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In this issue

Building an Open Interface Finite Element Model of the Clifton Suspension Bridge

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Abstract

Society is dependent on aging infrastructure, which usually operates outside its expected life. Replacing this infrastructure is often an unviable option due to its cost and disruption. A structure's operational life might be extended if the features of its aging are better understood, enabling preventive maintenance to compensate. Digital Twins (the continuous comparison between sensor measurements and a mathematical model) are one way of enabling this sort of data-driven decision making. However, despite the possibilities for this technology, its take up amongst industry has been slow, in part because infrastructure managers are unsure of how the technology will support them. This work develops a methodological framework to enhance this uptake in the field of systems engineering and the system development life cycle, using the developed knowledge to inform how an operational Digital Twin should be created. The requirements capture is the most important part of any system design development process. We present a Digital Twin development method, grounded firmly in a thorough requirements capture, and illustrate how those requirements inform many of the later design decisions. We then present our method through a case study of the Clifton Suspension Bridge, UK. Our method provides a series of actionable steps, the completion of which will facilitate the creation of a Digital Twin able to support operational decisions. By fulfilling the requirements of infrastructure managers, we hope to encourage the uptake of the technology.

1. A Digital Twin for Infrastructure

A Digital Twin is a mathematical model of a real object, which is automatically updated to reflect changes in that object using real data (CDBB, 2020). As well as being able to run simulations about possible future events, a Digital Twin of a structure also allows the infrastructure manager to estimate values about the real object that cannot be directly measured. To deliver this functionality, however, the modelling software must be able to interface with the other components of the Digital Twin, namely the structural health monitoring (SHM) system that collects sensor data, and machine learning algorithms that interpret this data to identify how the model can be improved (Gunner et al., 2021). Most commercial modelling software packages do not provide these Application Programming Interfaces (APIs), making them unsuitable for integration into a Digital Twin.

2. A Requirement for Open Interfaces

The aim of this project was to create an 'open-interface' model of the Clifton Suspension Bridge (CSB) that will form one of the building blocks for an experimental Digital Twin for this iconic structure in Bristol (UK). Although structural models of the CSB exist, they are limited in both functionality and sophistication, making them unsuitable for use in a Digital Twin. For a Digital Twin to operate autonomously and in real-time, the software must manipulate and invoke the structural model, tuning the model parameters based on the observed sensor readings.

The OpenSees finite element modelling software was selected for the creation of the Digital Twin ready model, as it is one of the few pieces of open-source structural modeling software that has all the necessary APIs.

3. Building the Model

The information needed to build a finite element model (FEM) of the CSB has been gathered from a number of different sources (including multiple pre-existing models) to produce a detailed FEM of the bridge. The precise geometry of the CSB has been implemented in OpenSees for the first time, paving the way for the creation of a Digital Twin of Bristol's most famous landmark. Figure 1 gives an illustration of a FEM of the CSB, showing how the geometry of the structure was reproduced in the model.

The bridge geometry was validated by comparing the simulated bridge dynamics with real-world structural health monitoring data, collected from the CSB during an earlier project (Gunner et al., 2017). Figure 2 gives an illustration of the sensors that were deployed for this project.

The dynamic behaviour of a bridge can be understood as being made up of many different frequencies of oscillation, all superimposed over one another. These 'modes' can be measured on the real bridge, and by comparing their shape and frequency with the simulated dynamics produced by the model it is possible to assess the model's accuracy. The model parameters can then be adjusted to reduce the difference between the measured and modelled bridge dynamics. This process can now be done automatically, thanks to the open interfaces between the model and the sensors' data.

4. Fitting the Pieces Together

The creation of this open-interface model will enable a

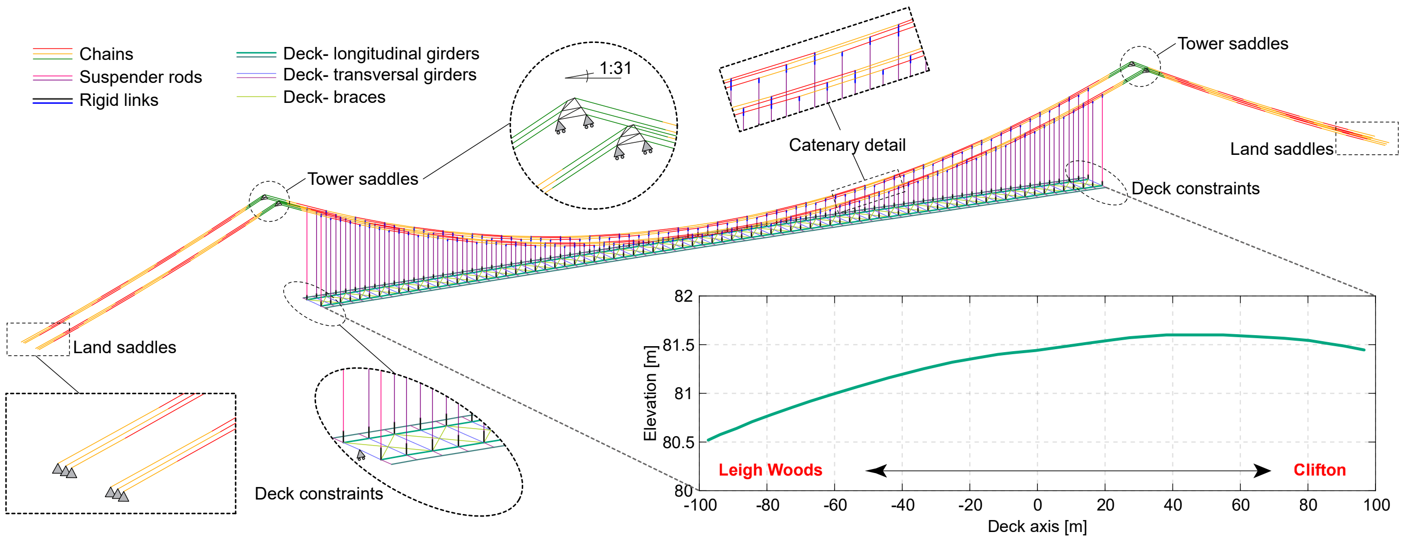

Figure 1: A finite element model of the Clifton Suspension Bridge, showing the relative elevation of the bridge deck and the length.

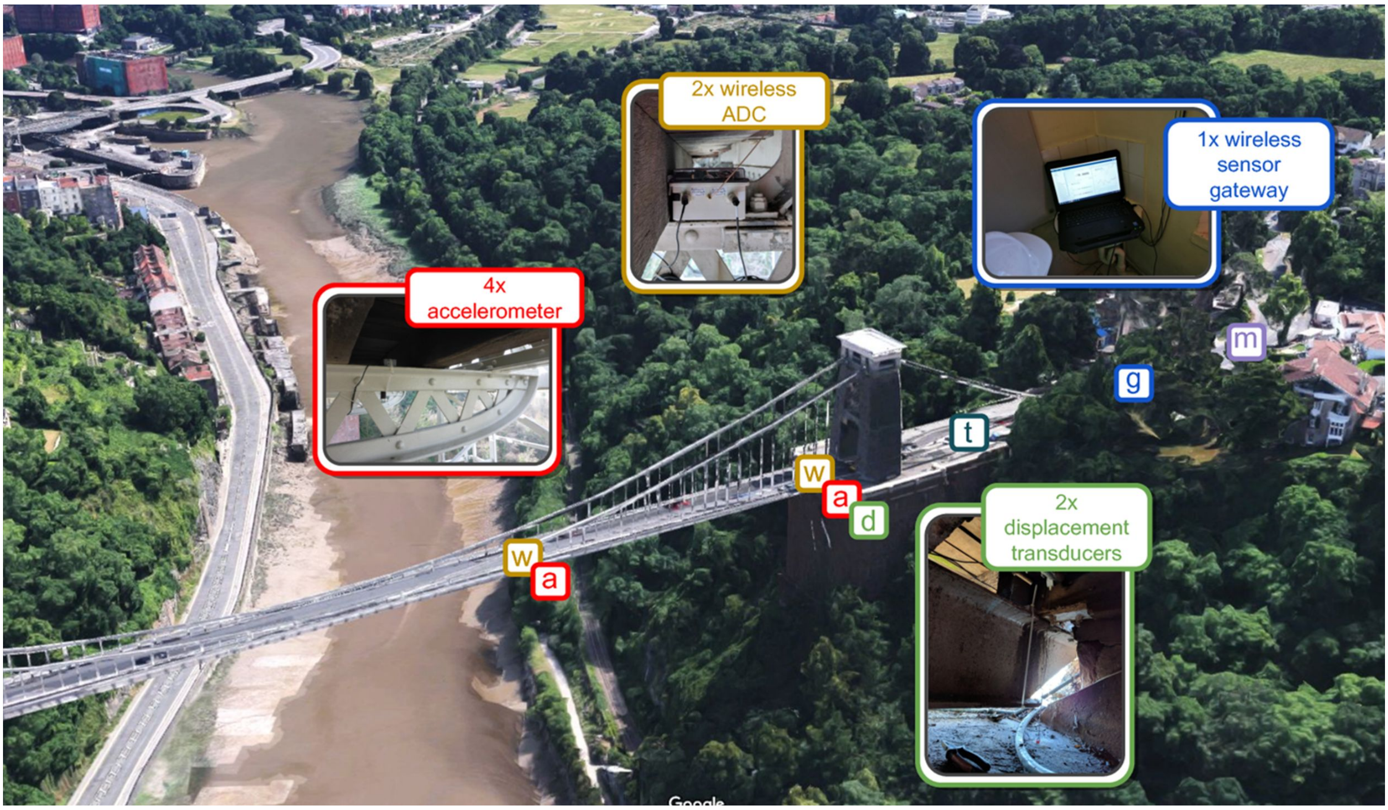

Figure 2: Illustration of the sensor deployment carried out as part of the Clifton Suspension Bridge Dashboard project. Base image from Google Maps.

new strand of research into Digital Twins, which will tackle some of the challenges that must be overcome before the technology can deliver insights to infrastructure managers.

The CSB is currently being instrumented with a range of structural sensing infrastructure, turning it into a 'living lab' as part of the UKCRIC project's Urban Observatories (UO) endeavour. The structural health monitoring system being developed will also have all the APIs required for integration into a Digital Twin, providing access to both real-time and historic structural dynamics data, as well as information about the loading applied to the bridge through wind, vehicles, and changes in temperature.

With both the sensing and modelling components of the Digital Twin developed, we will be able to start addressing the many technical challenges associated with automatic model updating. For example, modifying the model to match recorded data is an inverse problem, requiring a system to explore among the many different model configurations that match the observed sensor data. Developing an algorithm able to select the configuration that best represents the physics of the real object is a significant challenge, but this project will create a testbed that enables the scientific community to explore these challenges.

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Notable Earthquakes
March 2023 – July 2023

Reported by British Geological Survey

Issued by: Davie Galloway, British Geological Survey, August 2023.
Non British Earthquake Data supplied by: United States Geological Survey.

			Time			Dep	Magnitude			
Year	**Day**	**Mon**	**UTC**	**Lat**	**Lon**	**km**	**ML**	**Mb**	**Mw**	**Location**
2023	01	MAR	05:36	4.83S	149.50E	600			6.6	BISMARCK SEA, PNG
2023	02	MAR	18:04	15.38S	166.39E	17			6.5	VANUATU
2023	04	MAR	06:41	29.50S	178.80W	211			6.9	KERMADEC ISLANDS
2023	05	MAR	11:46	58.39N	1.07E	9	1.7			CENTRAL NORTH SEA
2023	06	MAR	04:08	58.05N	1.65E	26	1.7			CENTRAL NORTH SEA
2023	09	MAR	03:43	54.48N	1.30W	29	2.2			HILTON, NORTH YORKSHIRE
2022	19	JUL	03:06	56.73N	9.25W	13	2.2			NORTH ATLANTIC OCEAN
2023	14	MAR	04:25	53.87N	3.60W	5	2.1			IRISH SEA
2023	16	MAR	00:56	30.17S	176.21W	10			7.0	KERMADEC ISLANDS
2023	18	MAR	17:12	2.50S	79.85W	68			6.8	ECUADOR
At least 18 people killed, around 500 others injured and widespread damage occurred in several provinces in southern Ecuador and northern Peru.										
2023	20	MAR	14:23	52.81N	2.43W	8	2.1			NEWPORT, SHROPSHIRE
2023	21	MAR	16:47	36.52N	70.94E	192			6.5	HINDU KUSH, AFGHANISTAN
At least 21 people killed (10 in Afghanistan, 11 in Pakistan), over 423 others injured (80 in Afghanistan, 343 in Pakistan) and many houses destroyed or severely damaged in the epicentral region.										
2023	22	MAR	16:00	23.42S	66.50W	228			6.5	ARGENTINA
2023	23	MAR	19:53	54.41N	1.67W	3	1.8			RICHMOND, NORTH YORKSHIRE
2023	26	MAR	21:26	51.11N	3.77W	16	1.6			SIMONSBATH, SOMERSET
2023	28	MAR	03:14	53.70N	1.17E	6	2.2			SOUTHERN NORTH SEA
2023	29	MAR	18:24	53.19N	0.20W	29	2.2			HORNCASTLE, LINCOLNSHIRE
2023	02	APR	18:04	4.32S	143.17E	70			7.0	PAPUA NEW GUINEA
At least 8 people killed, many more injured and over 850 homes and buildings damaged in East Sepik province.										
2023	03	APR	03:06	52.44N	159.25E	101			6.5	KAMCHATKA
2023	07	APR	21:26	57.01N	1.83E	10	3.6			CENTRAL NORTH SEA
Felt by several workers on the manned Shearwater Process, Utilities and Quarters (PUQ) platform (3 EMS).										
2023	09	APR	14:39	51.86N	4.44W	6	1.8			MEIDRIM, CARMARTHENSHIRE
2023	10	APR	00:28	56.48N	6.41W	3	1.9			MULL, ARGYLL & BUTE
2023	13	APR	12:52	50.60N	4.57W	5	1.5			BOWITHICK, CORNWALL
2023	14	APR	09:55	6.04S	112.05E	597			7.0	JAVA SEA, INDONESIA
2023	14	APR	13:09	56.40N	9.99W	31	1.6			NORTH ATLANTIC OCEAN

			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	ML	Mb	Mw	Location
2023	15	APR	05:01	48.79N	2.34W	5	2.4			ENGLISH CHANNEL
2023	18	APR	04:31	22.30S	179.46E	595			6.7	SOUTH OF FIJI ISLANDS
2023	19	APR	00:33	56.47N	6.43W	3	2.2			MULL, ARGYLL & BUTE
2023	19	APR	02:16	57.68N	5.54W	6	1.8			SLATTADALE, HIGHLAND
2023	22	APR	01:25	56.76N	5.11W	9	2.7			FORT WILLIAM, HIGHLAND
Felt Fort William, Corpach, Onich, Glencoe, Kinlochleven and a few other surrounding villages and hamlets, mainly from within around 15 km of the epicentre (4 EMS).										
2023	24	APR	20:01	0.78S	98.53E	34			7.1	WEST SUMATRA, INDONESIA
2023	28	APR	03:13	25.27S	178.42E	598			6.6	SOUTH OF FIJI ISLANDS
2023	29	APR	15:06	57.69N	5.54W	3	1.8			SLATTADALE, HIGHLAND
2023	06	MAY	00:32	54.97N	7.98W	14	2.3			GLENDOWAN, CO DONEGAL
Felt throughout the Donegal area (4 EMS).										
2023	10	MAY	16:01	15.60S	174.61W	210			7.6	SAMOAN ISLANDS
2023	19	MAY	02:57	23.19S	170.76E	18			7.7	LOYALTY ISLANDS
2023	20	MAY	01:50	23.06S	170.46E	36			7.1	LOYALTY ISLANDS
2023	20	MAY	02:09	22.95S	170.48E	10			6.5	LOYALTY ISLANDS
2023	20	MAY	14:37	56.48N	6.40W	3	1.8			MULL, ARGYLL & BUTE
2023	21	MAY	14:56	43.44S	39.37E	10			6.8	PRINCE EDWARD ISLANDS
2023	25	MAY	03:05	8.93N	77.09W	13			6.5	CARIBBEAN SEA
2023	30	MAY	07:51	56.59N	6.22W	7	1.8			MULL, ARGYLL & BUTE
2023	30	MAY	13:05	56.58N	6.18W	7	1.5			MULL, ARGYLL & BUTE
2023	31	MAY	08:56	51.80N	4.80W	13	1.6			NARBERTH, DYFED
2023	05	JUN	04:06	56.40N	5.48W	3	1.1			OBAN, ARGYLL & BUTE
Felt Oban and Dunbeg (3 EMS).										
2023	15	JUN	18:06	22.98S	177.21W	167			7.2	TONGA ISLANDS
2023	16	JUN	16:38	46.49N	0.68W	110	5.6			WESTERN FRANCE
Felt throughout western France (5 EMS).										
2023	28	JUN	20:21	52.93N	1.94W	8	3.3			TEAN, STAFFORDSHIRE
Felt Staffordshire, Derbyshire, Nottinghamshire and West Midlands, mainly from within around 30 km of the epicentre. (4 EMS).										
2023	02	JUL	10:27	17.88S	174.94W	229			6.9	TONGA ISLANDS
2023	07	JUL	17:21	53.32N	0.95W	6	1.6			CAWKWELL, LINCOLNSHIRE
2023	10	JUL	20:28	20.19N	62.30W	14			6.6	NORTH ATLANTIC OCEAN
2023	15	JUL	06:58	51.77N	3.14W	19	2.0			BLAINA, GWENT
2023	15	JUL	07:21	51.32N	1.25E	3	1.9			STOURMOUTH, KENT
2023	16	JUL	06:48	54.15N	159.83W	32			7.2	ALASKA PENINSULA
2023	17	JUL	03:05	38.20S	70.47W	186			6.6	ARGENTINA

Year	Day	Mon	Time UTC	Lat	Lon	Dep km	Magnitude ML	Mb	Mw	Location
2023	19	JUL	00:22	12.81N	88.13W	69			6.5	EL SALVADOR
2023	22	JUL	09:24	61.61N	2.20E	20	3.2			NORWEGIAN SEA

Forthcoming Events

Evening Lecture

Rehabilitation of the Gumbasa irrigation system following the Palu earthquake

Barnali Ghosh, Peter Sharp
Institution of Civil Engineers
Also broadcast online
27 September 2023 (6:00 - 8:00 pm)

Synopsis

The Gumbasa project saved the regional economy and local community in the aftermath of a major earthquake. The project meets the three pillars of sustainability by the adoption of performance based seismic design and using softer, lower carbon solutions to rehabilitate a major irrigation system. The engineering assessment of the main canal reconstruction or rehabilitation of the irrigation system aimed for 'Building Back Better' approach by encompassing resilience in our design The project won the Geotechnical Association's Ground Engineering Sustainability Award in 2022. The judges said "This award demonstrates our commitment to embedding sustainability and social outcomes in every aspect of project delivery within earthquake engineering, where most approaches focus on safety over sustainability. "

Dr Barnali Ghosh

Dr Barnali Ghosh is a Fellow at Institute of Civil Engineer (FICE). She is a chartered civil engineer with specialization in Earthquake Geotechnical Engineering. During her long career, she has acted as a seismic designer and reviewer for high-profile projects around the world. She has been propagating sustainable solutions for developing countries which have wide social outcomes. She remains connected to the academic world as a Royal Academy Visiting Professor at Cambridge University.

Dr Peter Sharp

Dr Peter Sharp is chartered geotechnical engineer with 30 years' experience in the management and technical direction of ground engineering and civil engineering projects, including proposals, planning, design and implementation of both routine and state-of-the-art ground investigations and interpretation of findings for all types of infrastructure and buildings. Peter has wide overseas experience of ground engineering projects within the Middle East, Europe, and South East Asia, including seismic analysis and design of earthworks and numerous piled and shallow footings and maritime structures in United Kingdom, United Arab Emirates, Kuwait, Qatar, Bahrain, Oman, Taiwan, China, South Korea, Papua New Guineas, and Australia.

Registration

The event will held in-person at the Institution of Civil Engineers and will be chaired by Mark Scorer. Attendance at this meeting is free for members and non-members alike. Prior registration is not required. Seats are allocated on a first come, first served basis. Tea, coffee and biscuits will be served from 5.30 - 6 pm. We encourage everyone to attend in person if they can.

The event will also be broadcast online. To attend the presentation online, please register for the event prior to joining via this link here. The registration process will provide you with the link you need to join the event.

SECED Fund Award

SECED runs an award scheme to offer financial support to individuals or teams whose academic studies, research, career, or volunteer work aligns with the aims of the Society. Applications for an award of up to £1,000 will be considered. SECED anticipates selecting one or two applications per annum. The total award in any one year is limited to £1,000.

The SECED Fund 2023 is now closed for new applications. SECED Fund 2024 will be open in June 2024. If you have any question related to the scheme or submission process, please contact the SECED Fund Subcommittee at seced.ymsc@gmail.com.

AGM and Evening Lecture

Cyclic response of rubberised alkali-activated concrete-filled steel tubes

Mohamed Elzeadani
Institution of Civil Engineers
Also broadcast online
25 October 2023 (6:00 - 8:30 pm)

Note: The Society for Earthquake and Civil Engineering Dynamics (SECED) Young Members AGM will take place at 6:00 pm, followed by the lecture at 6:30 pm and networking drinks in the ICE bar at 7:15 pm.

Synopsis

This study examines the cyclic behaviour of square steel tubes infilled with rubberised alkali-activated concrete. The concrete is made up of a slag-based mix activated with solid anhydrous sodium metasilicate. The rubber content, as replacement of natural aggregates, is varied up to a high replacement ratio of 60%. Specimens are tested under lateral cyclic loading with a co-existing axial load of 15 and 20% of the cross-sectional axial capacity. A detailed account of the cyclic tests is given, covering 8 concrete-filled steel specimens and 2 hollow steel specimens. Complementary material and section tests are also provided. The experimental results are discussed in detail covering the member stiffness, displacement, capacity, ductility, energy dissipation and failure mechanisms. The results show that while high rubber replacement ratios result in significant losses in concrete strength, the corresponding reduction in member capacity of the concrete-filled tubes is significantly less due to the contribution of steel confinement. Specimens with rubberised concrete infill exhibited higher ductility and energy dissipation when compared to specimens incorporating non-rubberised concrete infill. The test results generally demonstrate the favourable inelastic lateral cyclic behaviour of the steel tubes infilled with rubberised alkali-activated concrete.

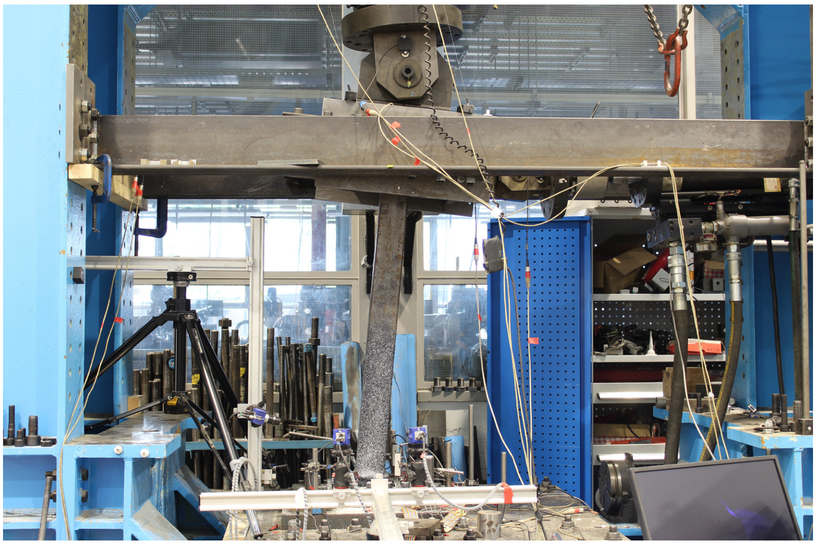
Mohamed Elzeadani

Mohamed is a PhD student in the Department of Civil and Environmental Engineering at Imperial College London. His PhD research is focused on the mechanical and structural behaviour of rubberised alkali-activated concrete, including the material characterisation and structural response under cyclic loading conditions. His technical interests involve developments in sustainable concrete materials, numerical modelling, and mechanics-based solutions for concrete structures under various loading conditions.

Registration

In-person attendance at this meeting is free and no registration is required. Seats are allocated on a first come, first served basis. Tea, coffee and biscuits will be served from 5:30 pm – 6:00 pm. After the talk, a networking event (7:15-8:30 pm) will be hosted in the ICE bar. SECED will provide one free drink in the bar to all who attends the lecture.

The event will also be broadcast online. To attend the presentation online, please register for the event prior to joining via this link here. The registration process will provide you with the link you need to join the event.



Cyclic testing of square steel tubes infilled with rubberised alkali-activated concrete.