大学院教育支援機構（DoGS）海外渡航助成金　報告書
Outcome report

計画名 **Plan**	Data-Driven Surrogate Models Using Deep Learning Techniques for Solving Inverse Problems
氏名 **Name**	CHEN DEBAO
研究科・専攻・学年 **Graduate school/Division/Year level**	Graduate School of Engineering/Department of Civil and Earth Resources Engineering/D2
渡航国 **Country**	Hong Kong SAR, China
渡航日程 **Travel schedule**	2023 年 8 月 28 日 ～ 2023 年 9 月 10 日

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渡航計画の概要 Outline of the travel plan

The increasing number of bridges in Japan aged over 50 years, projected to reach 55% in the next decade, poses significant challenges, including a shortage of skilled labor and rising maintenance costs. Addressing these challenges necessitates the development of precise numerical models for assessing the structural integrity of existing bridges. My research aims to establish digital twin models for accurately evaluating the condition of aging bridges and supporting their structural inspection and maintenance. At Kyoto University, my laboratory possesses a significant repository of empirical data in real-world bridge engineering, which can be employed to validate the efficacy of digital twin models. Moreover, Assistant Professor Wang Jiaji’s team at The University of Hong Kong’s Department of Civil Engineering employs cutting-edge deep learning methods to build structural digital twins, enhancing the efficiency of conventional finite element (FE) models. By working closely together on digital twins of real-world bridges, the two teams can more effectively address critical issues in this field.

The purpose of the planned travel is to participate in joint seminars and facilitate collaboration between two teams from Kyoto University and The University of Hong Kong. The two teams are currently immersed in the research domain of “Data-driven surrogate models using deep learning techniques for solving inverse problems”. The primary objective of this journey is to contribute to the development of my doctoral dissertation by facilitating a deeper understanding of the latest developments, promoting the exchange of best practices, and encouraging the exploration of innovative ideas. This will provide me with an opportunity to acquire insights into emerging research trends and receive in-person guidance from Prof. Wang Jiaji. Furthermore, I plan to leverage supercomputer resources for the development of a digital twin model that harnesses experimental data from the Public Works Research Institute (PWRI, 国立研究開発法人土木研究所). Another objective of the trip is to complete the research on this collaborative subject and publish the findings in an international journal.

成果 Outcome

A multitude of avenues exist for the application of machine learning (ML)/ neural network (NN) models in the context of physics-based systems. This variability is contingent upon factors such as the availability of observational data and the depth of comprehension regarding the underlying physics. These considerations lead to a broad classification of ML/NN methodologies, encompassing forward (physics-driven), data-driven, and hybrid approaches that integrate both physics and data assimilation principles, as shown in Fig. 1.

The FE method is a technique to solve partial differential equations numerically. Commercial finite element analysis (FEA) software packages such as Abaqus and Diana are widely used in engineering for the simulation and analysis of complex bridge structures. These software packages provide robust and efficient solvers for solving the governing equations of a system, and they typically have user-friendly interfaces that allow engineers to quickly set up and run simulations. However, building and updating an FE model using commercial software can be computationally expensive and time-consuming, especially for large and complex real-world bridge structures.

Conversely, a surrogate model, often referred to as a metamodel, is developed through a data-driven methodology. By aggregating input pairs, consisting of design parameters, and their corresponding outputs into a training dataset, a statistical model can be constructed using this compiled dataset. Subsequent to the training process, surrogate models generally exhibit greater simplicity and efficiency when compared to FE models. Employing surrogate models as a stand-in for FE models within the Bayesian model updating framework to solve inverse problems offers the potential to diminish the computational expenses linked with model updating and conduct parameter space exploration with greater efficiency.

During my stay at The University of Hong Kong, I dedicated my efforts to developing a surrogate model for the prestressed concrete (PC) box girder using Fourier Neural Operator (FNO) [1]. The experimental study on PC girders was conducted collaboratively with the Public Works Research Institute, as illustrated in Fig. 2. Before my visit to The University of Hong Kong, I had already constructed a 3D FE model using Abaqus and generated the requisite training data.

By engaging in face-to-face discussions and communication during a concentrated period, I addressed some of the challenges I had encountered in my current research while working towards establishing the surrogate model. Under Prof. Wang's expert guidance, I found some potential solutions to these issues and explored this endeavor on Nvidia Modulus Sym [2], an open-source platform. During discussions with Mr. Tian Xiaoge, I gained insights into the design of multi-channel input and output configurations when applying FNO—a challenge that both of us had identified in our research. Consequently, we have decided to collaborate on code development utilizing the supercomputer (Fig. 3).

Additionally, I had the privilege of visiting the Structural Engineering Testing Laboratory and the shaking table at the Department of Civil Engineering. I also participated in a vibration test of a multi-story steel frame structure, broadening my practical experience. Through collaborative case studies and engaging in discussions with Ph.D. students from The University of Hong Kong, I refined my research ideas within the scope of my current research topic. Given the diversity of each student's research field and knowledge background, our interactions have consistently provided opportunities for gaining fresh insights through mutual exchange.

During my two-week stay in Hong Kong, I also had the pleasure of meeting with Prof. Zhang Jize at The Hong Kong University of Science and Technology, whom I had previously encountered at the IFIP conference at Kyoto University. I was fortunate to be invited to attend the Ph.D. defense of a candidate who focused on Bayesian model updating within his department—a truly enlightening experience. Additionally, I reached out to a friend, who is currently a visiting Ph.D. scholar at The Hong Kong Polytechnic University (PolyU). He graciously guided me through a visit to the pedestrian bridge health monitoring visualization platform established by Prof. Xia Yong on the PolyU campus.

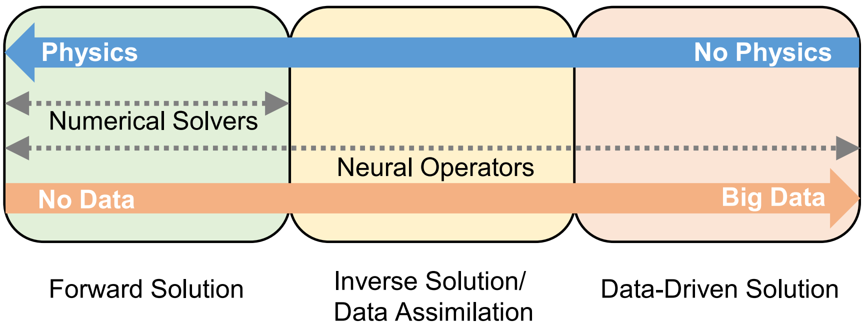

Fig. 1 Technical scheme of the methodology.

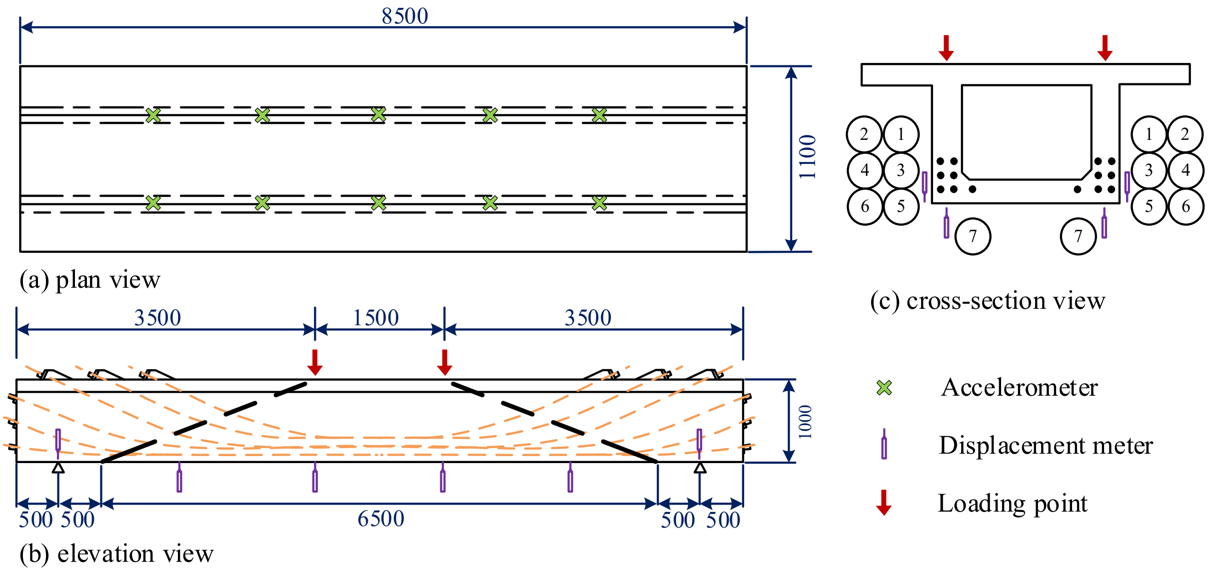

Fig. 2 Experimental study on PC girders (Unit: mm).

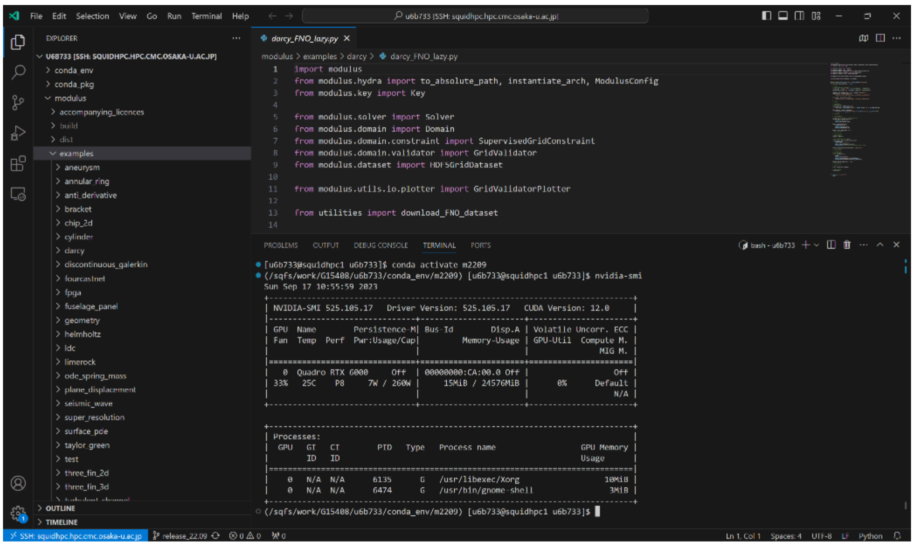

Fig. 3 Using the Nvidia Modulus on the supercomputer.

今後の展望 Prospects for the future

I will maintain continuous and close communication with the research team at The University of Hong Kong through regular online meetings. Once I finish constructing the surrogate model, I will utilize it to perform a Bayesian model update for inferring the model parameters from the model response. Upon completing the ongoing case study, I intend to publish the research findings in a journal.

Finally, I would like to extend my sincere appreciation to the Division of Graduate Studies (DoGS) at Kyoto University for sponsoring this short-term visit to Hong Kong. Additionally, I wish to take this moment to extend my heartfelt gratitude to Prof. Wang for hosting me at The University of Hong Kong.

This visit provided me with invaluable opportunities to collaborate with his research team, engage in stimulating discussions, and explore the vibrant city of Hong Kong. I am profoundly thankful for the unwavering support of my supervisor, Kim-sensei, at Kyoto University throughout this journey.

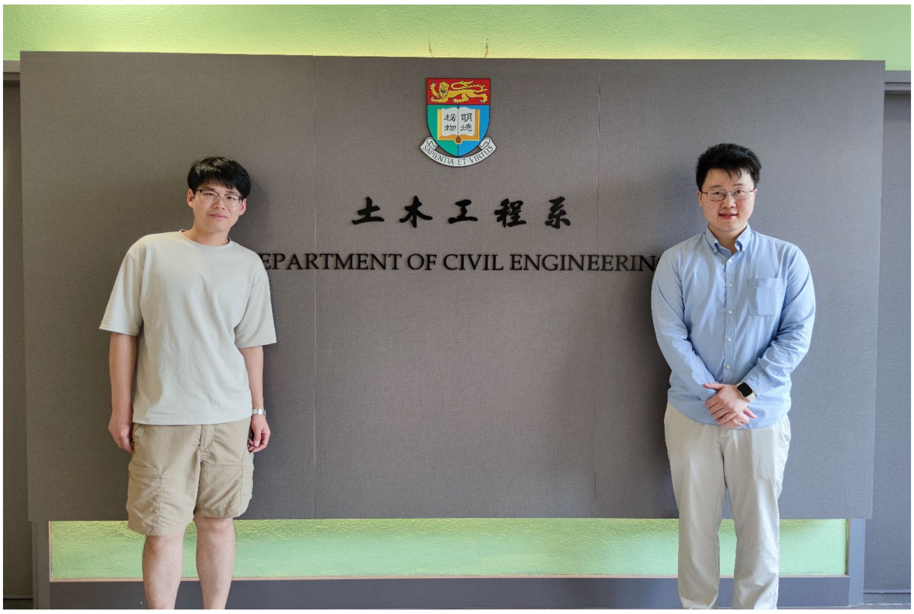

Fig. 4 Group photo with Prof. Wang (Left: me, Right: Prof. Wang)

Fig. 5 Group photo with Prof. Wang’s students (From left to right: Fu, Chawit, me, and Tian)

参考文献 References

[1] Li, Zongyi, Nikola Kovachki, Kamyar Azizzadenesheli, Burigede Liu, Kaushik Bhattacharya, Andrew Stuart, and Anima Anandkumar. "Fourier neural operator for parametric partial differential equations." arXiv preprint arXiv:2010.08895 (2020).

[2] https://docs.nvidia.com/deeplearning/modulus/modulus-sym/index.html