Opportunities and challenges of AI in seismic engineering

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ABSTRACT

Artificial Intelligence, whose defining feature is its ability to learn from data, has become integral to our everyday lives. Its raise to ubiquity has been fuelled by a rapid development of ever more efficient algorithms and a widespread recognition of their many potential advantages. This has also affected the field of seismic engineering, although to a greater extend research than practice. From ground motion characterization to structural design, or the evaluation of structural integrity and system resilience levels, a large number of applications of AI tools are being constantly published making AI a new research frontier in seismic engineering. This paper will start by discussing a general framework within which to understand AI and its potential uses in seismic design and assessment. This will be followed by a more in-depth discussion of two examples of recent use of AI in research carried out in the Emerging Structural Technologies Research Group at Imperial College. The paper will finish with an overall presentation of findings as well as areas of potential concern.

The first case study concerns the use of AI to guide the search for optimal forms of arch-type structures to be used as shielding for extra-terrestrial habitats under uncertain environmental conditions. To this end, an unsupervised machine learning model (Convolutional Autoencoder) capable of detecting patterns in arch shapes and differentiating between their stress and displacement contours was created. The model architecture and the steps taken to automatize the data generation are discussed in detail. A preliminary clustering analysis is performed to gain insight into the variation of arch shapes and related contours between cluster centroids in the latent space. Besides, a regression model is built to investigate the relationship between the input geometric variables and the latent space representation and help the 'random walk' type of user explorations. This is followed by an implementation of a Bayesian optimizer that seeks to minimize material usage while remaining within the limits of stress and strain admissibility. This case study proves that the autoencoder and regression models can produce arch shapes with logical structural contours given a set of input geometric variables. Similarly, the results of optimal arch configurations, although not massively different from those obtained using the more traditional variational formulations, offer insights into the potential benefits of using AI in the exploration of large design spaces.

The second case-study explores the incorporation of physical relationships to improve the prediction of AI models in the presence of sharp nonlinearities. For this purpose, the estimation of seismic rocking, a type of response that is experienced by a wide variety of structures ranging from small valuable exhibits to large bridge piers, is examined. A Physics-informed Convolutional Neural Network is created for this purpose. Importantly, this model is aimed at improving the predictive power of traditional neural networks by encoding the known physics into its constraints opening the door for the use of limited training datasets. Two models are created. The first model assumes the availability of both rotation and angular velocity while the second model relies only on acceleration measurements. A detailed statistical analysis follows and the ability of these models to predict the full rocking response-history of rigid bodies is evaluated. The results show that the formulated network can estimate the response of uplifting rigid bodies very efficiently provided that the blocks do not overturn.

The above-mentioned examples serve to underline the common challenges encountered in the application of AI in general and to current aspects of seismic engineering, in particular. Issues of explainability, interpretability and generalization are discussed. The need for shared high-quality data and the infusion of physics and domain knowledge into AI models is also stressed.

Christian Málaga holds a PhD in Structural Engineering from Imperial College London (UK) and is currently Associate Professor (Senior Lecturer) in Structures in the Department of Civil and Environmental Engineering where he is the Director of Undergraduate Admissions for the MEng in Civil Engineering and the Director of the MSc programme in Earthquake Engineering.

His research is centered on improving the response of structures and structural systems to short-term and long-term stressors through emerging structural technologies. It spans the areas of structural mechanics, applied dynamics and structural design. Of particular interest are engineering problems arising in extreme or hostile environments such as earthquake-prone areas and extra-terrestrial settings; for whose solution he leverages innovative technological tools and state-of-the-art numerical and experimental techniques including the design and implementation of passive, semi-active and other protective strategies. His research has received several prizes including the Tso Kung Hsieh Research Award from the Institution of Civil Engineers, the Structures Best Research Paper Prize from the Institution of Structural Engineers, and the Unwin Prize from Imperial College London.

Having practiced for several years in large and small infrastructure projects in Latin America, Christian is continuously involved in specialized consultancy internationally and serves on a number of committees related to international code development and the advancement of engineering practice. Christian is the current UK Deputy National Delegate to the International and European Associations for Earthquake Engineering (IAEE and EAEE) and Imperial's representative to the EU consortium EFEHR (European Facilities for Earthquake Hazard and Risk).