the evolving demands of modern construction practices.

## Description of method and results

In nature, interlocking structures are widely observed in the biological tissues of various animal and plant species, such as nacre, bone, and teeth. These natural interlocking structures exhibit enhanced strength and toughness compared to their elements (Rivera et al., 2020), inspiring extensive efforts to incorporate similar principles into engineering structures. Motivated by the geometrically interlocking designs found in natural biomaterials, a novel CFS built-up section using an interlocking design is proposed as shown in Fig 1.

The novel CFS built-up section consists of two CFS channel sections with interlocking parts. The interlocking parts can have different shapes, such as dovetail slots, "Ω" shapes, and others. It can be formed by cold-rolling to provide greater flexibility in forming the shape of interlocking parts or by brake-pressing for improved cost-effectiveness. Taking practical manufacturing feasibility and economy into consideration, this project adopts the dovetail

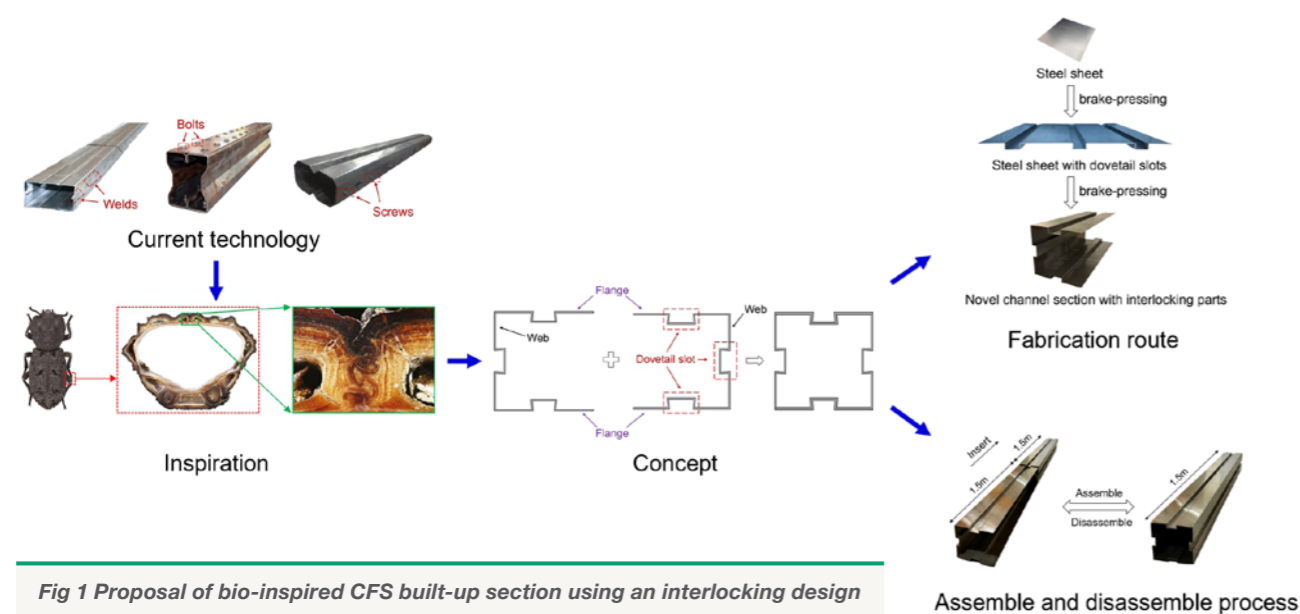


Fig 1 Proposal of bio-inspired CFS built-up section using an interlocking design

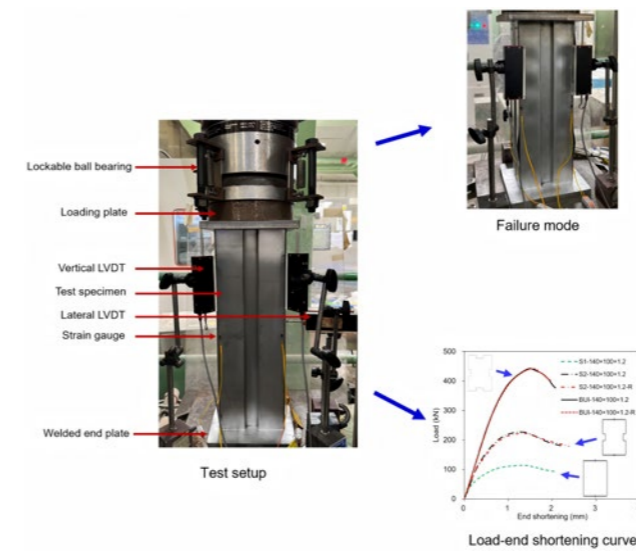


Fig 2 Stub column test

slot achieved through brake-pressing. The dovetail slots are positioned at the flanges of the novel channel section to facilitate connection. It should be noted that these dovetail slots serve not only as connectors but also as stiffeners to effectively enhance structural performance by stiffening the section against local buckling. Consequently, the web of the novel channel section is also equipped with a dovetail slot to further improve its resistance against local buckling. The novel cold-formed steel built-up section can be assembled and disassembled without relying on traditional connectors. Instead, two of these innovative channel sections can be vertically inserted or removed through their respective dovetail slots on the flanges, as shown in Fig 1.

Compared to the traditional connection methods, the interlocking design offers superior advantages. The elimination of discrete connectors simplifies the assembly process, reducing labour requirements and streamlining construction operations. The interlocking feature enhances its sustainability by facilitating disassembly and reuse. It allows for easy replacement of potentially damaged channel sections, which is particularly beneficial in long-term applications. This reusability aspect not only extends the life cycle of the materials but also aligns with sustainable construction practices by reducing waste and promoting resource efficiency. In addition, the interlocking design ensures exceptional structural integrity, significantly enhancing the load-carrying capacity. An experimental programme was conducted to examine the structural behaviour of this new type of CFS built-up section stub column and compare it with the traditional counterpart using screws. The stub column test setup and test results are shown in Fig. 2. It can be observed that the design successfully achieves the interlocking effect, ensuring that two individual channel sections remain connected throughout the entire testing process. Additionally, this novel built-up section stub column exhibits a significant increase in ultimate capacity compared to traditional counterpart using screws within the same configuration.

## Potential for application of results

This novel interlocking design represents a significant advancement in construction technology, as it eliminates the need for traditional connectors and offers a practical, eco-friendly alternative to conventional methods. It has high potential for use in light-gauge steel structures, prefabricated systems, and modular integrated construction (MiC) structures, enabling rapid, tool-free assembly and non-destructive disassembly. This facilitates module reuse, component replacement, and full structural recycling, directly supporting circularity in construction and reducing construction waste. For light-gauge steel framing, the interlocking design streamlines the creation of robust structural members without traditional connectors, improving off-site manufacturing efficiency and on-site installation speed. The dovetail slots act as stiffeners, allowing for more material-efficient, high-performance members. It also offers excellent potential for temporary and relocatable structures, such as disaster-relief housing and event pavilions, where speed and reusability are critical. **By merging enhanced structural performance with inherent sustainability, this interlocking design presents a practical, eco-friendly advancement for modern building practices.**

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# Analysis of the delamination mechanisms of mass timber products

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## Introduction

The need to reduce carbon emissions from construction projects has made timber products a sought-after material in the past decade. The requirement for timber products with structural performance comparable to the one of steel and concrete has led to the invention of mass timber. Mass timber is a term describing a group of engineered wood products consisting of multiple layers of timber lamellae formed into a panel using an adhesive (The Alliance for Sustainable Building Products, no date). Mass timber is represented by materials such as cross-laminated timber (CLT) and glued-laminated timber (Glulam), both comparable in structural strength to concrete and steel but having lower overall carbon emissions. The difference between CLT and Glulam is the orientation of the lamellae, for CLT the lamellae are perpendicular to one another while for Glulam they are parallel. Fig 1 shows the orientation of the timber layers of CLT and Glulam.

Yasir et al. (2025) and Ferreira et al. (2017) explain that delamination of the layers, described by the formation of cracks, may occur for reasons such as loading or natural aging, and leads to compromised structural strength and fire resistance. Yet, the delamination mechanisms of CLT and Glulam are not fully studied which raises concerns when they are considered for construction. The research aims to establish the delamination mechanisms of CLT and Glulam samples subjected to loading. The objectives of the project are:

- Using a high-resolution digital camera for observing the behaviour of CLT and Glulam during a three-point bending test
- Performing a digital image correlation (DIC) analysis to establish the crack formation mechanisms

## Data acquisition and analysis

Cross-laminated and glued-laminated timber samples with spans of either 150mm or 450mm are subjected to a three-point bending test. Table 1 shows the dimensions variety of the tested samples.

Material	Span	Width	Thickness
CLT	150mm or 450mm	Between 40mm and 160mm	60mm or 100mm
Glulam	150mm or 450mm	60mm or 100mm	Between 40mm and 160mm

A three-point bending tests subjects the samples, supported on both ends of the span, to a load applied in the middle of the span until the sample breaks. The test allows for the measurement of the strength of the material. A digital camera is placed at 0.65m from the machine along with a box light allowing for high-quality videos of the samples to be recorded. This approach eliminates the requirement for manual monitoring and recording of the crack formation, leading to a minimised risk of human error when observing the behaviour of the materials during the test. Fig 2 shows an image of the test set-up.

The video recordings of the samples under the applied load are analysed using digital image correlation (DIC) methods for determining the delamination of the samples, particularly looking at the cracks and the associated direction, location, and size. Furthermore, annotations are added to the frames of the video to describe the cracks and allow for the investigation of patterns when they are forming (OpenCV, 2024).

## Application of the results and future development

Three-point bending test combined with the application of imaging provide detailed observations of the behaviour of CLT and Glulam subjected to loading. The application of DIC techniques allows for the monitoring of the delamination mechanisms of the members and minimise the reliance on manual observations. The performed analysis expands on the knowledge of crack related failure of layered engineered wood products which will inform decisions about their safe application in construction projects. Additionally, the obtained analysis results provide initial datasets for training machine learning models for predicting the delamination of CLT and Glulam.

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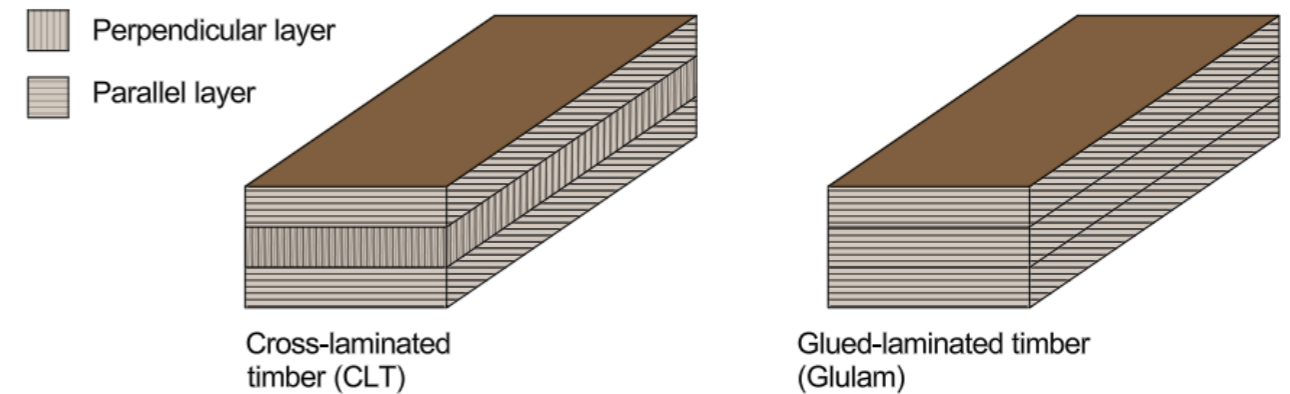


Fig 1 CLT and Glulam layers orientation

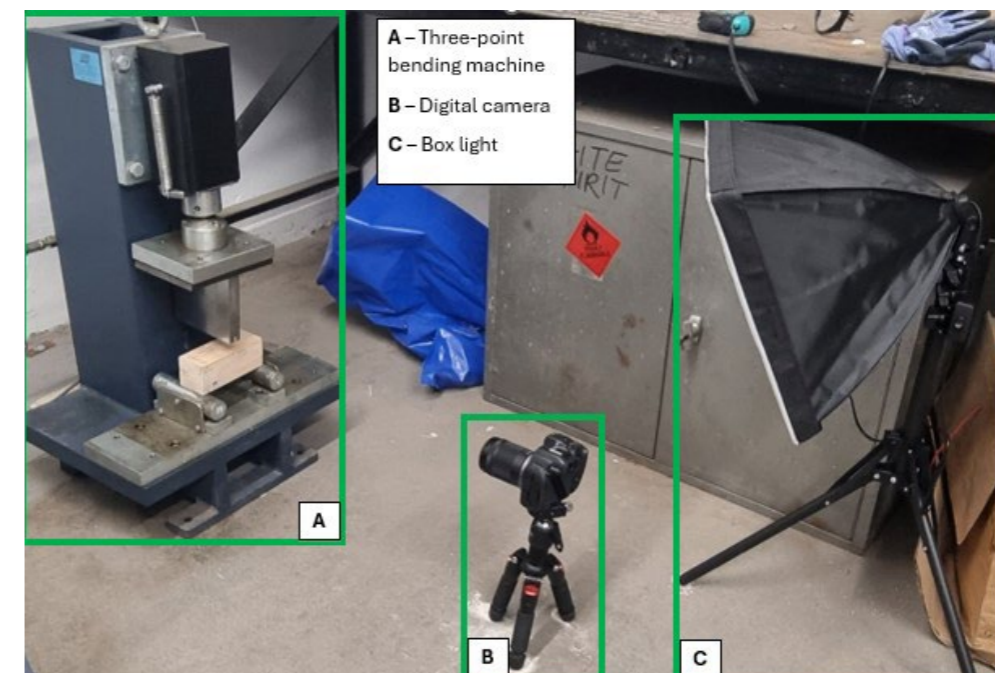


Fig 2 Three-point bending test and imaging set-up

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# Experimental investigation of two-side fastened roof diaphragms made of trapezoidal sheets

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## Project objectives and goals

The objective of this research project is to investigate the structure–cladding interaction of steel roof diaphragms formed by trapezoidal sheets, where the diaphragms are connected to the supporting structure on only two sides. Such arrangements are widely used in Eastern Europe, yet they are not covered by current European design recommendations (ECCS – TC7, 1995). The project aims to:

- quantify the shear capacity and stiffness of two-side fastened diaphragms;
- identify key influencing parameters of diaphragm behaviour;
- assess the applicability and limitations of existing analytical approaches;
- propose extensions to current design methodologies.

## Description of method and results

A comprehensive experimental investigation was conducted on roof diaphragm assemblies tested under in-plane loading. The test setup consisted of two 2.5 m bays with a total specimen length of 3.0 m, where the marginal rafters were fixed and the intermediate rafter was free to move and subjected to controlled displacement. Fig. 1 and Fig. 2 illustrate the experimental test setup. A total of 20 trapezoidal sheet diaphragm configurations were investigated. The studied parameters included:

- seam fastener distribution;
- panel-to-purlin fastener distribution;
- purlin height, thickness and orientation;
- differences between continuous and overlapped purlins;
- sheet geometry, thickness, and single or double-skin arrangements.

The experimental diaphragm stiffness values were determined using the 40% secant stiffness evaluation procedure adopted in American diaphragm testing guidelines (O'Brien et al., 2017). This method defines stiffness as the slope of the force–displacement curve at 40% of the maximum recorded load, enabling consistent comparison between specimens.

Analytical predictions based on existing European design methodologies (Lőrincz et al., 2024a; Lőrincz et al., 2024b) revealed notable discrepancies when compared to the experimental results, highlighting the insufficiency of current procedures for two-side fastened diaphragm arrangements. In their strict form, the provisions of ER

No. 88 do not permit the application of analytical design methods to diaphragms fastened to the main structure on only two sides. Consequently, the analytical approach required adaptation using the provisions of Davies and Bryan (1982), who allow such configurations for so-called “lightly loaded diaphragms”. However, this classification is not clearly defined in the literature and its practical meaning remains ambiguous. Nevertheless, even with this adapted analytical framework, the combined procedure could be applied only to a limited subset of the experimentally investigated configurations: out of the 20 tested trapezoidal sheet diaphragm arrangements, analytical stiffness predictions could be obtained for only nine cases. This further emphasizes the restricted validity range of the current ECCS-based design framework and the need for its extension grounded in comprehensive experimental evidence.

Results demonstrate that diaphragm stiffness is strongly influenced by the diaphragm-to-rafter connection behaviour. The experimentally observed trends confirm the findings of previous numerical investigations presented by Nagy et al. (2023a), which highlighted the decisive role of rafter–purlin connection stiffness in governing the stressed skin effect of corrugated sheet diaphragms. A more detailed experimental evaluation of these behavioural trends is presented by Lőrincz et al. (2024c), focusing specifically on the influence of continuous and overlapped purlin arrangements at intermediate rafters.

Further insight into diaphragm performance is provided by Nagy et al. (2023b). Typical failure mechanisms included seam fastener bolt tilting accompanied by localized sheet damage, as well as local and distortional buckling of Z-purlins. Comparative analyses of specimens with varied parameters demonstrated that double sheeting resulted in approximately double diaphragm stiffness and shear capacity relative to single-sheet systems. Similar stiffness increases were observed for configurations with fixing in every corrugation compared with alternate trough fastening.

## Potential for application of results

The outcomes of this research provide an improved understanding of diaphragm action in steel portal frame structures with two-side fastened trapezoidal sheet cladding systems. The experimental database provides structural engineers with a basis for deciding when diaphragm effects may be neglected or must be explicitly



Fig 1 Test setup without trapezoidal sheets

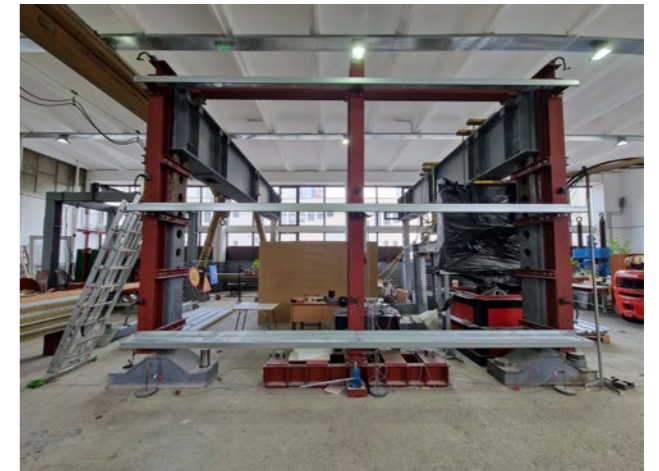


Fig 2 Test setup with trapezoidal sheets

considered in global analysis. The results contribute to support future extensions of European design standards toward the inclusion of non-standard diaphragm configurations commonly encountered in engineering practice.

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# Experimental investigation of lightweight cold-formed steel frames with semi-rigid connections

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## Project objectives and goals

This research investigates the joint-stiffness of joist-stud connection by analysing the moment-rotation curves for different types of connections. The moment-rotations were plotted using three types of methods which include Inclinometers, LVDTs and DIC (Digital Image Correlation). Accurate measurement of joint rotation is essential in predicting the rotational stiffness. All these results were also compared with the theoretical model developed based on the experimental results of lap-shear tests for screws.

The main objectives of this research are:

- To compare and correlate the moment-rotation curves obtained from LVDTs, DIC along with the theoretical graph during beam-column joint testing.
- To identify the causes of discrepancies between the two measurement systems, including the influence of gauge definition, local deformation, and filtering.
- To develop a standardized methodology for integrating DIC and LVDT data for reliable experimental evaluation of joint rotational behaviour.

## Description of method and results

### Experimental Setup

A total of 10 T-frame tests under quasi-static loading were carried out till failure by varying the joint stiffness using different pattern of screw connections between joist-stud. Four LVDTs, four inclinometers and two DIC set up were employed to capture the deformation and failure during the tests. Out of 10 tests, 2 tests were performed without the floor sheathing (NF) and rest with 18 mm thick plywood as floor sheathing (F). Load-displacements of all the tests and moment-rotation were plotted after the tests were completed. Fig 1 shows the experimental set-up for T-frame test. The Table 1 below shows the average measured geometric dimensions of all the ten test specimens along with the labelling as discussed above where t denotes thickness, h denotes the web depth, b denotes the flange width and l represents lip length. The subscript letters "j" and "s" represents "joist" and "stud" respectively.

The moment-rotation relationship was established using the following equations Eqn (1-8):

$$\text{From Inclinometers: } \theta_{joint} = \theta_{beam} - \theta_{column} \quad (1)$$

$$\text{From LVDTs: } \theta_{column} = \frac{\delta_{col,top} + \delta_{col,bottom}}{h_{1,col} + h_{2,col}} \quad (2)$$

$$\theta_{beam} = \frac{\delta_{beam,top} + \delta_{beam,bottom}}{h_{1,beam} + h_{2,beam}} \quad (3)$$

From DIC:

$$\text{Beam: } \theta_{beam} = \frac{dv}{dx} ; \text{ Column: } \theta_{column,top} = \frac{dv}{dx} ; \quad (4)$$

$$\theta_{column,bottom} = \frac{dv}{dx} \quad (5)$$

$$\theta_{column} = \text{Average} (\theta_{column,top} ; \theta_{column,bottom} ) \quad (6)$$

$$\theta_{joint} = \theta_{beam} - \theta_{column} \quad (7)$$

$$\text{Moment on joist on each side: } \frac{P_u L_c}{2} \quad (8)$$

$L_c$  is calculated from the loading point to the center of the stud which is 1.75 m for all the tests.

$P_u$  is the maximum load for each cycle in kN.

In the above equations;  $\theta_{column}$  and  $\theta_{beam}$  represents the rotations of column and beam respectively.  $\delta_{col,top}$  and  $\delta_{col,bottom}$  denotes the slip recorded by LVDTs for the top and bottom part of column respectively. Furthermore,  $h_{1,col}$  and  $h_{2,col}$  represents the height of the LVDT on top and bottom part of column respectively calculated from the centre of the joint and same can be explained for  $\theta_{beam}$ . Lastly,  $\theta_{joint}$  is the joint rotation calculated using Eqn 7 and  $\frac{dv}{dx}$  represents the slope with reference taken as (x- axis: u and y-axis: v).

### Interpretation of results

Following are key outcomes from the experiment carried out along with a typical failure mode shown in Fig 2.

- The rotation data from DIC are with good agreement with the LVDTs data
- There is an equal increase in stiffness by proportion when shifting from non-flooring to flooring for same type of specimen with same connection type.

Table 1 Average measured geometric dimensions of tested specimens

Specimen ID	$t_j$ (mm)	$b_j$ (mm)	$h_j$ (mm)	$l_j$ (mm)	$t_s$ (mm)	$b_s$ (mm)	$h_s$ (mm)	$l_s$ (mm)
TF1-W3-F	1.28	49.58	269.97	10.80	1.63	75.05	150.02	13.82
TF1-W5-F	1.29	49.96	269.98	10.89	1.63	74.95	150.03	13.95
TF1-WpC1-F	1.29	49.98	270.01	10.93	1.63	75.01	150.00	13.99
TF2-WpC2-F	1.19	62.01	209.98	13.69	2.00	75.05	180.13	14.06
TF3-W3-F	1.28	74.82	240.02	13.81	1.55	74.94	150.00	13.94
TF3-W5-NF	1.30	74.84	239.98	13.77	1.61	74.69	150.02	13.97
TF3-W5-F	1.28	74.82	240.02	13.81	1.62	74.84	149.99	13.72
TF3-WpC2-NF	1.29	74.96	240.05	13.98	1.61	74.98	150.00	13.95
TF3-WpC2-F	1.29	74.96	240.07	13.86	1.62	75.01	150.00	13.98
TF4-WpC1-F	1.60	74.94	269.98	13.70	1.61	74.71	149.97	13.75

- All the tested specimens underwent 10 cycles before failure
- Stiffness increases upon increasing the joint rigidity.

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Fig 1 Experimental layout of T-frame tests (Structures Laboratory, Imperial College London)



Fig 2 Distortional buckling at joist flange and web

# Enhancement of recycled cementitious materials by accelerated carbonation

**16 Henrique Comba Gomes**  
University of Plymouth

## Project objectives and goals

The aim of the research was to investigate the enhancement potential of accelerated carbonation on cementitious materials considering the performance of mortars casted with recycled concrete aggregates as replacement for sand produced from conventional concrete. The objectives to achieve the aim are:

- Crush concrete to produce recycled fine aggregates (RFA).
- Characterise RFA physical properties.
- Cast mortars with different replacement rates of sand by recycled fine aggregates.
- Carbonate the recycled mortars after water cure.
- Evaluate the performance of the recycled mortars by investigating mechanical and durability aspects before and after the carbonation process.

## Description of method and results

The investigation started by crushing parent concrete casted considering 0.60 water-to-cement ratio (W/C) and average compressive strength of 18.70 MPa after 28 days of water cure. The concrete was casted and crushed in the

laboratory of the University of Plymouth to produce RFA between 0.063-4.00 mm according to the British Standard 12620:2002 + A1:2008 (BSI, 2002b) as shown in Fig. 1. RFA were characterised concerning void content, particle and bulk density and water absorption and compared to natural sand (NFA). The results for the characterisation tests are exposed in Table 1.

The results present higher void content and water absorption and smaller particle density and bulk density, suggesting an increase in porosity in RFA compared to NFA. The main explanation relates to the creation of microcracks during the crushing process (Wabhitkar *et al.*, 2025) and the presence of the mortar attached to RFA surface, creating an interfacial transition zone (ITZ) between the old aggregate and the adhered mortar (Shi *et al.*, 2016), leading worst performance compared to NFA (Brito and Saikia, 2013).

0.60 W/C mortars were casted with 0, 20, 40, 60, 80 and 100% replacement rate. Due the high porosity of RFA, W/C of 60, 80 and 100% mixes were increased to 0.66, 0.78 and 0.84 to allow the proper mixing of the materials.



Fig 1 Recycled fine aggregate

The mortars were than cured for 28 days in water and them exposed to accelerated carbonation condition with 10% CO<sub>2</sub> concentration and 60±5% relative humidity for 28 days. The efficiency of the treatment was evaluated by compressive (CS), tensile (TS) and flexural strength (FS) (BSI, 1999), water absorption by immersion (WAI) and capillarity (WAC) (BSI, 2002a) and chloride migration (CL) (Nordtest, 1999) before (BC) and after (AC) accelerated carbonation conditions, respectively. The carbonation depth (CD) was measured after 7 and 28 days according to BS 12390-12 (BSI, 2021) to track the pH decrease. Fig. 2 show the compressive strength values, and Table 2 show the other properties evaluated.

It is possible to observe that mortars with higher RFA had a worst performance considering mechanical and durability properties, which is related to the poor performance of RFA. However, the carbonation treatment improved the mechanical properties of the mixes while decreased the susceptibility of the mixes against durability impacts. This is a promising result in what concerns the potential for accelerated carbonation as a treatment for recycled concrete aggregates.

## Potential for application of results

The applicability of recycled concrete aggregates to replace sand in cementitious mixes is reduced compared to coarse materials due performance limitations by the BS EN 12620 (BSI, 2002b) and BS EN 8500-2 (BSI, 2023). On this sense, this study aims to contribute to technically improve the application of RFA in construction materials by enhancing the performance of recycled mixes on mechanical and durability aspects. In addition, the volume of fine aggregates applied in cement-based materials is proportionally higher compared to coarse ones, so increasing the application of RFA in mortar and concrete mixes would also improve the sustainability in the construction field.

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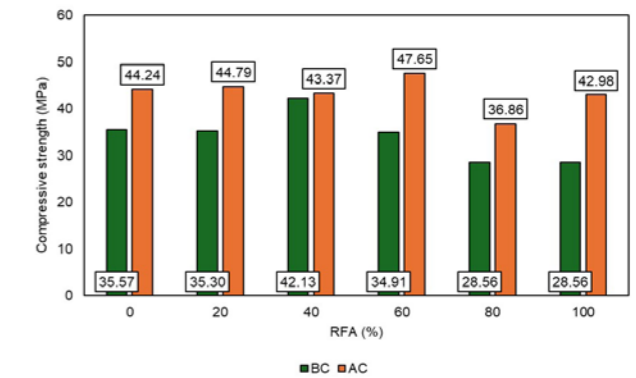


Fig 2 Compressive strength of recycled mortars

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**Table 1 Fine aggregates characterisation**

Material	Void content (%)	Particle density (g/cm <sup>3</sup> )	Bulk density (g/cm <sup>3</sup> )	Water absorption (WA) (%)
NFA	34	2.52	1.67	2.14
RFA	48	2.51	1.31	10.47

**Table 2 Recycled mortars properties**

RFA (%)	TS (MPa)		FS (MPa)		WAI (%)		WAC (kg/m <sup>2</sup> √min)		CD (mm <sup>2</sup> /d)		CL (10 <sup>-12</sup> m <sup>2</sup> /s)	
	BC	AC	BC	AC	BC	AC	BC	AC	7d	28d	BC	AC
0	4.00	4.57	7.23	9.40	8.92	6.07	0.30	0.31	0.09	0.11	18.64	16.18
20	4.45	5.15	8.28	10.30	7.42	7.33	0.27	0.19	0.05	0.09	24.74	19.26
40	3.76	4.22	7.61	9.34	10.81	8.96	0.30	0.19	0.07	0.08	20.7	12.8
60	3.47	4.31	6.63	7.93	12.15	9.24	0.27	0.25	0.09	0.11	25.15	19.33
80	3.29	3.04	6.63	8.48	12.63	9.23	0.37	0.21	0.13	0.14	26.86	24.81
100	3.11	3.87	7.24	6.77	12.63	10.49	0.43	0.28	0.13	0.15	30.74	34.72

# Utilisation of pumice for low carbon lightweight structural concrete

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## Project objectives and goals

This project investigates natural pumice as a dual function material for structural concretes: (i) a supplementary cementitious material (SCM) when finely ground; and (ii) a lightweight coarse aggregate. The goals are to quantify the pozzolanic reactivity and mineral composition and establish physical properties relevant to lightweight structural mix design. Furthermore, this research will map a route from material characterisation, optimisation of concrete mix, testing structural element, Finite Element Modelling (FEM) based design integration for low carbon structural applications. Prior work supports pumice's potential both as a reactive pozzolan and as a structural lightweight aggregate, motivating this dual pathway (Abbas et al., 2023).

## Description of method and results

### (a) Standards and materials

Physical characterisation was carried out in accordance to BS EN 1097-6 (particle density/specific gravity), BS EN 1097-3 (bulk density) and BS 812-112 (Aggregate Impact Value, legacy). Test materials were: ground pumice (<38 µm and 53 µm) for SCM studies; graded pumice as lightweight coarse aggregate; and reference dense aggregate.

### (b) Physical properties

Specific gravity (OD/SSD): pumice 1.45/1.38 vs dense aggregate 2.56/2.51.

The much lower particle density confirms high internal porosity. The OD-SSD gap indicates meaningful water uptake, so pre-saturation or water/batch adjustments will be essential to control workability and effective w/c in later mix trials.

Bulk density (kg·m<sup>-3</sup>): pumice ≈666 (loose) / ≈732 (compacted) vs dense aggregate ≈1408 / ≈1541. A ~600–750 kg·m<sup>-3</sup> reduction in aggregate contribution to fresh density. With appropriate paste design, this points to structural lightweight concrete (SLWC) suitability while reducing dead loads, compared to normal weight concretes.

Aggregate Impact Value (AIV): pumice ≈10.8%, dense aggregate ≈7.5%.

Both are within typical structural ranges; the slightly higher AIV for pumice reflects lower toughness and

should be accommodated by appropriate grading and sensible maximum replacement fractions in early mixes.

### (c) Pozzolanic reactivity – Chapelle Test

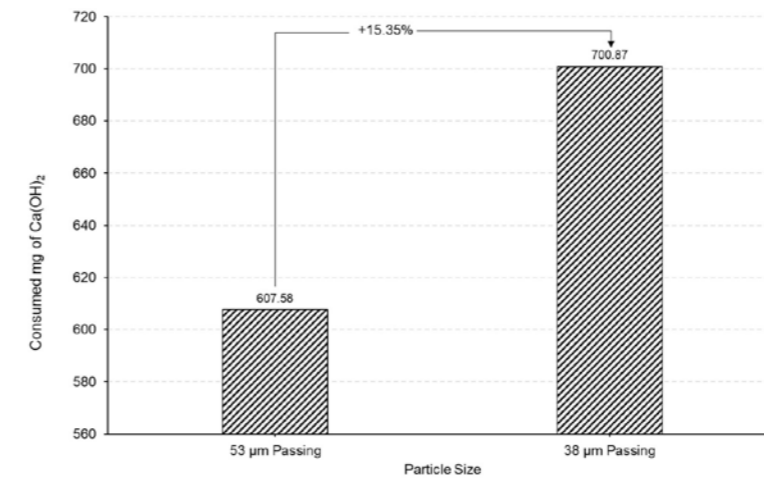
The results of the reactivity test are depicted in Fig 1, which show that ground pumice powder with particle size less than 38 µm exhibits higher pozzolanic activity than the 53 µm fraction (NF P 18-513, 2012). This is due to the more exposed reaction surface (as a result of breaking into smaller particles). Particle sizes between 38 and 53µm result in less reactivity, albeit still with good reactivity. Thus, fine pumice powder can be used as binder replacement, to consume portlandite and generate secondary C-A-S-H gel (Zhu and Richardson, 2023) during cement hydration, enabling conventional clinker reduction. Natural pozzolans of pumice/volcanic ash origin have exhibited such reactivity and durability benefits in early cement systems.

### (d) Mineralogy analysis using X-Ray Diffraction (XRD)

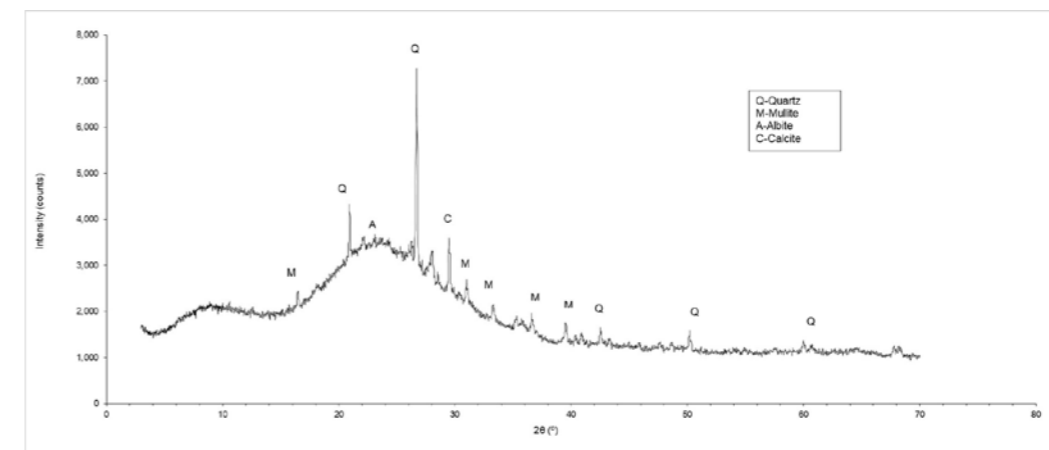
The results of the XRD analysis are summarised in Table 1, which shows that the silica–aluminosilicate assemblage (quartz, mullite, albite) is consistent with a volcanic origin. Crystalline phases were identified using XRD analysis; part of pumice's reactivity typically arises from the amorphous glass fraction which Chapelle Test's results effectively capture. The presence of calcite material suggests partial carbonation of reactive surfaces during processing/storage; this is common and does not preclude pozzolanity. Together, XRD analysis and Chapelle Test provide a coherent picture: a reactive natural pozzolan with sufficient alumino-silicate content to contribute to later age binding. Fig 2 show the XRD analysis of ground pumice powder.

**Table 1 Mineral Composition Content**

Mineral Composition	% Content
Quartz	34.3
Mullite	19.5
Albite	27.7
Calcite	13.8
LOI	4.7



**Fig 1 Comparison of Pozzolanic Reactivity**



**Fig 2 XRD Analysis Chart on Ground Pumice**

### e) Chemical compatibility

Pumice powder pH level was 9.33, representing mild alkalinity compatible with cement pore solution chemistry. The true density was 2.37–2.39 g cm<sup>-3</sup>, which can be used in volumetric replacement calculations to reconcile mass-based dosages with target paste volumes in mix design.

## Conclusions

- As SCM: the measured Chapelle Test values justify clinker reduction trials with finely ground pumice in the binder. Natural pumice/volcanic pozzolans have previously shown favourable pozzolanic/ASR mitigating behaviour in cement systems, supporting this direction.
- As lightweight aggregate: the large drop in bulk density indicates realistic scope to achieve SLWC unit weights with careful paste design, aiding deadload reduction and embodied carbon cuts at element and system level. Independent studies developing pumice based LWAC report both density reductions and embodied carbon advantages, reinforcing the application potential of the approach.

## Potential for application of results

The combination of high pozzolanity (fine pumice) and low aggregate density provides a credible route to lightweight, lower clinker structural concretes. In practice this can translate to reduced member self-weight (smaller foundations, improved seismic response) and lower

embodied carbon at material and system levels. Published developments in pumice based LWAC/lower clinker binders support this trajectory and provide benchmarks for next phases.

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# Experimental investigation of corrosion effects on the structural performance of reinforced concrete slabs incorporating distributed fibre optic sensing

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## Project objectives and goals

Corrosion is a multi-billion pound threat to transport infrastructure, silently compromising the safety of ageing bridges. With over 70% of the UK's highway bridges constructed from reinforced concrete (RC) and many exceeding their design life, they are increasingly subjected to environmental aggression, particularly chloride-induced corrosion (Rao et al., 2018), a process that is expected to be further intensified by climate change.

While the residual capacity of corroded beams and columns has been widely reviewed (Kashani et al., 2019) experimental evidence and systematic understanding of the structural behaviour of corroded two-way slabs, key components of bridge decks, remain limited. Recent studies have begun to explore this, investigating slab-column connections (Qian et al., 2022) and bandwidth corrosion (Said and Hussein, 2019); However, the absence of reliable guidelines for full-scale bridge decks under corrosion presents a clear challenge for industry and underscores the need for a simplified, computationally efficient, yet accurate nonlinear grillage model for bridge assessment.

The development of such a model requires high-quality experimental data to bridge the gap between isolated academic studies and real-world practice. Accordingly, the specific objectives of this research are:

- To investigate the impact of reinforcement corrosion on the load-carrying capacity, stiffness degradation, and failure modes of two-way RC slabs.
- To compare the behaviour of single-layer (R1) versus double-layer (R2) reinforcement configurations, representing different reinforcement designs.
- To utilise Distributed Fibre Optic Sensing for continuous strain monitoring and high-resolution 3D scanning for precise pitting analysis. This high-fidelity data will provide the precise calibration needed for future finite element modelling in OpenSees, ultimately delivering a robust tool for asset managers.

## Description of method and results

Six, two-way reinforced concrete slabs were fabricated and tested under controlled laboratory conditions. Each slab measured 1700 × 1700 × 150 mm. The specimens were divided into two series according to reinforcement layout: the R1 series comprised single-layer slabs with only bottom reinforcement (11 × B12 bars in both directions) and the R2 series comprised double-layer slabs with bottom (11 ×

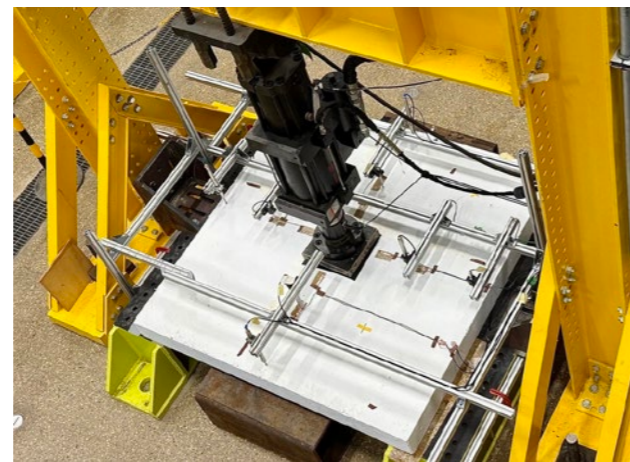


Fig 1 Test setup and instrumentation

B12) and top (11 × B10) reinforcement. To simulate decades of environmental degradation, an impressed-current electrochemical corrosion technique was applied. The slabs were conditioned to represent three target corrosion states: uncorroded control (C0), lightly corroded (C1) and highly corroded (C2). Following corrosion conditioning, each slab was loaded monotonically at its centre using a 500 kN hydraulic actuator and a 300 × 300 mm loading plate under displacement control. Instrumentation comprised a dense array of strain gauges, LVDTs, and distributed fibre-optic sensors (Fig1).

Following structural testing, the extracted and cleaned reinforcement underwent gravimetric weighing and high-resolution 3D optical scanning to quantify both mass loss and localised pitting. These scans enabled calculation of local cross-sectional reductions, centroidal shifts and local second moments of area, metrics that are not revealed by average mass-loss alone.

The experimental results demonstrate that corrosion has a substantial impact on the structural response of the slabs, affecting capacity, stiffness, and the governing failure mechanism. With increasing corrosion, specimens exhibited lower initial stiffness, different crack pattern, and reduced peak loads relative to their uncorroded controls.

The experimental results showed that failure mechanism transitions are influenced by reinforcement layout and corrosion severity. In the R1 series, uncorroded and lightly

Table 1 Summary of experimental tests

Specimen	Reinforcement Layer	Corrosion Target	Failure Mode
R1C0	Single	Uncorroded	Brittle Punching
R1C1	Single	Light (~10%)	Brittle Punching
R1C2	Single	Heavy (~20%)	Flexural
R2C0	Double	Uncorroded	Flexural-Punching
R2C1	Double	Light (~10%)	Flexural
R2C2	Double	Heavy (~20%)	Flexural

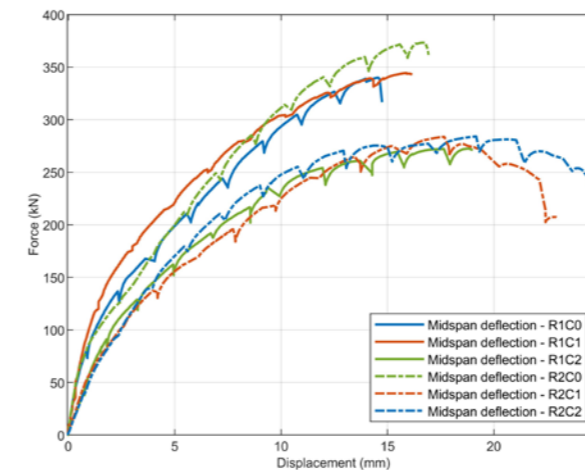


Fig 2 Load versus central deflection response for single and double-layer specimens with varying levels of corrosion

corroded specimens failed in brittle punching shear, with ductile flexural failure occurring only in the heavily corroded specimen. In contrast, the double-layer (R2) configuration was more sensitive, the uncorroded control failed in flexural-punching mode, while even light corrosion caused a shift to purely flexural failure. This behavioural change indicates that corrosion not only weakens the reinforcement but also alters the slab's overall structural response. Table 1 summarises the critical performance metrics.

The accuracy of strain gauge measurements was constrained by their positioning, as sensors situated between or directly on cracks provided only partially reliable data. In contrast, fibre optic sensors allowed continuous strain monitoring across both the top and bottom slab surfaces, providing a comprehensive strain profile. Additionally, fibre optic monitoring of hammer tests at 2 mm intervals revealed a clear reduction in dominant frequency, effectively tracking progressive stiffness degradation and accumulating damage. This facilitated a more detailed understanding of slab behaviour, including neutral axis displacement, and enabled rigorous verification of the numerical model to ensure accurate predictions.

## Potential for application of results

These findings have direct implications for the assessment and management of ageing RC bridge decks. The observed shift from brittle punching to ductile flexural failure suggests

that corrosion can fundamentally alter the governing limit state of slabs. Current assessment methods often assume that failure mode remains constant throughout a structure's life; the experimental evidence shows that this assumption may be unsafe for corroded decks.

Crucially, the experimental data provide valuable input for calibrating the finite element model, enabling the development of simplified, yet nonlinear grillage models in OpenSees that are fast, reliable, and applicable to whole-bridge system assessment. Such models can significantly improve predictions of residual capacity and service life, enabling bridge owners to make more informed decisions about load restrictions, maintenance prioritisation and long-term asset management.

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# Robustness-based design of precast concrete structures

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## Project objectives and goals

Progressive collapse arises when the loss of one or a few elements leads to disproportionately larger damage. Precast structures, which are the subject of this research, are particularly vulnerable to progressive collapse because of their inherent discontinuities. Design procedures for ensuring robustness include prescriptive tying rules, like those in Eurocode 2 (2004), and direct methods that consider accidental column removal. Tying rules were first introduced in the UK following the 1968 Ronan Point building collapse. They implicitly assume that catenary action develops following sudden column loss and therefore provide prescriptive rules for ties. Full-scale tests and field observations show that these rules are not always effective. On the other hand, direct methods of assessing column loss are time-consuming and lack clear implementation guidance. Both methods overlook the capabilities of different structural systems and connection types in developing alternative load paths (ALPs) after a support loss. They also have shortcomings in properly accounting for dynamic effects. As a result, structures designed according to current methods for robustness face uncertainty in their performance, raising doubts about whether they can meet the guidelines' presumptions. These concerns have shaped the objectives of this research, which entail:

- Carrying out a comprehensive investigation into the effect on robustness of parameters, such as joint detailing, and the location of the damage.
- Quantifying the effect of key parameters, such as joint detailing, on the development of ALPs.
- Developing guidance for robustness-based design and joint detailing, incorporating the considered parameters with emphasis on precast structures. Such guidance is currently limited in scope and unrealistic.

## Description of method and results

In order to investigate ALPs against progressive collapse, typical precast systems with different joint details under different sudden column removal scenarios are considered. Robustness is quantified using the energy-based method (Izzuddin et.al, 2008), which compares the system's pseudo-static capacity, derived from its static load-displacement response, with the instantaneously applied gravity load following a column removal. The dynamic effects are fully considered in this method.

One of the considered cases is a commonly used joint detail in precast concrete structures (Fig 1), which was also used in a full-scale test of a precast concrete building under sudden column removal (Buitrago et al.,2023). The building consisted of two 6 m bays and three 5 m bays in each perpendicular direction. Precast beams, supporting 6 m hollow-core slabs, were seated on corbels and connected to them with 2Ø20 dowel bars. A structural topping was placed over the slab units and beams. Continuity ties were 3Ø20 in the edge beams and 3Ø25 in internal beams according to the DoD guidelines (2009). The building showed only small deformations under three column-removal scenarios, making it an interesting case for studying potential ALPs.

A detailed numerical component-based finite element model was developed in ADAPTIC (Izzuddin, 1991) (Fig 1), and nonlinear static analysis was carried out for the parametric studies. The model considered only the frame action, excluding slab effects. Three sudden column-removal scenarios were analysed: C (corner), E5 (edge along the 5 m spans), and E6 (edge along the 6 m spans). As shown in Fig 2, the pseudo-static load factor exceeded 1.0 in all cases, but numerical displacements were larger than the measured values due to neglecting the stiffening effect of slabs. Flexural failure occurred at a chord rotation of about 0.1 rad, before catenary action could form, due

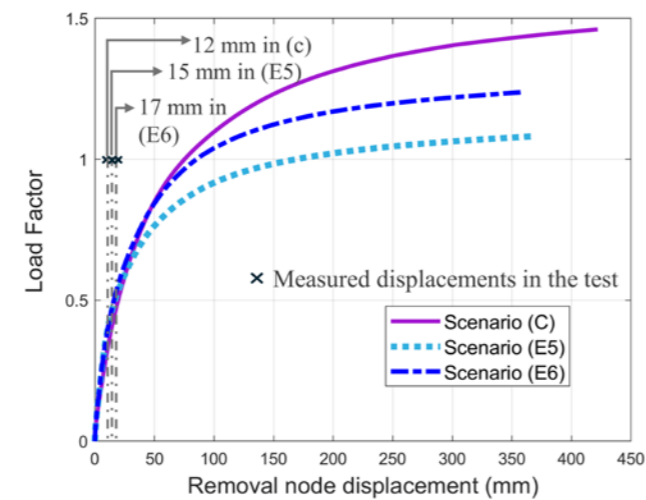


Fig 1 Connection detail and component-based model

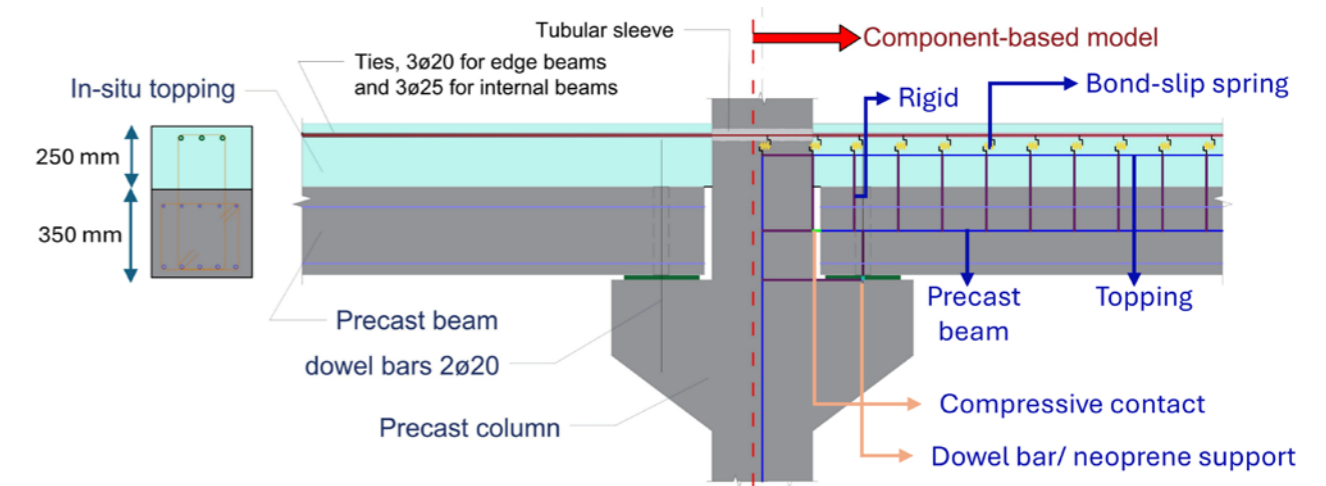


Fig 2 Pseudo-static load-carrying capacity for different removal scenarios

to rupture of top ties or dowel bars. Although the ties were intended to develop catenary action, this was not the case here. The provided ties were unable to develop any catenary action, once again raising concerns regarding the design assumptions.

## Potential for application of the results

Current prescriptive tying methodologies for ensuring robustness typically assume the development of catenary action, while ignoring the influence of many parameters on whether the provided ties will be effective. Many studies have shown the inadequacy of these methods. This raises the question of whether the actual structural behaviour should be considered in robustness-based design. This study aims to use its findings to develop improved guidance for robustness-based design, which incorporates actual structural behaviour.

This study explores the capability of different structural systems and connection types to develop ALPs following column loss, allowing each system to be designed for the mechanism it can realistically mobilise in such scenarios. Ultimately, guidance on connection design and detailing will also be proposed. This would provide engineers with a reliable reference that directly accounts for structural behaviour and key parameters such as damage location.

The use of energy-based method in this study provides a realistic measure for robustness, helping to overcome the vague definition of damage extent and acceptance criteria in implementing direct column removal methods in the guidelines.

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# Graphene Oxide Concrete – Have we got it right?

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## Project objectives and goals

Only modest improvements have been found for the addition of graphene oxide (GO) to concrete, how can the full potential be realised? The high number and various parameters included in studies on GO cementitious composites make it very hard to reliably quantify the improvement. The goal is to assess if there is sufficient improvement from the addition of GO to concrete to warrant its inclusion. The following objectives are used for this goal:

- Quantify the impact of GO on the mechanical and durability properties of GO concrete and mortar, particularly resistance to chloride ingress.
- Simulate GO in concrete using Molecular Dynamics and COMSOL modelling.
- Test the electrical conductivity properties of GO mortar to develop a framework of assessing the suitability of chloride ingress test methods.
- Investigate the microstructural and chemical properties to aid understanding of the mechanisms at play.
- Develop and conduct life cycle assessments of GO concrete to evaluate the goal.

The experimental work is primarily to produce data on plain GO concrete tested in controlled conditions without additions such as fly ash to confirm a baseline of how much GO impacts the properties. Plain GO concrete has been investigated for example in the key study by Mohammed et al. (2015) and more recently the extensive study by Fonseka et al. (2025). In this work higher dosages of GO are tested at a range of curing ages.

Accelerated and laboratory-based chloride ingress tests can only give an indication of future performance. Electrically accelerated chloride ingress tests such as the RCM and RCPT have been questioned; conductive material such as carbon or steel in the sample may influence the results.

Analysis of literature discovered a trend of the optimum GO dosage for chloride resistance increasing with increasing curing age, therefore a range of longer curing ages were investigated (Liu et al. 2022; Yu & Wu 2020; Chu et al. 2020).

## Description of method and results

A series of experimental tests were carried out, five batches of concrete and mortar were cast with 0, 0.05, 0.1, 0.5

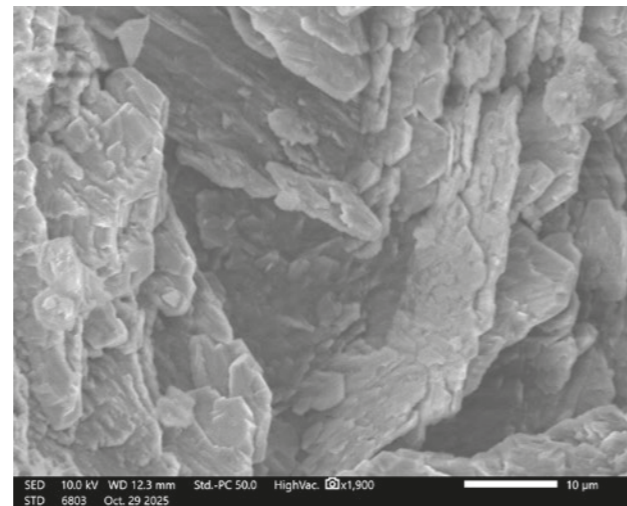


Fig 1 SEM image of Graphene Oxide mortar

and 1.0 wt.%. Mechanical properties of concrete and mortar tested were compression, flexural and a tensile test. Chloride ingress resistance was tested with Rapid Chloride Migration (RCM) test.

Shear mixing was used to disperse the GO in water which has a similar action on the GO platelets as sonication, (the prevailing method of dispersion), yet additionally stirs the suspension which is a practical advantage. Shear mixing has greater upscaling potential and is being used with graphene applications.

The microstructure of GO concrete is investigated with a scanning electron microscope (SEM) using scanning and back scattered electrons (BSE) and energy dispersive x-ray spectroscopy (EDS). Fig 1 shows the layering and crystal arrangement which can be compared to other dosages.

Fig 2 shows the chloride migration coefficient is slightly reduced at 168 days for 0.1 wt% GO dosage. However, it is premature to conclude that the shift of optimum GO dosage increasing with increasing curing age, given the small difference in chloride migration coefficient and single dosage exhibiting this: 0.1 wt%. Further experiments are underway.

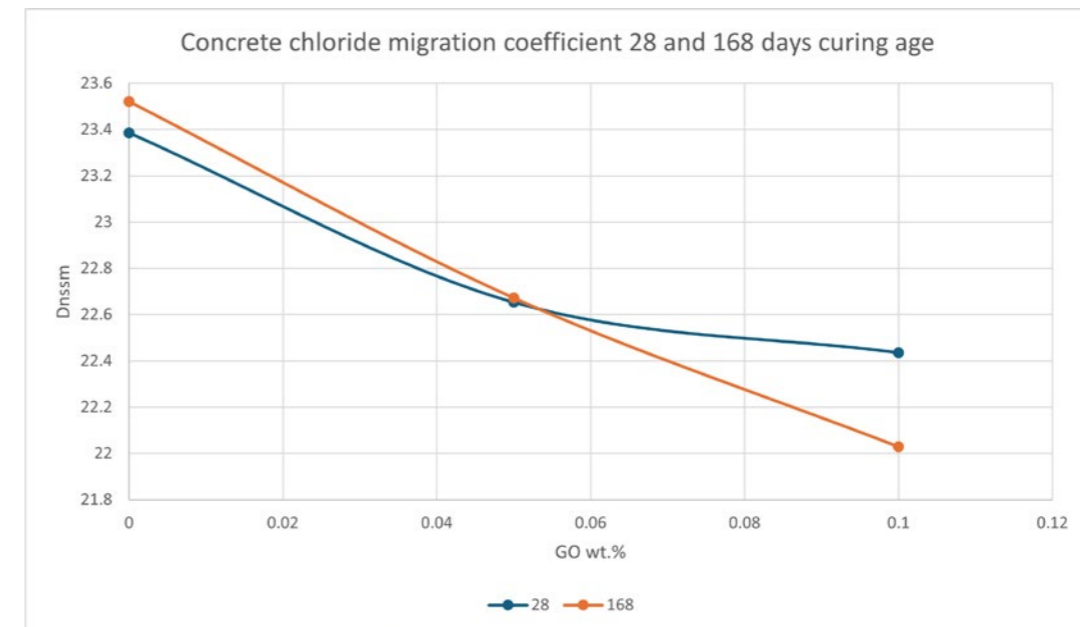


Fig 2 Chloride migration coefficient at 28 and 168 days curing age for 0, 0.05 and 0.1 wt.% GO

## Potential for application of results

The application of a finding that the optimum dosage of GO increasing with increasing curing age may have implications for the dosage used in practice and for investigation of the mechanism. This prompts questions of whether the effect of GO is indeed nucleation in the hydration phase, only or if there is an ongoing strengthening process (Basquiroto de Souza et al., 2022). For example, chloride ions being trapped on GO sheets or a mechanism leading to increased binding of chloride (Long et al., 2022).

The application of well dispersed, upscaled GO concrete production could be wide ranging, the suitability to offsite manufacturing is easy to appreciate (Sai and Jagadeesh, 2025). There is considerable scope for an agent to be developed which could unlock the potential for GO to be fully realised. If however, the improvements are modest: 20-40% (as found in literature and present experiments) there is still a case for the inclusion of this relatively inexpensive nanomaterial. Life cycle assessment will be conducted to assess the reduction in carbon emissions.

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# Numerical simulation of anisotropic plastic compressive behaviour and failure mechanisms of timber for TCC applications

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## Project objectives and goals

Amid the climate emergency, demand for sustainable construction materials is rising. Timber offers significant environmental benefits as a construction material, including carbon sequestration, lower embodied energy and end-of-life recyclability compared with conventional materials such as concrete and steel. Consequently, the use of timber in construction is increasing rapidly. Timber-Concrete Composites (TCC), integrate the complementary mechanical properties of timber and concrete with the environmental benefits of timber to create a low-carbon structural material. Numerical simulation of TCC, which enables realistic representation of nonlinear structural behaviour and associated failure modes, requires appropriate constitutive models for both materials. While concrete constitutive models are well established, timber models remain limited due to complex anisotropy, species variability and diverse product types.

Timber behaves linearly elastic up to yield, after which, under compression, it exhibits ductile, direction-dependent failure mechanisms that are often underemphasised yet are essential for assessing TCC performance. In this study, a timber material model was developed in ADINA non-linear finite element software and validated by simulating the mechanical behaviour of timber under compression to observe its anisotropic plastic behaviour and the associated direction-dependent failure mechanisms in the three principal material directions. This was achieved through numerical simulation of experimental uniaxial compression tests, as described below:

- Longitudinal compression test – parallel to the grain.
- Tangential compression test – perpendicular to the grain, along the growth rings.
- Radial compression test – perpendicular to the grain, perpendicular to the growth rings.

## Description of method and results

The inherent anisotropy of timber makes it more challenging to accurately simulate its material behaviour. The fact that most materials exhibit some degree of internal organisation allows the stress-strain relationship to be further simplified (Hosford, 2009). Most timber composites are symmetric about three mutually perpendicular planes, which makes it an orthotropic material. Orthotropic materials are characterised by their directional properties. Timber can be referenced to a cylindrical coordinate system in which the longitudinal direction (L) corresponds

to the grain, the tangential direction (T) follows the curvature of the growth rings and the radial direction (R) aligns with the wood rays. From a theoretical perspective, the mechanical behaviour of timber is analysed using a rectangular coordinate system, where the curved growth rings are considered as planar layers (Bodig and Jayne, 1982) (Fig 1).

ADINA does not contain an in-built constitutive material model for timber. Therefore, the plastic-orthotropic material model available in ADINA was employed in this study to develop a tailored material model for timber. One of the major challenges in the numerical simulation of timber lies in determining the precise material parameters along the three orthogonal directions. This difficulty arises because its mechanical behaviour is strongly dependent on grain orientation, species, moisture content, temperature and growth characteristics such as knots or density variations. Obtaining reliable experimental data in all three directions is both time-consuming and costly, and such data are

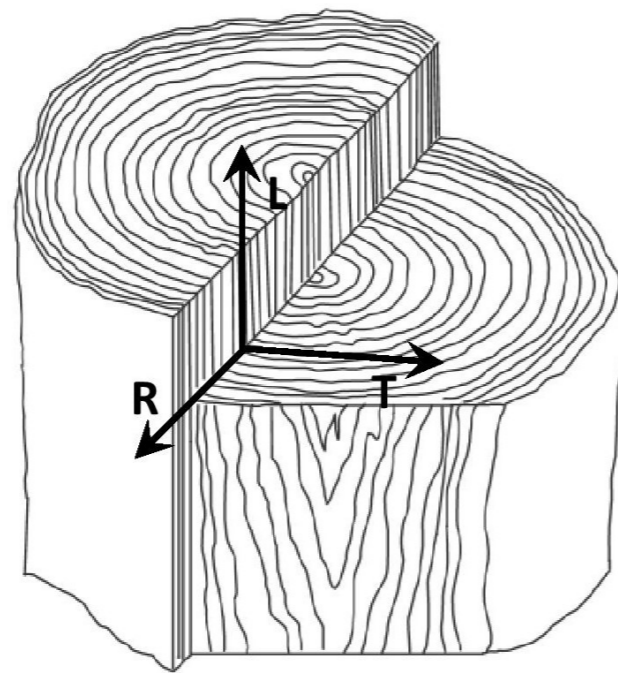


Fig 1 Orthotropic material directions in timber: longitudinal (L), tangential (T) and radial (R)

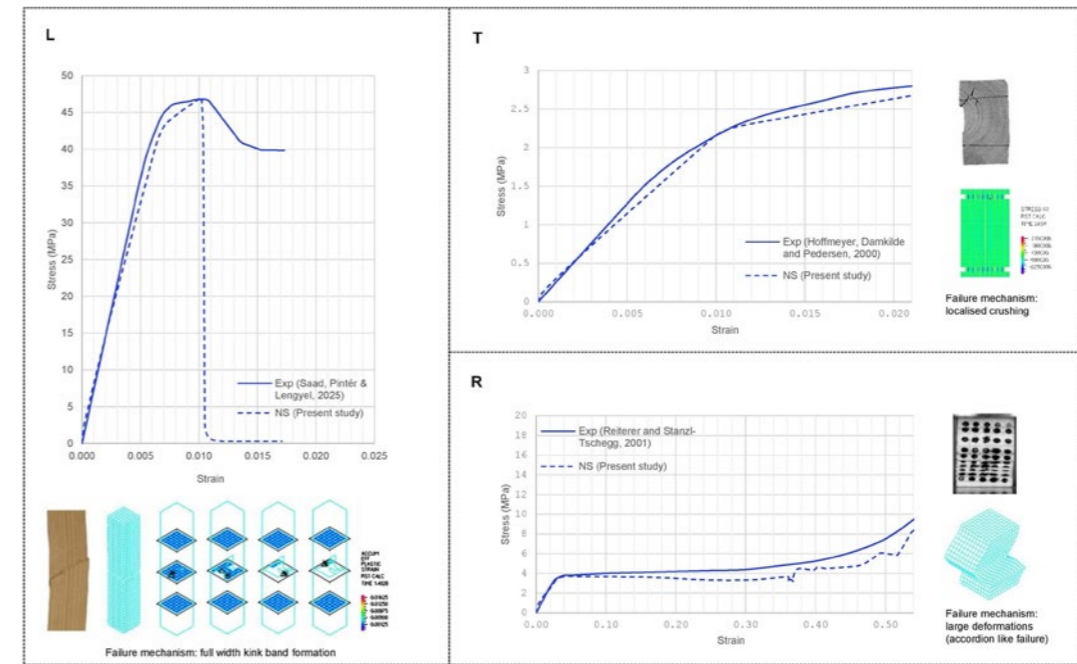


Fig 2 Comparison of experimental and numerical simulation results: stress-strain behaviour and failure mechanisms under uniaxial compression in the L, T and R directions

often limited in the literature or inconsistent across sources even with the same species of timber. Bodig and Jayne (1982) state that despite these sources of variation, material properties are generally related to one another according to characteristic ratios as given in Eqn 1.

$$\begin{aligned} E_L : E_R : E_T &\approx 20 : 1.6 : 1 \\ G_{LR} : G_{LT} : G_{RT} &\approx 10 : 9.4 : 1 \\ E_L : G_{LR} &\approx 14 : 1 \end{aligned} \quad (1)$$

By applying these commonly accepted ratios, the moduli of elasticity in the longitudinal, radial and tangential directions ( $E_L, E_R$  and  $E_T$ ), as well as the shear moduli associated with the three orthogonal planes ( $G_{LR}, G_{LT}$  and  $G_{RT}$ ), can be estimated from the known properties in one direction with reasonable accuracy.

The Hill yield condition and the associated hardening models in ADINA were adapted to capture the anisotropic plastic behaviour of timber. Failure was defined using a prescribed maximum effective plastic strain. Simulations were performed based on published experimental studies of Nordic spruce (*Picea abies*), the most widely used softwood species in Nordic glulam production. The results were compared with the experimental data to validate the numerical analyses. Across all three material directions, the model showed good agreement with both the stress-strain behaviour and the expected failure mechanisms (Fig 2) under uniaxial compression, demonstrating that the developed material model in ADINA accurately represents the orthotropic plastic behaviour of timber.

## Potential for application of results

The developed material model can be further extended to investigate the tensile and flexural behaviour of timber.

Future work will focus on examining the nonlinear structural response of TCC beams, with the aim of numerically evaluating their behaviour and providing recommendations for more effective design. This approach will address the limitations of current design methods, which typically assume linear-elastic behaviour in TCC systems. In addition, the developed material model can be applied to the simulation of timber structural elements to capture their orthotropic plastic behaviour, thereby supporting the development of optimised timber design solutions.

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