NARODOWE CENTRUM NAUKI

PRELUDIUM-24

Proposal for funding of a research project conducted by a researcher who does not hold a doctorate degree

[draft]

Vibration-based structural damage identification of steel structures integrating wavelet-based scalogram and deep learning method

mgr inż. Neda Asgarkhani

Gdansk University of Technology

GENERAL INFORMATION

Title in Polish	Identyfikacja uszkodzeń konstrukcji stalowych na podstawie drgań, integrująca skalogram oparty na falkach oraz metodę głębokiego uczenia się
Title in English	Vibration-based structural damage identification of steel structures integrating wavelet-based scalogram and deep learning method
Keywords in Polish	Monitorowanie stanu konstrukcji; Badanie konstrukcji na stole wstrząsowym; Algorytm uczenia maszynowego; Ciągła transformata falkowa; Modernizacja budynków
Keywords in English	Structural health monitoring; Shaking table test of structures; Machine learning algorithm; Continuous wavelet transform; Retrofitting buildings
Duration [in months]	12
Research field	ST - Physical Sciences and Engineering
Primary NCN Review Panel	ST8 - Production and processes engineering (i.e. chemical-, civil-, environmental-, mechanical-, biomechanical-, energy-, transport-, biological- processes and models)
Auxiliary NCN Review Panels	ST8_02 - Maritime/hydraulic/water engineering, civil engineering, aerospace engineering

ABSTRACT [in English]

The study focuses on innovative approaches for assessing damage in connections of low-rise steel structures using experimental tests and innovative machine learning (ML) algorithms. It combines convolutional neural networks (CNNs) and continuous wavelet transform (CWT) with global vibration signals from seismic excitation (employing different seismic records for varied intensity measures) to evaluate steel structural connection health conditions. The research encompasses comprehensive experimental and methodological frameworks by creating rigid and semi-rigid connections to analyze structural responses under different conditions using the shaking table test. Recording floor-level accelerations, structural responses, and connection behavior under various seismic conditions can provide a wide range of data for ML algorithms. Then, by preprocessing the data and utilizing wavelet analysis to transform collected data into scalograms, detailed time-frequency insights into structural vibrations are provided. Using advanced ML techniques (particularly CNNs and deep learning (DL) algorithms) to predict and classify structural connection rigidity based on visual features extracted from the scalograms obtained during seismic loading, it is possible to provide an image-based dataset for CNNs, which can help to recognize the defects of connections. Moreover, it aims to propose a retrofitting scheme using shape memory alloy (SMA) bolts to improve the capability of the connections of steel structures. The aim is to use the ability of the SMA bolts for reducing the residual drift of structures after seismic loads, therefore, a detailed discussion is prepared as to how to implement those bolts and the effects of them for retrofitting. The CWT provides a thorough analysis of the response signals across various frequency bands, enabling the detection of both localized and distributed damage. This dual approach ensures high accuracy in identifying the location of damaged connections, which is crucial for effective intervention and maintaining the structural safety of the building. The proposed methodology provides a robust framework for structural health monitoring (SHM), specifically targeting the damage identification of steel connections and the prediction of current rigidity. The experimental validation on various steel structures with different connection defects and seismic loading conditions demonstrates the efficacy of the approach for accurately detecting and classifying damage in structural connections. The ML-based predictions can modify the models in engineering software (i.e., ETABS and ABAQUS) and provide a considerable benefit for the industry to use the results of this study. Since the database of the ML-based model can be updated by adding more data points, the proposed model can be used in the future based on the newly added datasets and can be extended to more structural defects, which will be the aim of PI to be explored.

APPLICANT

Applicant's status	1. University

PARTICIPATING ENTITIES

1. Gdansk University of Technology	
Entity's name in English	Gdansk University of Technology
Address of registered office	ul. Gabriela Narutowicza 11/12, 80-233 Gdańsk, pomorskie, Poland
Contact address	ul. Gabriela Narutowicza 11/12, 80-233 Gdańsk, pomorskie, Poland
Contact information	Phone Number: 58 347 14 74 E-mail: proren@pg.edu.pl WWW: http://pg.edu.pl
Electronic delivery box ESP (ePUAP)	/politechnikagdanska/projekty
Electronic delivery address (ADE)	AE:PL-96874-63482-HDEBH-16
Head of the entity / authorised representative	Dariusz Mikielewicz, Prorektor ds. Nauki
NIP (tax identification number)	5840203593
REGON (statistical identification number)	000001620
KRS (court register number)	-

SHORT DESCRIPTION

[in English]

1- Title

Vibration-based damage identification of steel connections of structures using wavelet-based scalogram and deep learning technique

2- Scientific aim of the project

Structural health monitoring (SHM) strategies concerning the assessment of connection damage in steel structures encompass various techniques to detect, evaluate, and manage potential damage or degradation within structural connections. Advanced technologies, including machine learning (ML) and deep learning (DL) algorithms, are increasingly integrated into SHM systems to analyze collected data patterns and predict potential connection failures. In addition, the literature confirm that seismic performance and risk assessment of buildings have been widely investigated by researchers and some preliminary prediction tools have been introduced according to prepared datasets [1-7]. They made a great effort to introduce novel ML methods for estimating seismic responses, seismic performance curves, and seismic failure probability curves to improve the evaluation of steel and reinforced concrete (RC) buildings. Traditional methods for identifying local connection damage necessitate costly instrumentation and specific sensor placement. Artificial intelligence (AI) has emerged as a viable solution to overcome the limitations of conventional vibration-based damage identification techniques. However, many AI-based methods lack comprehensive datasets for diverse damage conditions. To address this, Paral et al. [8] proposed a model-based approach utilizing a combination of CNN and continuous wavelet transform (CWT) applied to response signals. This method relies solely on global vibration signals generated by impulse excitation on the structure, subsequently leveraging an updated finite element model to consider connection flexibility for multiple functionalities. Experimental validation involves a two-story structural steel frame, and the proposed methodology's performance is verified through the identification of additional beam-column connection damage introduced in the test frame. Pal et al. [9] introduced a data-centric approach using DL for SHM of a steel frame with bolted connections. Leveraging a CNN-based architecture, the model extracts distinct features from time-frequency curves obtained from vibrations. These features enable differentiation between undamaged and damaged conditions, specifically focusing on various bolt states. Training accuracy averaged 100%, with a validation accuracy of 98.1%. Testing on new and related datasets showed the model's robustness and high accuracy in classifying different damage levels. The method demonstrates promising potential as an automated tool for monitoring connections in plane frame structures.

Conventional methods for detecting such damage necessitate costly instrumentation and specific sensor placements, leading to limitations [10]. Embracing the efficiency of AI, this research introduces an innovative approach leveraging a model-based scheme that combines CNNs and CWT with global vibration signals from seismic excitations. By utilizing updated finite element models accounting for connection flexibility, which are validated by experimental shaking table tests on different connections rigidities of steel structures, this methodology offers a versatile solution for evaluating and monitoring the health condition of steel connections. The study addresses the challenge of identifying structural damages that mostly occurs in connections of steel structures, often caused by factors like corrosion, fatigue, and accidental loads over time, and more importantly, the failure to meet the requirement of bolts and welding of the connection parts. Due to previous experience of the principal investigator (PI) in both areas of ML-based models (see [2-7]) and complex Morlet wavelet-based refined damage-sensitive model (see [11-14]), the proposed study can be conducted with high-quality research. This experience is expected to significantly enhance the performance of result assessment and overall study outcomes. The provided prediction model can be a useful tool for preliminary evaluation of damaged buildings with non-disturbing techniques, and provide a solution for recognizing those damaged connections.

3- The importance of the project

Finding the location of damaged connection can help structural designers to fix the issue as a retrofitting scheme and prevent the failure on the performance of building. Identifying the precise location of damaged connections within a building's structure is of paramount importance for structural designers. This capability allows for the implementation of targeted retrofitting measures to enhance the building's performance and prevent potential failures, particularly during seismic events. By accurately pinpointing damage location, designers can undertake focused repairs, which are more cost-effective and less disruptive compared to extensive interventions across the entire structure. Moreover, this approach is beneficial even in non-seismic areas, where buildings may suffer from structural degradation due to factors such as material fatigue and environmental conditions. Continuous monitoring and early detection of damage ensure timely maintenance, thereby prolonging the building's lifespan and ensuring safety. Although the literature points out the investigations on the damage detection, they do not use a wide range of experimental specimens as in this research are considered, and do not rely on those developed methodologies based on the CNNs and CWT. However, this research focused on the methodology employed involves the use of CNNs combined with CWT applied to the building's response signals. CNNs are adept at recognizing patterns, including noise indicative of structural anomalies. When CNNs output noise is analyzed, it can reveal signs of damage. The CWT provides a detailed analysis of the response signals across various frequency bands, enabling the detection of both localized and distributed damage. This dual approach ensures high accuracy in identifying the location of damaged connections, which is crucial for effective intervention and maintaining the structural safety of the building. Consequently, the integration of CNNs and CWT for damage detection offers a powerful tool for ensuring structural integrity, supporting both retrofitting efforts and the early detection and repair of damage in buildings.

This project is pioneering in its integration of advanced ML techniques with seismic retrofitting methodologies. While traditional retrofitting approaches rely heavily on empirical methods and heuristic rules, this study leverages the predictive power of ML to develop data-driven solutions that can adapt to a wide range of conditions. If the retrofitting scheme is perfectly executed, it is feasible to implement and replace the bolts of connections in steel structures with novel shape memory alloy (SMA) bolts. The research team has previously investigated this approach in a numerical study (see [15]) and found that using SMA bolts can significantly reduce the need for extensive modifications in connection details. Instead of overhauling the entire connection design, simply substituting the regular bolts with SMA bolts can achieve the desired improvement in performance. This innovative approach leverages the unique properties of SMA bolts, such as their ability to undergo deformation and return to their original shape, thereby enhancing the resilience and longevity of the connection without necessitating complex structural alterations. In this study, the objective is to validate the proposed approach and introduce a novel retrofitting scheme as a substitute for conventional methods. This includes numerically validating the ABAQUS models for properly assigning and implementing SMA bolts in the structures. Therefore, this research aims to enhance the novelty of the field and provide an effective solution for the identified issues. This innovative approach not only improves the resilience and performance of retrofitted structures but also offers a practical and efficient alternative to traditional retrofitting techniques. The successful implementation of SMA bolts is expected to significantly contribute to advancement of structural engineering and development of effective constructional method for industry.

4- Project work plan

The ML-based model for estimating seismic response, seismic performance, seismic failure probability assessment, and seismic risk assessment of steel and RC structures have been preliminary investigated by PI and published in high ranked journals (please see [2-7, 16]). Predicting the seismic response of the 2-Story structure were investigated by 32 ML-models improved during the PI investigation, to preliminary investigate the capability of the ML techniques. The preliminary investigation confirm that the proposed methodology could accurately predict seismic responses and enhance the retrofitting strategies for damaged buildings. This validation underscores the potential of ML models to revolutionize traditional approaches, offering more precise, data-driven insights that improve the resilience and safety of structures. Fig. 1 presents the preliminary evaluation. Fig. 2 present scatter plots of wavelets-based rDSFs of the 4-Story structure, considering maximum story drift ratio (SDR) for each damage pattern (DP) under selected ground motions. As can be observed in these figures, the correlation coefficient (ρ) is very low and negative. This indicates an inverse relationship between rDSFs and SDR. The results show that the Morlet and proposed cmorfb-fc wavelet-based rDSF are strongly correlated versus maximum SDR. Therefore, it can be concluded that due to seismic load effects the ρ factor is decreased. Furthermore, correlation between rDSF and maximum SDR is decreased more for the low-rise structures. On the other hand, the low-rise structures are damaged more during seismic ground motion. This strong correlation suggests that these wavelets are effective in capturing the damage-sensitive features of the structure under seismic loading. Fig. 3 illustrates the wavelets-based rDSF of the 4-story structure under the selected ground motion.

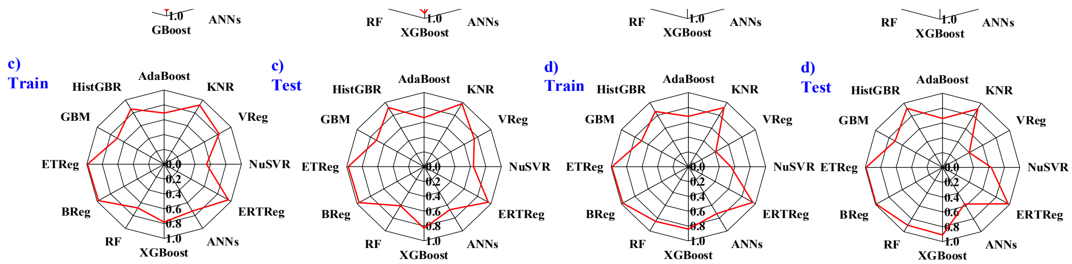

Fig. 1. Pie charts for the prediction results of train and test datasets using ML algorithms on the 2-Story structure assuming four soil types subjected to selected record subset.

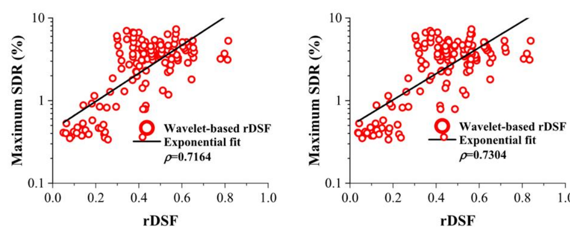

Fig. 2. Mode shapes and wavelet-based rDSF of the 4-story structure subjected to selected ground motions: (a) rDSF based on Morlet wavelet, (b) rDSF based on cmor wavelet.

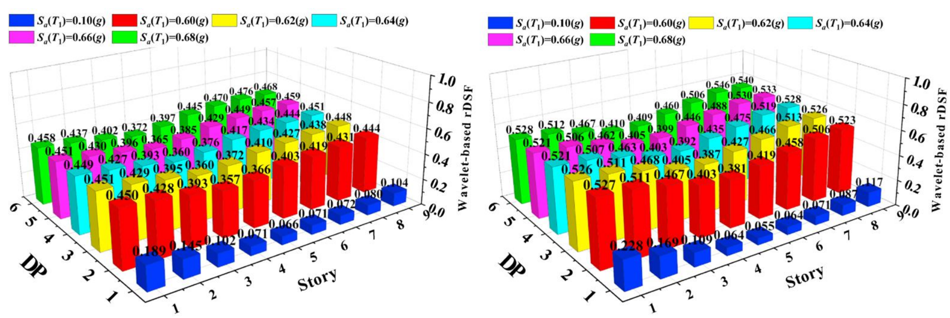

Fig. 3. Wavelets-based rDSF of the 4-story structure subjected to selected ground motion: (a) rDSF based on Morlet wavelet (asymh); (b) rDSF based on mor2.832-0.8404 wavelet (asymh).

Upon analysis of the results, it is evident that the differences between the first and second stories for the first time, and between the second and third stories for the second time, are more pronounced compared to those between the third and fourth stories. These findings underscore the potential for further analysis and development using ML methods to enhance the accuracy of damage detection and prediction in steel structures. However, it is possible to use the results of CWT and enhance them with ML-based prediction methods to achieve higher accuracy in damage detection of steel structures. By integrating the detailed frequency and time-localized information provided by CWT with advanced ML algorithms, more precise and reliable predictions of structural damage can be obtained. This hybrid approach can leverage the strengths of both techniques, where CWT captures the intricate features of the structural response under seismic loads, and ML models use these features to learn complex patterns and make accurate damage predictions. Consequently, this can significantly improve the effectiveness of SHM systems and aid in the timely retrofitting and maintenance of steel structures, ensuring better safety and resilience.

5- Research methodology

The current study aims to provide a real framework of steel structures conditions, in which, the defects of connections can be evaluated by non-destructive methods such as SHM and ML-based damage detection model. It is necessary to validate the model with experimental tests on shaking table to monitor the behavior of structures under seismic loading. The experiment involves the meticulous design of low-rise steel structures varying in height and configuration. Specifically, 8 steel structures ranging from one to four stories are designed, each encompassing one to two bays and different rigid and semi-rigid connections. Different industrial used connections, categorized as rigid and semi-rigid connections, are modeled in ABAQUS software (see Fig. 4) to determine their rigidity and then to be defined for structures. Therefore, a wide range of case study structures are investigated with different assemblies to consist of a comprehensive study on damages of connections. The design intricacies incorporate precise specifications for steel components, emphasizing accuracy in measurements and adherence to structural standards.

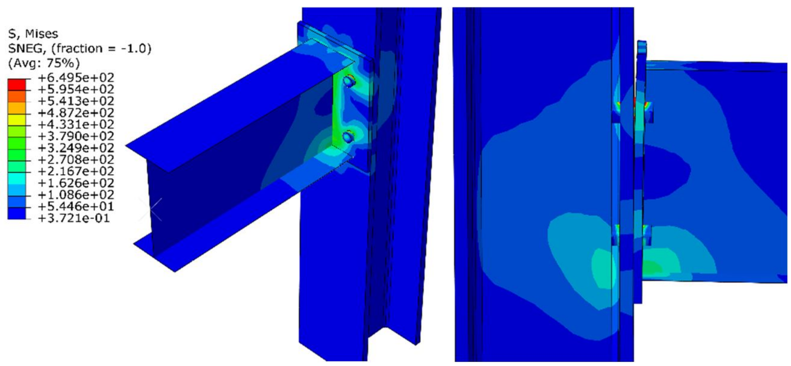

Fig. 4. Modeling of steel connections in ABAQUS software and investigating the effects of semi-rigid connection.

The seismic design codes of ASCE 7–22 [16], AISC 360–22 [17], and AISC 341–22 [18] have been used to design structures. Then, according to dimensional analysis provided in literature, the scale of 1/10 has been considered to provide the shop drawing of the structural elements of beam, column, and connections. The dimensional analysis has been applied to all characteristics to consider their effects on the results of experiments. This approach helps in achieving accurate and reliable data that can be effectively translated to real-world scenarios. Then, the provided experimental structures will be tested on shaking table to monitor the seismic behavior of structures and record the seismic demands for each floor levels. By providing the scalograms of seismic responses using CWT, the dataset can be prepared and interpreted for use in ML models. Scalograms, which are visual representations of the time-frequency characteristics of the structural responses, captured during seismic loading, offer detailed insights into how the structure behaves under different seismic conditions. These scalograms can be transformed into a comprehensive dataset, capturing the intricate patterns and variations in the structural vibrations. The prepared dataset serves as a rich source of information for training and validating ML models. By interpreting the scalograms, key features and patterns indicative of structural performance and potential vulnerabilities can be extracted. ML models can then be trained on this dataset to recognize these patterns, predict future structural responses, and even identify early warning signs of structural failure under seismic stress. Advanced ML techniques, particularly CNNs and DL methodologies, are employed for the prediction of structural connection defects and to improve a prediction model for this purpose. Through the utilization of CNNs and DL algorithms, the model is trained to accurately predict and classify the rigidity levels of structural connections based on the visual features extracted from the scalograms. Having the ML-based prediction model, it is aimed to propose a retrofitting scheme using SMA bolts to improve the capability of the steel connections. It is planned to finish the work in 12 months period by dividing the duties between team members and working according to scheduled time table, which is prepared according to previous experience on experimental test. The aim is to numerically implement the ability of the SMA bolts (i.e., the SMA material from Poland industry is verified in ABAQUS software as presented in Fig. 5) for reducing the residual drift of structures after seismic loads, therefore, a detailed discussion is prepared to how implement SMA bolts and the effects of them for retrofitting. This procedure can be extended by numerically validated models to be used for improving connections defects. In the future, after thorough refinement and verification in terms of credibility of the prediction model, it is planned to extend the scope of research to other operational problems of buildings in industry. Since the database of ML-based model can be updated by adding more data points, the proposed model can be used in future based on the newly added datasets and can be extended to more structural defects in industry, which will be the aim of PI to be explored.

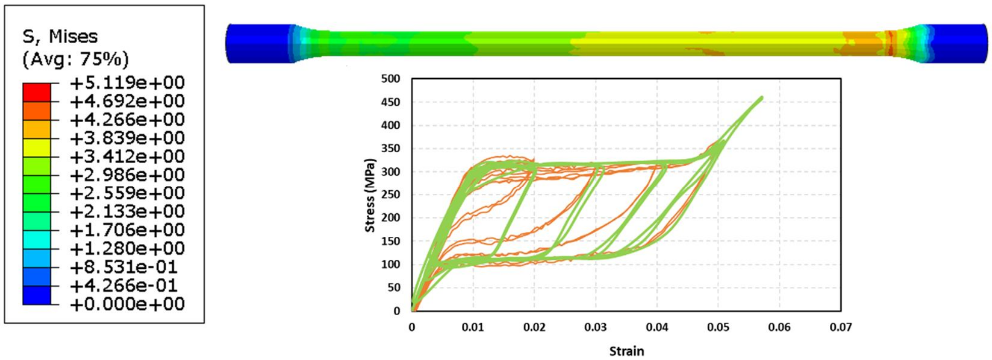

Fig. 5. Verifying the SMA material with experimental test [32] using ABAQUS software.

6- Research team

All team members are collaborated in design process and experimental tests to use their unique experience during the tests, reduce the likelihood of engineering defects, and improve the reliability of results. Prof. Robert Jankowski is monitoring the details of structures, methodology of the damage detection, and will be present during the shaking table tests. Prof. (Associate) Benyamin Mohebi extensive work on wavelet transform-based damage detection provides a foundation to rigorously test and refine the proposed CWT-based indicators, then, ensures alignment with industry needs and enhances the translational potential of the research (see examples in [11-14]). Their professional experience can lead to have a precise experimental test and avoid any mistakes during the tests. In addition, we will use the programming ability of mgr. Farzin Kazemi and mgr. Neda Asgarkhani to implement the methodology in ML algorithms (see examples in [2-7, 19, 20]). Moreover, the PI is also will work on project management and programming code align with experimental tests. However, the PI is the responsible for managing, dissemination and implementation of projects outcomes.

7- Risk analysis of project

Based on the analysis conducted, the risk associated with the project is deemed to be sufficiently low. Therefore, the decision is to proceed with the project without hesitation. No specific risk mitigation strategies or actions are deemed necessary as the identified risks fall within an acceptable range, warranting the continuation of the project as planned.

Table 1. Risk analysis of conducting experimental test.

Risk Event	Probability	Impact	Mitigation Measures
Equipment Failure	Medium	High	Regular maintenance and inspection of equipment. Backup equipment.
Sensor Malfunction	Low	Medium	Calibrate sensors before the test. Monitor sensor performance.
Data Loss or Corruption	Low	Medium	Implement data backup procedures. Data validation and redundancy.
Structural Failure	Low	High	Conduct thorough structural assessment before the test.
Safety Hazards	Medium	High	Implement strict safety protocols and provide safety training.
Inaccurate Measurements	Medium	Medium	Calibrate instruments properly. Cross-check measurements.
Human Error	Medium	Medium	Provide clear instructions and training to the research team.
Delays in Material Supply	Low	Low	Plan for adequate material inventory. Establish alternative sources.
Environmental Factors	Medium	Low	Monitor and control environmental conditions during the test.
Budget Overrun	Low	High	Develop a detailed budget plan. Monitor expenses closely.
Experience of the research team	High	High	The research team will be selected based on the various experience in a different field of research - this guarantees a quick response to any problems that may arise.
Prolonged research in the laboratory	Low	Low	In the case of a significant delay, it is possible to change the order of the stages of project implementation
Increase of steel price	Medium	High	In case of a significant increase in steel prices, it is planned to cover the increased costs from the proposal author's salary.

8- References

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DETAILED DESCRIPTION

[in English]

1- Title

Vibration-based structural damage identification of steel structures integrating wavelet-based scalogram and deep learning method

2- Scientific aim of the project

Structural health monitoring (SHM) strategies concerning the assessment of connection damage in steel structures encompass various techniques to detect, evaluate, and manage potential damage or degradation within structural connections. These strategies typically involve sensor-based systems that collect data on structural responses, such as vibration, displacement, and acceleration enabling continuous monitoring and assessment of connection integrity. Methods like vibration analysis, acoustic emission monitoring, and strain gauges aid in identifying anomalies, changes in structural behavior, or signs of damage, particularly in critical areas like bolted or welded connections [1]. Advanced technologies, including machine learning (ML) algorithms and deep learning (DL) methods, are increasingly integrated into SHM systems to analyze collected data patterns and predict potential connection failures. This proactive approach allows for early detection, accurate assessment, and timely maintenance or repairs to ensure the structural safety and longevity of steel connections within the overall framework [2]. DL is considered as a sub-branch of ML, and its applications in dealing with large amounts of data have been successfully demonstrated on many platforms. The DL models can capture and learn information that is hidden in the data to predict different patterns via stacked blocks of layers that form the DL skeleton [3]. Broadly, vibration-based methods for damage detection fall into two categories: model-based (parametric) and non-model-based (non-parametric). Model-based approaches rely on computational models and assumptions about the structural system, typically offering high accuracy. However, in practical applications, obtaining precise structural information might be challenging, as a result, non-parametric methods come into play. These methods analyze response data without presuming any structural characteristics, making them valuable for identifying damages without relying on predefined structural models [4]. Different algorithms and methodologies have been developed for each level of the damage identification process, including the management of historical information on the functioning of the structure, and they often use different sensors and actuators, materials, and configurations. Some of works available in the literature have focused on problems related to hybrid SHM approach for damage detection in steel bridges [5], load-carrying capacity assessment of semi-rigid steel structures [6], vibration-based damage detection [7-9], localization and classification of structural damage [10], and failure mode identification of double shear bolted connections [11]. In addition, the literature confirm that seismic performance and risk assessment of buildings have been widely investigated by researchers and some preliminary prediction tools have been introduced according to prepared datasets [12-18]. They made a great effort to introduce novel ML methods for estimating seismic responses, seismic performance curves, and seismic failure probability curves to improve the evaluation of steel and reinforced concrete (RC) buildings.

At the level of damage detection, aspects such as sensor locations and the use of wireless sensor networks as well as the use of specific kinds of sensors or sensor networks, such as microelectromechanical systems, accelerometers, optical fibers, vibration sensors, and pressure-based sensors have been addressed as novel SHM of buildings. To have a better understanding in SHM of structures, Mosallam et al. [19] examined damage detection in a 3-story steel frame with wireless sensors and accelerometers. It uses experimental shaking table data and finite element simulations for two detection approaches. One calibrates a model to find stiffness loss, minimizing the difference between predicted and measured dynamics. The other uses the modal assurance criterion to identify changes between undamaged and damaged conditions. Both methods effectively detect structural damage. Liu and Zhang [20] introduced a novel method using CNN for assessing ultra-low cycle fatigue-induced damage in structural steel fuse members' post-hazard. Unlike traditional mathematical models, CNNs can interpret high-dimensional features within extensive raw data. The approach employs a saliency-based visualization technique to illustrate the model's identification of key features. A micromechanical fracture index serves as the damage quantifier, labelling images in the training dataset. Large training datasets are generated using cumulative plastic strain contour plot images from finite element simulations. Parametric studies validate and refine this DL-based damage assessment method, which is further validated using real experimental images from cyclic testing of a steel-notched plate specimen. Results indicate that this method offers a promising automated solution for swiftly assessing structural steel fuse member damage. Zhang et al. [21] introduced SHMnet, a new deep convolutional neural network tailored for identifying challenging structural conditions in steel frames with bolted connection damage. They optimized the network architecture and training data preparation for this specific application. Through impact tests on steel frames with varied bolted connection damage, even a single loosened bolt, they use time-domain monitoring data from a single accelerometer for training. Parametric studies cover various factors like layer numbers, sensor locations, dataset quantity, and noise levels were done. SHMnet demonstrates effectiveness and reliability, achieving over 98% accuracy across at least four independent training datasets while avoiding vibration node points for sensor placement. Even with up to 60% additive Gaussian noise, SHMnet maintains high accuracy, unlike traditional methods relying on modal parameters. This method has potential as a robust framework for structural condition identification, transforming SHM practices. According to literature review, some investigations have been focused on exploring the acceleration responses of steel moment-resisting frames (MRFs) subjected to various ground motions, employing incremental dynamic analysis (IDA) for nonlinear damage diagnosis. Initially, the auto-regressive moving-average with exogenous input (ARX) model, supplemented by a stabilization diagram, is employed to evaluate the natural frequencies of the MRFs. This method provides a robust foundation for understanding the dynamic characteristics of the structures under study. In the subsequent step, they introduce complex Morlet wavelet-based refined damage-sensitive features, which incorporate higher mode contributions and end-effect modifications, thereby enhancing the sensitivity and accuracy of damage detection [22-25].

Traditional methods for identifying local connection damage necessitate costly instrumentation and specific sensor placement. Artificial intelligence (AI) has emerged as a viable solution to overcome the limitations of conventional vibration-based damage identification techniques. However, many AI-based methods lack comprehensive datasets for diverse damage conditions. To address this, Paral et al. [26] proposed a model-based approach utilizing a combination of CNN and continuous wavelet transform (CWT) applied to response signals. This method relies solely on global vibration signals generated by impulse excitation on the structure, subsequently leveraging an updated finite element model to consider connection flexibility for multiple functionalities. Experimental validation involves a two-story structural steel frame, and the proposed methodology's performance is verified through the identification of additional beam-column connection damage introduced in the test frame. Pal et al. [27] introduced a data-centric approach using DL for SHM of a steel frame with bolted connections. Leveraging a CNN-based architecture, the model extracts distinct features from time-frequency curves obtained from vibrations. These features enable differentiation between undamaged and damaged conditions, specifically focusing on various bolt states. Training accuracy averaged 100%, with a validation accuracy of 98.1%. Testing on new and related datasets showed the model's robustness and high accuracy in classifying different damage levels. The method demonstrates promising potential as an automated tool for monitoring connections in plane frame structures. Investigation on this matter can indicate that the impact of the topic on international research area is high and more studies focused on this matter [28-30], while still there is a lack on the comprehensive assessment of those steel structures having different assemblies and connection rigidities. However, this research can discuss more details on the novel damage detection methods and include a wide range of structures.

Conventional methods for detecting such damage necessitate costly instrumentation and specific sensor placements, leading to limitations [31]. Embracing the efficiency of AI, this research introduces an innovative approach using a model-based scheme that combines CNNs and CWT with global vibration signals from seismic excitations. By utilizing updated finite element models accounting for connection flexibility, which are validated by experimental shaking table tests on different connections rigidities of steel structures, this methodology offers a versatile solution for evaluating and monitoring the health condition of steel connections. The study addresses the challenge of identifying structural damages that mostly occurs in connections of steel structures, often caused by factors like corrosion, fatigue, and accidental loads over time, and more importantly, the failure to meet the requirement of bolts and welding of the connection parts. Due to previous experience of the principal investigator (PI) in both areas of ML-based models (see [13-18]) and complex Morlet wavelet-based refined damage-sensitive model (see [22-25]), the proposed study can be conducted with high-quality research. This experience is expected to significantly enhance the performance of result assessment and overall study outcomes. The provided prediction model can be a useful tool for preliminary evaluation of damaged buildings with non-disturbing techniques, and provide a solution for recognizing those damaged connections.

3- The importance of the project

Finding the location of damaged connection can help structural designers to fix the issue as a retrofitting scheme and prevent the failure on the performance of building. Identifying the precise location of damaged connections within a building's structure is of paramount importance for structural designers. This capability allows for the implementation of targeted retrofitting measures to enhance the building's performance and prevent potential failures, particularly during seismic events. By accurately pinpointing damage location, designers can undertake focused repairs, which are more cost-effective and less disruptive compared to extensive interventions across the entire structure. Moreover, this approach is beneficial even in non-seismic areas, where buildings may suffer from structural degradation due to factors such as material fatigue and environmental conditions. Continuous monitoring and early detection of damage ensure timely maintenance, thereby prolonging the building's lifespan and ensuring safety.

Although the literature points out the investigations on the damage detection, they do not use a wide range of experimental specimens as in this research are considered, and do not rely on those developed methodologies based on the CNNs and CWT. However, this research focused on the methodology employed involves the use of CNNs combined with CWT applied to the building's response signals. CNNs are adept at recognizing patterns, including noise indicative of structural anomalies. When CNNs output noise is analyzed, it can reveal signs of damage. The CWT provides a detailed analysis of the response signals across various frequency bands, enabling the detection of both localized and distributed damage. This dual approach ensures high accuracy in identifying the location of damaged connections, which is crucial for effective intervention and maintaining the structural safety of the building. Consequently, the integration of CNNs and CWT for damage detection offers a powerful tool for ensuring structural integrity, supporting both retrofitting efforts and the early detection and repair of damage in buildings.

Since prediction tool and improving its ability with developed ML-based methods and experimental dataset can be an enhanced method for structures, it this research, the ability of the model can be experimentally investigated for retrofitting damaged buildings having permanent deformation known as residual drift. Retrofitting a damaged structure with ML-based methods involves a systematic plan to enhance the seismic resilience and reduce the residual deformations due to connection defects. The objective of the experimental test is assessing the seismic defects of buildings focusing on connection defects, and introducing a procedure for using ML-based methods for retrofitting damaged buildings to control the residual drift. The impact of this study Seismic events poses a significant threat to the structural integrity of buildings, with connection defects being a critical weak point that can lead to catastrophic failures. Addressing these defects is essential to enhance the resilience of buildings and ensure the safety of their occupants. By focusing on connection defects, this study aims to fill a critical gap in the current understanding of seismic vulnerability, providing insights that can lead to more effective retrofitting strategies. The application of ML-based methods for retrofitting is a novel approach that promises to offer more accurate and efficient solutions compared to traditional techniques.

This project is pioneering in its integration of advanced ML techniques with seismic retrofitting methodologies. While traditional retrofitting approaches rely heavily on empirical methods and heuristic rules, this study considers the predictive power of ML to develop data-driven solutions that can adapt to a wide range of conditions. The novel application of ML for controlling residual drift in retrofitted buildings represents a significant advancement in the field, as it introduces a higher level of precision and adaptability in addressing seismic defects. The impact of this study extends beyond immediate practical applications. By demonstrating the efficacy of ML-based retrofitting methods, this project will pave the way for future research in the intersection of structural engineering and artificial intelligence. The findings can stimulate further investigations into advanced computational techniques for SHM and damage mitigation, thereby broadening the scope and capabilities of seismic engineering. Additionally, the development of a robust procedure for assessing and retrofitting connection defects will contribute valuable knowledge to the discipline, enhancing the overall resilience of built environments against seismic events. The project's outcomes will not only improve current practices but also inspire innovative research directions, ultimately advancing the field of earthquake engineering and contributing to safer, more resilient infrastructure. In addition, the contribution of the research can foster international collaboration, enhancing the exchange of knowledge and expertise across borders.

By perfectly executing retrofitting scheme, it is feasible to implement and replace the bolts of connections in steel structures with novel shape memory alloy (SMA) bolts. The research team has previously investigated this approach in a numerical study (research team members have been worked on this topic in numerical studies [32]) and found that using SMA bolts can significantly reduce the need for extensive modifications in connection details. Instead of overhauling the entire connection design, simply substituting the regular bolts with SMA bolts can achieve the desired improvement in performance. This innovative approach considers the unique properties of SMA bolts, such as their ability to undergo deformation and return to their original shape, thereby enhancing the resilience and longevity of the connection without necessitating complex structural alterations. In this study, the objective is to validate the proposed approach and introduce a novel retrofitting scheme as a substitute for conventional methods. This includes modelling and implements SMA bolts in the structures. Therefore, this research aims to enhance the novelty of the field and provide an effective solution for the identified issues. This innovative approach not only improves the resilience and performance of retrofitted structures but also offers a practical and efficient alternative to traditional retrofitting techniques. The successful implementation of SMA bolts is expected to significantly contribute to the advancement of structural engineering and development of more effective seismic retrofitting strategies for industry.

4- Project work plan

The ML-based model for estimating seismic response, seismic performance, seismic failure probability assessment, and seismic risk assessment of steel and RC structures have been preliminary investigated by PI and research team members and published in high ranked journals (please see [13-18]). Predicting the seismic response of the 2-Story structure were investigated by 32 ML-models improved during the PI investigation, however, some of them have been neglected due their less accurate results. It should be noted that due to the sophisticated nature of ground motion records, there is no single adequate model for all types of similar issues. However, we aimed to propose a general graphical user interface that can use all of the ML models in one tool for prediction purposes. Fig. 1 presents the scatter graph for the prediction results of train and test datasets using the XGBoost algorithm on the 2-Story structure subjected to selected record subset. According to the prediction results, the XGBoost algorithm achieved R^2 equal to 0.98 and 0.97 for the training and testing datasets. This shows the ability of the ML model for estimating the seismic response of the 2-Story structure. To better compare the results of all ML algorithms, Fig. 2 illustrates the pie charts for the prediction results of train and test datasets on the 2-Story structure assuming four soil types subjected to selected record subset. It can be concluded that some of ML models are weak on predicting those responses, while some of them have the highest accuracy. Therefore, it can be used as prediction tool for seismic response assessment of buildings. More in detail results are presented in Table 1. The preliminary investigation into the capabilities of the ML models confirmed that the proposed methodology could accurately predict seismic responses and enhance the retrofitting strategies for damaged buildings. This validation underscores the potential of ML models to revolutionize traditional approaches, offering more precise, data-driven insights that improve the resilience and safety of structures.

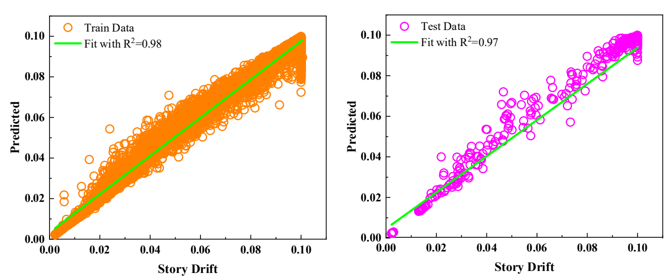
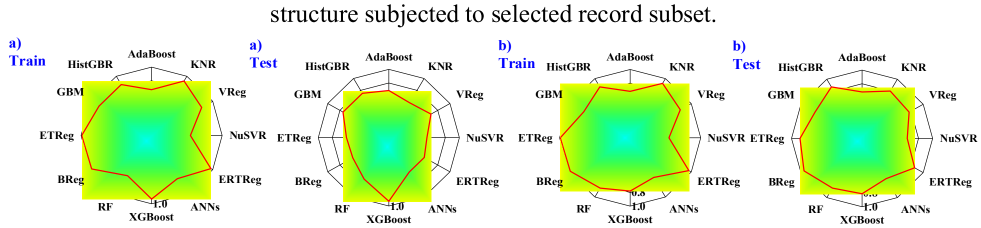


Fig. 1. Scatter graph for the prediction results of train and test datasets using XGBoost algorithm on the 2-Story structure subjected to selected record subset.



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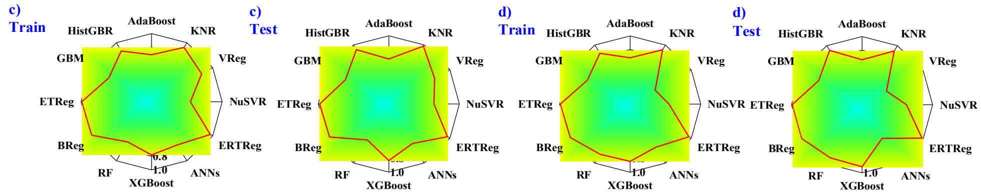

Fig. 2. Pie charts for the prediction results of train and test datasets using ML algorithms on the 2-Story structure assuming four soil types subjected to selected record subset.

Table. 1. Comparing the model metrics of all ML algorithms for prediction of the 2-Story structure subjected to selected record subset.

ML algorithms	Conventional Method				Developed Method			
	Train Dataset		Test Dataset		Train Dataset		Test Dataset	
	R^2	MSE	R^2	MSE	R^2	MSE	R^2	MSE
XGBoost	0.78	2.3E-04	0.83	2.1E-04	0.84	1.6E-04	0.91	1.1E-04
RF	0.68	3.4E-04	0.61	4.7E-04	0.85	1.6E-04	0.90	1.2E-04
BReg	0.98	2.6E-05	0.97	3.4E-05	0.98	2.6E-05	0.99	1.3E-05
ETReg	0.99	1.3E-06	0.98	2.8E-05	0.99	1.3E-06	0.99	6.9E-08
GBM	0.70	3.2E-04	0.71	3.6E-04	0.70	3.2E-04	0.71	3.6E-04
HistGBR	0.86	1.5E-04	0.92	1.0E-04	0.86	1.5E-04	0.92	9.6E-05
AdaBoost	0.69	3.3E-04	0.66	4.2E-04	0.68	3.4E-04	0.66	4.2E-04
KNR	0.92	8.7E-05	0.98	2.5E-05	0.92	8.7E-05	0.91	1.1E-04
VReg	0.82	1.9E-04	0.75	3.0E-04	0.41	6.3E-04	0.50	6.2E-04
NuSVR	0.55	4.8E-04	0.64	4.3E-04	0.55	4.8E-04	0.63	4.5E-04
ERTReg	0.96	3.7E-05	0.96	4.7E-05	0.96	3.9E-05	0.98	2.2E-05
ANNs	0.73	2.8E-04	0.67	4.1E-04	0.73	2.9E-04	0.57	5.5E-04

The total acceleration responses obtained from the structure were utilized to compute the natural frequencies using the Auto-Regressive model with exogenous input (ARX) method. This method is recognized as the most accurate and widely used among system identification techniques, ensuring precise determination of the structural natural frequencies. A single input-four output ARX method was employed to estimate the first natural frequency of the 4-story structure. This approach allows for a comprehensive analysis of the dynamic characteristics by considering the influence of multiple response outputs. To determine the appropriate model order for the ARX method, stabilization diagrams were plotted alongside Power spectral densities (PSDs). These tools provide a visual representation of the model's stability and frequency content, aiding in the selection of an optimal model order. For instance, as illustrated in the stabilization diagram presented in Fig. 3, a model order of 14 was found to be sufficient to accurately capture the first-mode natural frequency of the structure. This meticulous process ensures that the selected ARX model order effectively reflects the dynamic behavior of the structure, thereby enhancing the reliability and precision of the frequency estimation. This method can be used as a preliminary estimation tool for experimental structures of this study, allowing to evaluate them for potential dynamic characteristics and structural integrity. By accurately determining the natural frequencies through the ARX method, it is possible to identify any discrepancies or anomalies in the structural behavior. This early assessment can be crucial for detecting potential issues and planning appropriate retrofitting or strengthening measures. Additionally, the use of stabilization diagrams and PSDs in conjunction with the ARX method provides a robust framework for ensuring the reliability and accuracy of the preliminary estimations. This approach not only aids in the initial evaluation of experimental structures but also enhances the overall understanding of their dynamic performance under various conditions. The inclusion of seismic input signals is not merely illustrative; however, it is crucial for understanding transient dynamic behaviors of steel connections under realistic loading conditions. The motivation lies in seismic risks and the unique challenges they pose in detecting connection damage; however, they represent a critical failure mode for steel connections, particularly in regions prone to earthquakes.

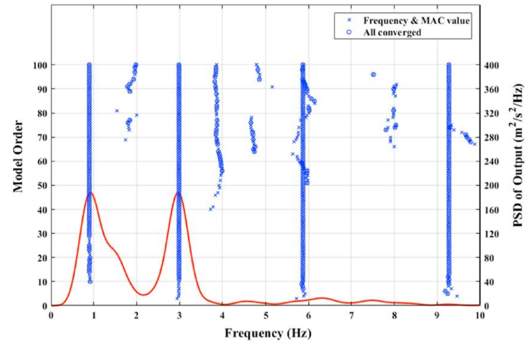

Fig. 3. Stabilization diagram of the 4-story structure using the ARX method.

Fig. 4 present scatter plots of wavelets-based rDSFs of the 4-Story structure, considering maximum story drift ratio (SDR) for each damage pattern (DP) under selected ground motions. As can be observed in these figures, the correlation coefficient (ρ) is very low and negative. This indicates an inverse relationship between rDSFs and SDR. The results show that the Morlet and proposed cmorfb-fc wavelet-based rDSF are strongly correlated versus maximum SDR. Therefore, it can be concluded that due to seismic load effects the ρ factor is decreased. Furthermore, correlation between rDSF and maximum SDR is decreased more for the low-rise structures. On the other hand, the low-rise structures are damaged more during seismic ground motion. This strong correlation suggests that these wavelets are effective in capturing the damage-sensitive features of the structure under seismic loading. However, the ρ factor decreases due to the effects of seismic loads, highlighting the complexity of the damage mechanisms during such events. Fig. 5 illustrates the wavelets-based rDSF of the 4-story structure under the selected ground motion. Upon analysis of the results, it is evident that the differences between the first and second stories for the first time, and between the second and third stories for the second time, are more pronounced compared to those between the third and fourth stories. These notable variations are particularly evident in these stories between DP_1 and DP_2, with the first significant change occurring between DP_1 and DP_2 for the second story and extending to the third story. Consequently, the second story is identified as more susceptible to experiencing the first plastic hinge formation under DP_2. These findings underscore the potential for further analysis and development using ML methods to enhance the accuracy of damage detection and prediction in steel structures. However, it is possible to use the results of CWT and enhance them with ML-based prediction methods to achieve higher accuracy in damage detection of steel structures. By integrating the detailed frequency and time-localized information provided by CWT with advanced ML algorithms, more precise and reliable predictions of structural damage can be obtained.

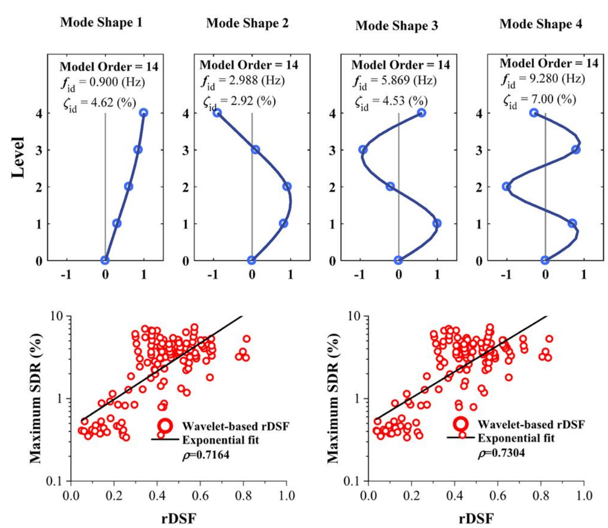

Fig. 4. Wavelets-based rDSF of the 4-story structure subjected to selected ground motions: (a) rDSF based on Morlet wavelet, (b) rDSF based on cmor wavelet.

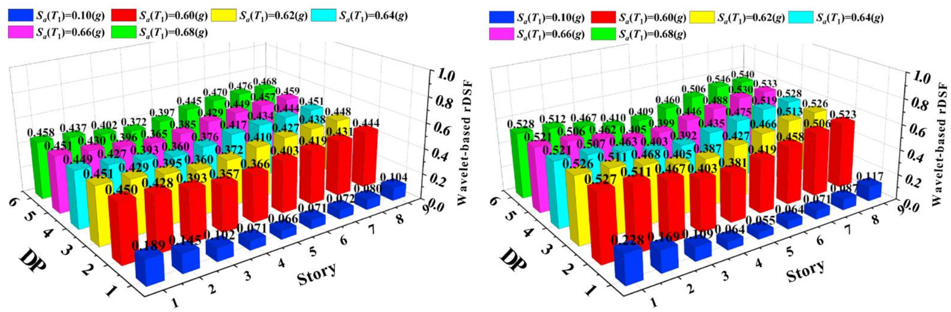

Fig. 5. Wavelets-based rDSF of the 4-story structure subjected to selected ground motion: (a) rDSF based on Morlet wavelet (asymh); (b) rDSF based on cmor2.832-0.8404 wavelet (asymh).

This hybrid approach can consider the strengths of both techniques, where CWT captures the intricate features of the structural response under seismic loads, and ML models use these features to learn complex patterns and make accurate damage predictions. Consequently, this can significantly improve the effectiveness of SHM systems and aid in the timely retrofitting and maintenance of steel structures, ensuring better safety and resilience. The research team's experimental expertise has been demonstrated through various types of experiments conducted throughout their careers (e.g., see [33, 34]). This extensive experience enhances the reliability of the experimental results and mitigates the risk of financial loss, ensuring a higher level of confidence in the study's outcomes. Their proven record of accomplishment includes successful execution of complex experimental protocols, effective troubleshooting of unforeseen issues, and the ability to produce reproducible and accurate data. This depth of experience ensures that the proposed experiments will be conducted efficiently and effectively, maximizing the value of the resources invested and contributing to the advancement of the field with high quality and reliable results.

5- Research methodology

The current study aims to provide a real framework of conditions of steel structures, in which, the defects of connections can be evaluated by non-destructive methods such as SHM and ML-based damage detection model. It is necessary to validate the model with experimental tests on shaking table to monitor the behavior of structures under seismic loading. Therefore, the methodology of research has been described as follows:

5-1- Design phase

The experiment involves the meticulous design of low-rise steel structures varying in height, bay length and configuration. Specifically, steel structures ranging from 1-, to 4-story elevation are designed, each encompassing one or two bays, and rigid and semi-rigid connections (i.e., various bolt states like fully loose, hand tight and fully tight (i.e., prestressed) are considered according to rigidity determined in ABAQUS software). According to seismic codes, soil type D is considered for a region with seismic category II, regular dead and live loading for floor levels of buildings are assumed, and seven near-field seismic records are selected for the considered region. The structures are modeled in different floor weights and are tested on shaking table to achieve more case studies compared to literature. The design intricacies incorporate precise specifications for steel components, emphasizing accuracy in measurements and adherence to structural standards. The seismic design codes of ASCE 7–22 [35], AISC 360–22 [36], and AISC 341–22 [37] have been used to design structures. Then, according to dimensional analysis provided in literature, the scale of 1/10 has been considered to provide the shop drawing of the structural elements of beam, column, and connections. All the beams and columns are detailed as plate girder to be constructed as bolt connection, and the connections have been considered as rigid and semi-rigid detail. The structural members are designed to have typical shape in each floor levels according to the design output of ETABS software. However, this can lead to a fast assembling of structures during the analysis and reduces experiment time. In addition, the structures were modeled in ABAQUS software to include material test details and precise modeling of structural members. This can lead to prepare verified models for increasing dataset of ML models. All shop drawing is prepared in detail considering the dimensional analysis to improve the results of analysis to those real-world buildings. The dimensional analysis has been applied to all characteristics to consider their effects on the results of experiments. The reason behind choosing this scale is the size of the shaking table in institute and reducing the effects of unwanted variables and boundary conditions. By selecting an appropriate scale, it ensures that the experimental setup is manageable within the constraints of the shaking table while maintaining the fidelity of the model. This approach helps in achieving accurate and reliable data that can be effectively translated to real-world scenarios. Then, the provided experimental structures have been tested on shaking table to monitor the seismic behavior of structures and record the seismic demands for each floor levels. It is noteworthy that due to limitation of performing this kind of analysis, all methodologies on this research area have been performed on experimental scaled specimens.

5-2- Construction of structural elements

Following the meticulous design phase, the construction stage focuses on correctly prepare details of drawing shop, which should be fitted in assembling of structures. The study conducts experimental validation on 4 steel structures with one or two bays to provide a wide range of data points for ML model. Therefore, in total, 8 steel structures will be assembled and tested for two rigidity conditions and seven records. It is estimated that these structures can be ready for construction according to shop drawing by one month. Since there will be no possibility of using predefined sections, all elements are considered as plate girder and constructed in company. Each floor levels have a typical beam section to avoid any workforce mistakes during assembling, and columns of structures have been typically designed according to the results of designed structures in ETABS software and dimensional analysis of ABAQUS software. Attention is given to ensuring the accuracy and precision of construction, adhering strictly to the design specifications set forth during the planning phase, while structural elements will be constructed by two months. Therefore, the assembling and testing of those cases will be started within three months of starting the project. Since pre-testing and checking the accuracy of the results are the most important task, we will devote two weeks for this matter and then start to assembling the case studies. After preparing elements, it will be possible to assemble them in different aforementioned cases to fulfill the required number of structures. The bolt connections are designed to fulfill the code requirements and the need of design loads; therefore, it is possible to use undamaged sections and only replace those demolished structural elements. However, in preliminary evaluation, it is revealed that the connections are mostly damaged during the experimental test, then, the number of connections were increased during the construction. For finalizing experimental tests of structures, three months are considered, while during these period, data processing and data preparation will be done. After finishing the experimental tests, dataset will be used for DL methods and proper algorithms will be tested to achieve the highest accuracy of prediction. It should be noted that in this stage of the work, data management, verification of numerical model and preparing the report and manuscript will be carried out in parallel activity during five months, and the last two weeks are devoted to uploading the data on the repository website.

5-3- Shaking table experiment setup

Upon completion of construction, the assembled steel structures are positioned on a seismic shaking table having dimension of 1.8 m and equipped to 20 kN actuator to perform seismic loads using a high-tech Rigol DG4062 waveform generator. This setup aims to simulate seismic loading akin to real seismic events. By utilizing seismic records, the experiment replicates the dynamic movements and forces experienced during seismic activities. Different types of seismic records with varying intensity measures will be applied to generate a wide range of data outputs. This comprehensive approach ensures that the experimental results capture the diverse responses of the structures under various seismic conditions, providing valuable insights for improving earthquake resilience. To monitor and collect data during the experiments, an array of advanced measurement devices is deployed, including strain gauges, accelerometers, displacement recorders, and a Quantum MX840B monitoring device. Strain gauges are attached to critical points on the steel structures to measure the strain and stress experienced during loading. At each floor level, accelerometers and displacement recorders will attach to record those responses to be converted to scalograms. It should be noted that these recorders are available in the laboratory and their accuracy have been tested. The team members have a good experience on experimental tests and working equipment and can assemble those recorders to the structures which can reduce the extra cost implemented to work and increase the speed of the preparing test setup.

5-4- Connection rigidity

To ascertain the impact of joint conditions on structural integrity, variations in connection rigidity are introduced. Specifically, two distinct joint conditions, categorized as rigid and semi-rigid connections, are established within the structures. Different industrial used connections are modeled in ABAQUS software (see Fig. 6) to determine their rigidity and then to be defined for structures. Therefore, different cases of steel structures having defects in their connections will be studied, which the defects are introduced based on the preliminary assessment of numerical models in ABAQUS software. This strategic variation seeks to investigate the differential responses of structures to lateral loading based on joint conditions. The idea of this research is to propose a prediction model based on DL method (i.e., CNNs) and CWT to find the damages and the thresholds of damage in connections of steel structures. This can widely help structural engineers to health monitoring of steel structures using the results of recorders, as well as the results of experimental tests can be used to validate the accuracy of the numerical model for preparing a user interface tool for industrial prospects.

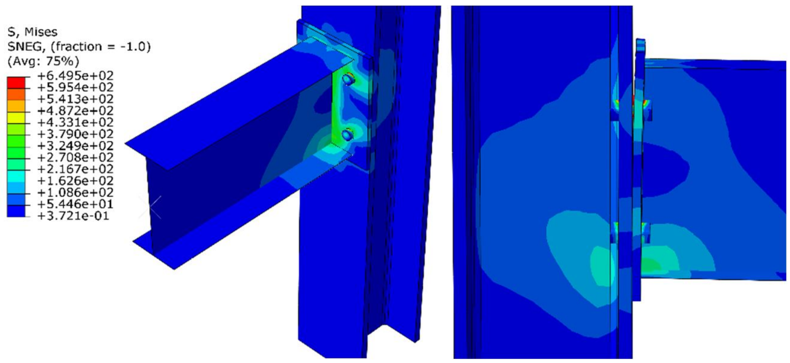

Fig. 6. Modeling of steel connections in ABAQUS software and investigating the effects of semi-rigid connection.

5-5- Data collection during seismic loading

Throughout the seismic loading process, comprehensive data collection mechanisms are employed. These mechanisms entail recording floor-level accelerations and displacements across the structures, capturing critical data on the structural response, and monitoring the behavior of the connections. Additionally, seismic intensity measures are meticulously recorded, providing in-depth insights into the dynamic behavior of the structures under varying seismic conditions. In addition, those considered structures are tested on different types of seismic records to ensure the effects of seismic loads on the behavior of structures. Accelerometers are strategically placed on the structure to measure the acceleration at various points during the seismic loads. These devices provide real-time data on the dynamic response of the structure, capturing how different parts of the structure move in response to seismic loads. The data from accelerometers are crucial for understanding the distribution of forces and for identifying potential weak points in the structure and converting them to scalograms. Displacement recorders are used to measure the relative displacement between different floor levels of the structure. These recorders can track both the horizontal and vertical movements, providing a comprehensive picture of how the structure deforms. The displacement data help in assessing the overall stability and integrity of the structure under seismic loading. The Quantum MX840B device is employed to enhance the precision and reliability of data collection. This device can monitor multiple parameters simultaneously with high accuracy. It can integrate data from gauges, accelerometers, and displacement recorders, providing a synchronized and comprehensive dataset. The Quantum MX840B device can also process data in real-time, enabling immediate analysis and adjustments during the experiments. The results from all the measurement devices are collected in digital form, allowing for detailed analysis. The data collection process involves real-time monitoring, where all devices continuously record data during the seismic simulations, ensuring that transient phenomena and peak responses are accurately captured. The recorded data are logged into a central data acquisition system, which stores the data in a structured format, making it easy to retrieve and analyze. After the experiments, the data are processed to remove noise and to calibrate the measurements. Advanced software tools are used to analyze the data, generating graphs and charts that illustrate the structure's response to different seismic loads. It is noteworthy that the PI is the responsible for managing, dissemination and implementation of projects outcomes. Mr. Farzin Kazemi can control the data recorders results and prepare them for next step.

5-6- Wavelet analysis for Scalogram generation

The fast Fourier transform (FFT) is a mathematical algorithm that transforms time-domain data into its frequency-domain representation. This powerful tool is widely employed in signal processing to analyze both periodic and non-periodic signals. By applying FFT to the experimental data, one can obtain a frequency-domain representation that reveals key information about the structural response to seismic loading. Specifically, this analysis allows for the identification of prominent frequencies, amplitude levels, and their distribution across the frequency spectrum. Such insights are crucial for understanding the dynamic behavior of the structure under seismic stress and for identifying potential resonant frequencies that may pose risks during actual seismic events. In addition to FFT, the experimental setup incorporates the utilization of the wavelet platform to generate scalograms from the collected dataset. These scalograms provide a visual representation of the structural responses captured during seismic loading. Wavelet analysis is particularly advantageous as it transforms the dataset into a comprehensive array of scalograms, offering detailed insights into the time-frequency characteristics of the structural vibrations. Unlike FFT, which provides a global view of frequency content, wavelet analysis captures both the time and frequency aspects of the signal, making it possible to observe how the frequency content of the structural response evolves over time under varying seismic conditions. This dual approach, combining FFT and wavelet analysis, ensures a thorough understanding of the structural dynamics and enhances the ability to design more resilient structures capable of withstanding seismic events. By providing the scalograms of seismic responses, the dataset can be prepared and interpreted for use in ML models. Scalograms, which are visual representations of the time-frequency characteristics of the structural responses, captured during seismic loading, offer detailed insights into how the structure behaves under different seismic conditions. These scalograms can be transformed into a comprehensive dataset, capturing the intricate patterns and variations in the structural vibrations. The prepared dataset serves as a rich source of information for training and validating ML models. By interpreting the scalograms, key features and patterns indicative of structural performance and potential vulnerabilities can be extracted. ML models can then be trained on this dataset to recognize these patterns, predict future structural responses, and even identify early warning signs of structural failure under seismic stress. This approach considers the detailed, high-resolution data provided by the scalograms, ensuring that the ML models are well informed and capable of making accurate predictions, thereby, enhancing the overall understanding and resilience of the structures being studied. This section can be done in a joint work between team members leading by Prof. (Associate) Benyamin Mohebi.

5-7- Implementation of CNNs and DL techniques

In this section, advanced ML techniques, particularly CNNs and DL methodologies, are employed for the prediction of structural connection defects and to improve a prediction model for this purpose. Leveraging the generated scalograms as input data, the proposed ML model undergoes training and testing phases. Through the utilization of CNNs and DL algorithms, the model is trained to accurately predict and classify the rigidity levels of structural connections based on the visual features extracted from the scalograms. The general objective can be ensured through the achievement of the following objectives:

i. Experimental test using shaking table test can provide a wide range of data to be used for validating the numerical models that can be beneficial for having a model with real behavior. Therefore, it is possible to improve the datasets by numerical models that have been verified by experimental tests. In addition, this can increase the validity of numerical modeling and help structural designers to better understand the rigidity of connections.

ii. More data and numerical analyses are needed to create a powerful prediction model. According to literature, the algorithm created so far was based on numerical analysis and only was tested by limited number of structures. Meanwhile, the accurate modeling and modeling validation is not clearly investigated. However, in this research, case study structures have been experimentally tested subjected to a wide range of seismic records applied to shaking table and it is possible to increase this credibility by adding numerical models. This can provide a wide range of dataset based on the experimental and numerical datasets to improve the CNNs, CWT and ML-based model and prediction results. The provided ML model has been tested with an experimental test, demonstrating the effectiveness of the proposed approach in detecting and confirming beam-column connection damage within the test structure. Finally, the results can be reported as a preliminary prediction tool for constructional companies to be used for different purposes.

iii. At this stage, the aim of the activities is to create a procedure to be followed in the case of building analysis in terms of the influence of connection rigidities on the seismic behavior of steel structures. It is planned to create user-friendly tool such as graphical user interface for decision makers to assess the SHM of buildings and propose proper retrofitting scheme. The design of the system will allow for the analysis of the effectiveness of forecasting the impact of seismic loads on buildings using the ideas of CNNs, CWT, ML, and DL algorithms, and then to make correct operating decisions allowing to find the damaged connections and retrofit them. Therefore, the research project's objective is to demonstrate the possibility of using AI to create a prediction model based on the experimental test data for assessing structural damages of connections of steel structures on the comfort of using buildings and creating a procedure for newly built structures to check the defects of connections. This tool can reduce the computational and modeling time while improves the accuracy of damage identification.

iv. The combination of CWT-based signal processing with CNNs represents a novel integration aimed at addressing real-world challenges like noise sensitivity and varying environmental conditions. While sensitivity to noise and input covariance is acknowledged in the literature, this project addresses these challenges by incorporating denoising strategies and robust feature extraction within the ML pipeline. The training and validation procedures for CNNs will be detailed, including strategies for addressing noise sensitivity and generalizability. CNNs can identify and learn patterns from large datasets, which is more efficient than manually selecting features. The project tests how well the model performs under different conditions, like noise or input variability, by using methods such as adding diverse data, transferring knowledge from other tasks, and training the model to handle challenging scenarios to make it more reliable.

v. The scalograms can be generated by monitoring devices embedded in structures and infrastructures. These tools are invaluable for analyzing dynamic responses and identifying potential damages in real-world scenarios. However, this method can be tested on other types of loadings such as sinusoidal waveforms to assess the scalability and adaptability of the approach, explore characteristic patterns in the data, and identify optimal parameters for various applications. This controlled testing serves as a foundation for enhancing real-world monitoring strategies and improving damage detection methods.

5-8- Retrofitting scheme using shape memory alloy bolts

By preparing the ML-based prediction model, it is aimed to propose a retrofitting scheme using SMA bolts to improve the capability of the connections of steel structures. The aim is to numerically test the ability of the SMA bolts, which are produced in Poland industry, for reducing the residual drift of structures after seismic loads; therefore, a detailed discussion is prepared to how implement those bolts and the effects of them for retrofitting. Fig. 7 provides validation of SMA material using ABAQUS software. The validation of other steel materials is done to provide detailed modeling of structures in ABAQUS software. This procedure can be extended by numerically validated models to be used for improving connections defects. In the future, after thorough refinement and verification in terms of credibility of the prediction model, it is planned to extend the scope of research to other operational problems of buildings. Since the database of ML-based model can be updated by adding more data points, the proposed model can be used in future based on the newly added datasets and can be extended to more structural defects, which will be the aim of PI and research team to be explored. The ML-based predictions can modify the models in engineering software (i.e., ETABS and ABAQUS) and provide a considerable benefit for industry to use the results of this study and providing SMA bolts effects on the response of structures. This can hinder the industry-university cooperation and increase the horizons of this research for future.

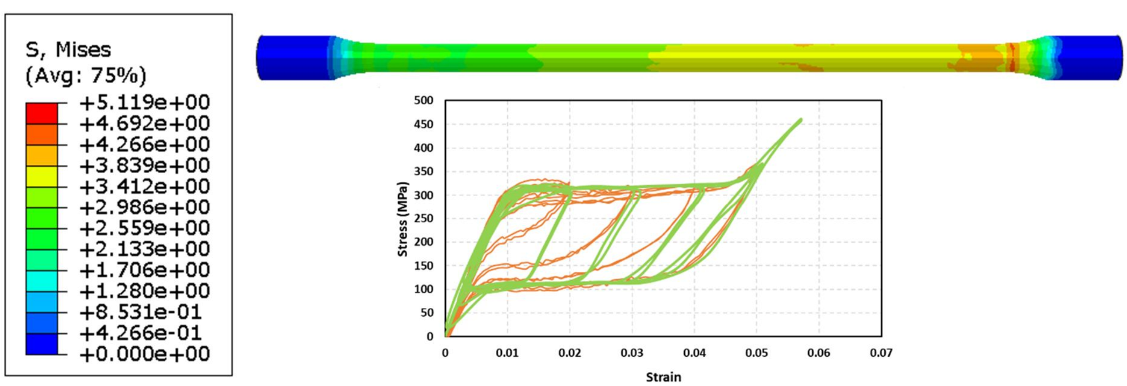

Fig. 7. Verifying the SMA material with experimental test [32] using ABAQUS software.

6- Research team

All team members are collaborated in design process, experimental tests, and numerical modeling to use their unique experience during the project for reducing the likelihood of engineering defects and improve the reliability of results. Prof. Robert Jankowski will monitor the details of structures, methodology of the damage detection, and will be present during the shaking table tests. Prof. (Associate) Benyamin Mohebi extensive work on wavelet transform-based damage detection provides a foundation to rigorously test and refine the proposed CWT-based indicators, then, ensures alignment with industry needs and enhances the translational potential of the research (see examples in [22-25]). Their professional experience can lead to have a precise experimental test and avoid any mistakes during the tests. In addition, we will use the programming ability of mgr. Farzin Kazemi and mgr. Neda Asgarkhani to implement the methodology in ML algorithms (see examples in [13-18, 32-34]). Moreover, the PI is also will work on project management and programming code align with experimental tests. However, the PI is the responsible for managing, dissemination and implementation of projects outcomes.

7- Risk analysis of project

Risk analysis is a systematic process designed to identify, assess, and mitigate potential threats and uncertainties that may impact the successful outcome of a project. In the context of this project, a comprehensive risk analysis methodology has been established to evaluate various dimensions of potential challenges and vulnerabilities. Initially, the risk analysis begins with a preliminary study involving several techniques such as SWOT (Strengths, Weaknesses, Opportunities, and Threats), PHA (Preliminary Hazard Analysis) (presented in Fig. 8), and a 5-step analysis. These methods serve as foundational tools to comprehensively assess the project landscape. SWOT analysis helps in identifying internal strengths and weaknesses along with external opportunities and threats, offering a broad perspective on the project's positioning. PHA aids in identifying potential hazards and risks at an early stage. The 5-step analysis further refines the understanding of potential risks by systematically breaking down the elements and processes of the project. In the context of risk analysis, the focus primarily lies on the probability and potential impact of negative events or failures that could hinder project success.

STRENGHTS • experience • expert knowledge • partially constructed database • a well-developed and detailed program of activities	**WEAKNESSES** • inconsistent results • too few results • low reliability of the algorithm • structural defects in analysis
OPPORTUNITIES • the possibility of building a professional research team • highly scored publications • patent application • long-term scientific development • establishing new cooperation	**THREATS** • no participants in the project • no data • no liquid financing • the impact of the pandemic • the impact of the war • problems with publication • problems with conferences

Fig. 8. Architecture of SWOT Analysis.

Understanding the uncertainties and their potential consequences is crucial for effective risk management. Risk, in this context, is predominantly associated with adverse outcomes rather than positive events. For this project, risk analysis involves multifaceted approaches to manage uncertainties effectively. It encompasses the identification of potential risks, qualitative and quantitative assessments of their likelihood and impact, and the development of risk mitigation strategies. These strategies may include risk avoidance, risk reduction, risk transfer, or risk acceptance, depending on the nature and severity of identified risks. Additionally, risk analysis in project management involves continuous monitoring and reassessment throughout the project lifecycle. A dynamic process adapts to changes new insights and evolving circumstances. Regular risk reviews, updates to risk registers, and scenario planning are essential components to ensure that risk management remains responsive and effective. The analysis aims not only to foresee potential pitfalls but also to enable proactive measures to mitigate and manage risks effectively, thereby enhancing the project's chances of success.

7-1- Risk management stages

Risk management involves several stages that collectively enable organizations to identify, assess, mitigate, and monitor risks throughout the project lifecycle. These stages provide a structured framework for addressing potential uncertainties and minimizing their impact on the project's objectives.

1- Risk Identification

This stage involves systematically recognizing and cataloging potential risks that could affect the project. It includes techniques like brainstorming, documentation review, SWOT analysis, and expert interviews to identify various types of risks - from financial and technical to operational and environmental.

2- Risk Assessment

Once risks are identified, they need to be evaluated based on their likelihood of occurrence and potential impact on the project. Quantitative and qualitative methods are used to assess risks, assigning probabilities and consequences. This stage often involves risk matrices, probability-impact grids, or risk scoring systems.

3- Risk Mitigation Planning

After assessing risks, strategies are developed to minimize or eliminate their impact. This stage focuses on designing action plans to reduce the probability or severity of identified risks. Strategies might include risk avoidance, risk transfer, risk reduction, or acceptance. It also involves setting up contingency plans to manage unforeseen events.

4- Risk Monitoring and Control

Risk management is an ongoing process. This stage involves actively tracking identified risks, monitoring their status, and ensuring that implemented mitigation strategies are effective. Regular reviews, progress checks, and adjustments to risk management plans are made to accommodate changing circumstances.

5- Risk Communication and Reporting

Effective communication of risks and their potential impacts is crucial for stakeholders' understanding and decision-making. This stage involves sharing risk information, reporting progress on risk mitigation, and ensuring that stakeholders are aware of the potential risks and the steps taken to address them.

6- Continuous Improvement

Risk management doesn’t end with the identification and mitigation of risks. Organizations continuously evaluate and learn from their risk management processes. Lessons learned from previous projects or incidents are used to improve future risk management strategies and approaches.

These stages are iterative and often occur in parallel, ensuring that risks are continually identified, assessed, addressed, and monitored throughout the project's lifecycle. Effective risk management requires a proactive approach and regular reviews to adapt to evolving project conditions and external factors.

7-2- Preliminary hazard analysis

PHA is a fundamental method used to assess risk by evaluating the probability and severity of potential failures or hazards. It employs a matrix-based approach that quantifies the likelihood of failure (P) on a scale of 1 to 6 and the severity of its consequences (S) on the same scale. The analysis calculates the risk score (R) by multiplying the probability (P) and severity (S) scores together. The resulting value determines the risk level associated with the identified hazard. The classification of risk levels based on the calculated value (R) is as follows:

- *Acceptable Risk (R = 1 - 3):* Risks falling within this range are considered acceptable, signifying a lower probability of occurrence or minimal consequences. They usually require routine monitoring and minor control measures.
- *Acceptable Risk after Thorough Assessment (R = 4 - 9):* Risks in this range indicate a moderate level of risk that might need further examination or assessment to ensure their acceptability. They could require additional mitigation strategies or periodic monitoring.

- *Unacceptable Risk, Requires Reduction (R = 10 - 36):* Risks categorized in this range are deemed unacceptable due to higher probability or severe consequences. These hazards demand immediate attention and substantial measures to reduce their probability of occurrence or minimize their impact.

The PHA method provides a straightforward yet effective means to initially assess risks associated with potential failures or hazards, aiding in the prioritization of mitigation efforts and risk management strategies.

7-3- Result of risk analysis

The risks are evaluated using a probability (P) and severity (S) scale, and their combined score (R) determines the risk level. The effective factors have been considered as follows:

External Factors:

- No Participants in the Project (P=3, S=2, R=6): Indicates a moderate probability (P=3) of having no participants in the project with moderate consequences (S=2), resulting in a moderate risk score (R=6).
- No Data (P=2, S=3, R=6): Represents a lower probability (P=2) but higher severity (S=3), yielding an equivalent risk score (R=6).
- No Liquid Financing (P=1, S=5, R=5): Indicates a low probability (P=1) but severe consequences (S=5), resulting in a significant risk score (R=5).
- Impact of the Pandemic: Description without specific probability or severity rating.
- Problems with Publication (P=2, S=3, R=6): Moderate probability (P=2) and severity (S=3), culminating in a moderate risk score (R=6).
- Problems with Conferences (P=4, S=1, R=4): Higher probability (P=4) but lower severity (S=1), leading to a moderate risk score (R=4).
- Impact of the War (P=2, S=3, R=6): Like problems with publication, exhibiting moderate probability (P=2) and severity (S=3), resulting in a moderate risk score (R=6).

Internal Factors:

- Inconsistent Results (P=1, S=3, R=3): Low probability (P=1) and moderate severity (S=3), resulting in a low-risk score (R=3).
- Too Few Results (P=2, S=2, R=4): Moderate probability (P=2) and severity (S=2), leading to a moderate risk score (R=4).
- Low Reliability of the Algorithm (P=2, S=2, R=4): Similar to too few results, showing moderate probability (P=2) and severity (S=2), resulting in a moderate risk score (R=4).

The description provides a matrix summarizing the probability and severity of each identified risk, aiding in the evaluation and categorization of risks based on their potential impact and likelihood of occurrence.

7-4- Five step methodology

1- Identification of Threats: The following threats were identified:

- No Participants in the Project
- No Data
- No Liquid Financing
- Impact of the Pandemic
- Problems with Publication
- Problems with Conferences
- Impact of the War
- Too Few Results
- Low Reliability of the Algorithm

2- Determining Who May Be at Risk and How: The project manager and their research team are at risk. Failure to achieve project goals might lead to the loss of research funding, thereby preventing the implementation of the grant.

3- Occupational Risk Assessment Based on Registered Threats: Risk assessment involves using the following formula:

R = S x E x P x L [-]

Represents the risk level on a 4-point scale:

- 0-5: Negligible Risk
- 5-50: Low but Significant Risk
- 50-500: High Risk
- 500-~: unacceptable risk

S - The degree of damage generated by a given type of threat, from 0.1 (very small, negligible damage) to 15 (huge damage)
E - The degree of exposure to a given type of hazard, from 0.5 (once a year) to 15 (permanent)
P - The degree of probability of the occurrence of damage caused by a given type of threat, from 0.033 (impossible) to 15 (certain)
L - The degree of the number of people exposed to the damage generated by a given threat, from 1 (1-2 people) to 15 (over 15 people)
4- In the fourth step, the analysis revealed that no factor surpasses the acceptable risk threshold (R < 5). Thus, it affirms the earlier conclusion that there are not any factors posing a significant threat to the project's implementation.
5- For the fifth step, ongoing risk control becomes crucial throughout the project execution to mitigate the impact of identified potential threats on the grant. Regular monitoring and preemptive measures should be implemented to minimize any adverse effects.
This assessment helps in categorizing risks based on their severity, exposure, probability, and potential loss, providing a scale to evaluate their significance and necessary mitigation strategies.

7-5- Assessment of risk analysis for current study

Based on the analysis conducted, the risk associated with the project is deemed to be sufficiently low. Therefore, the decision is to proceed with the project without hesitation. No specific risk mitigation strategies or actions are deemed necessary as the identified risks fall within an acceptable range, warranting the continuation of the project as planned.

Table 1. Risk analysis of conducting experimental test.

Risk Event	Probability	Impact	Mitigation Measures
Equipment Failure	Medium	High	Regular maintenance and inspection of equipment. Backup equipment.
Sensor Malfunction	Low	Medium	Calibrate sensors before the test. Monitor sensor performance.
Data Loss or Corruption	Low	Medium	Implement data backup procedures. Data validation and redundancy.
Structural Failure	Low	High	Conduct thorough structural assessment before the test.
Safety Hazards	Medium	High	Implement strict safety protocols and provide safety training.
Inaccurate Measurements	Medium	Medium	Calibrate instruments properly. Cross-check measurements.
Human Error	Medium	Medium	Provide clear instructions and training to the research team.
Delays in Material Supply	Low	Low	Plan for adequate material inventory. Establish alternative sources.
Environmental Factors	Medium	Low	Monitor and control environmental conditions during the test.
Budget Overrun	Low	High	Develop a detailed budget plan. Monitor expenses closely.
Experience of the research team	High	High	The research team will be selected based on the various experience in a different field of research - this guarantees a quick response to any problems that may arise.
Prolonged research in the laboratory	Low	Low	In the case of a significant delay, it is possible to change the order of the stages of project implementation
Increase of steel price	Medium	High	In case of a significant increase in steel prices, it is planned to cover the increased costs from the proposal author's salary.

8- References

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ABSTRACT FOR THE GENERAL PUBLIC

[in Polish and in English]

Project summary (PL):

Badania dotyczą innowacyjnych metod oceny uszkodzeń połączeń w niskich konstrukcjach stalowych z wykorzystaniem algorytmów uczenia maszynowego (ML) i testów eksperymentalnych. Metody te łączą zastosowanie splotowych sieci neuronowych (CNN) i ciągłej transformaty falkowej (CWT) z globalnymi pomiarami drgań pochodzącymi od wzbudzenia sejsmicznego (wykorzystując różne zapisy sejsmiczne dla różnych poziomów intensywności) w celu oceny stanu połączeń w konstrukcjach stalowych. Badania obejmują szczegółowe badania eksperymentalne i metodologiczne połączeń sztywnych i półsztywnych dla różnych poziomów odpowiedzi konstrukcji wzbudzanych do drgań za pomocą stołu wstrząsowego. Pomiar przyspieszeń drgań na poziomie różnych kondygnacji, odpowiedź konstrukcji jak i praca połączeń przy różnych odziaływaniach sejsmicznych może dostarczyć szerokiego zakresu danych dla algorytmów ML. Następnie, poprzez wstępne przetwarzanie danych i wykorzystanie analizy falkowej do przekształcenia zebranych danych w skalogramy, uzyskuje się szczegółowy obraz drgań konstrukcji w dziedzinie czasu i częstotliwości. Wykorzystując zaawansowane techniki ML (w szczególności CNN i algorytmy głębokiego uczenia się) do przewidywania i klasyfikowania sztywności połączeń konstrukcji w oparciu o cechy wizualne wyodrębnione ze skalogramów uzyskanych podczas obciążeń sejsmicznych, możliwe jest stworzenie zbioru danych opartego na obrazach dla CNN, który może pomóc w zdiagnozowaniu uszkodzeń w połączeniach konstrukcji. Ponadto, celem projektu jest zaproponowanie sposobu wzmacniania połączeń konstrukcji stalowych przy użyciu śrub wykonanych z materiału z pamięcią kształtu (SMA), w celu poprawy ich nośności. Celem badań eksperymentalnych będzie określenie zdolności śrub SMA do redukcji przemieszczeń konstrukcji poddanej wymuszeniom sejsmicznym, dlatego przygotowana zostanie szczegółowa procedura dotycząca sposobu zastosowania tych śrub i ich wpływu na wzmacnianie. Proponowana metodologia zapewnia podstawy do monitorowania stanu konstrukcji, szczególnie ukierunkowane na identyfikację i diagnozowanie uszkodzeń w połączeniach konstrukcji stalowych oraz ich sztywności. Wyniki przeprowadzonych badań eksperymentalnych konstrukcji stalowych z różnymi uszkodzeniami połączeń i zróżnicowanymi warunkami obciążenia sejsmicznego pokazują skuteczność zastosowanego podejścia do dokładnego wykrywania i klasyfikowania uszkodzeń w stalowych połączeniach konstrukcyjnych. Ponieważ baza danych modelu opartego na ML może być aktualizowana poprzez dodawanie kolejnych danych, proponowany model może być używany w przyszłości na podstawie nowo dodanych zbiorów danych i może być rozszerzony na więcej uszkodzeń konstrukcyjnych.

Project summary (EN):

The study focuses on innovative approaches for assessing damage in connections of low-rise steel structures using experimental tests and innovative machine learning (ML) algorithms. It combines convolutional neural networks (CNNs) and continuous wavelet transform (CWT) with global vibration signals from seismic excitation (employing different seismic records for varied intensity measures) to evaluate steel structural connection health conditions. The research encompasses comprehensive experimental and methodological frameworks by creating rigid and semi-rigid connections to analyze structural responses under different conditions using the shaking table test. Recording floor-level accelerations, structural responses, and connection behavior under various seismic conditions can provide a wide range of data for ML algorithms. Then, by preprocessing the data and utilizing wavelet analysis to transform collected data into scalograms, detailed time-frequency insights into structural vibrations are provided. Using advanced ML techniques (particularly CNNs and deep learning (DL) algorithms) to predict and classify structural connection rigidity based on visual features extracted from the scalograms obtained during seismic loading, it is possible to provide an image-based dataset for CNNs, which can help to recognize the defects of connections. Moreover, it aims to propose a retrofitting scheme using shape memory alloys (SMA) bolts to improve the capability of the connections of steel structures. The aim is use the ability of the SMA bolts for reducing the residual drift of structures after seismic loads, therefore, a detailed discussion is prepared as to how to implement those bolts and the effects of them for retrofitting. The CWT provides a thorough analysis of the response signals across various frequency bands, enabling the detection of both localized and distributed damage. This dual approach ensures high accuracy in identifying the location of damaged connections, which is crucial for effective intervention and maintaining the structural safety of the building. The proposed methodology provides a robust framework for structural health monitoring (SHM), specifically targeting the damage identification of steel connections and prediction of current rigidity. The experimental validation on various steel structures with different connection defects and seismic loading conditions demonstrates the efficacy of the approach for accurately detecting and classifying damage in structural connections. The ML-based predictions can modify the models in engineering software (i.e., ETABS and ABAQUS) and provide a considerable benefit for the industry to use the results of this study. Since the database of the ML-based model can be updated by adding more data points, the proposed model can be used in the future based on the newly added datasets and can be extended to more structural defects, which will be the aim of PI to be explored.

ETHICAL ISSUES

1. Studies on human embryos or human embryonic and fetal tissue	
Does your research involve the use of human embryos?	NO
Does your research involve the use of human embryonic or fetal tissues/cells?	NO
Does your research involve Human Embryonic Stem Cells (hESCs)?	NO
2. Humans	
Does your research involve human participants?	NO
Does your research involve physical or psychological interventions on the study participants?	NO
Does your research involve processing of genetic information?	NO
Is your research considered as medical experiment under the Act of 5 December 1996, the professions of doctor and dentist?	NO
Does the proposed resarch include applicable non-commercial clinical trial that must be registered in Central Register of Clinical Trials (https://www.clinicaltrialsregister.eu/) under the Act of 6 September 2001 (as amended) Pharmaceutical Law or the Act of 20 May 2010 (as amended) on medical devices?	NO
3. Human cells/tissues	
Does your research involve human cells or tissues (other than from Human Embryos, i.e. section 1) commercially available?	NO
Does your research involve human cells or tissues obtained within the project or from another project, laboratory or institution (non-commmercial)?	NO
4. Personal data	
Does your research involve personal data processing?	NO
Does your research involve further processing of personal data (secondary use) from other sources outside the research entity?	NO
5. Animals	
Does your research involve vertebrate animals or cephalopods?	NO
Does your research involve the use of animal biological specimens (e.g. blood, urine or others)?	NO
Does your research involve animal cells or tissues commercially available?	NO
6. Scientific collaboration with countries outside the European Union	
In case non-EU countries are involved, do the research-related activities undertaken in these countries raise potential ethics issues?	NO
Do you plan to use local human, cultural or natural resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	NO
Do you plan to import or export any material from non-EU countries into the EU?	NO
If your research involves low and/or lower middle income countries, are benefits-sharing measures foreseen?	NO
Could the situation in the country put the individuals taking part in the research at risk?	NO
7. Environment, Health and Safety (including genetically modified material)	

Does your research involve the use of organisms and microorganisms, tissues or cells genetically modified (GMO, GMM)?	NO
Does your research deal with endangered fauna and/or flora and/or protected areas?	NO
Does your research involve the use of elements that may cause harm to humans, including research staff?	NO
8. Cultural heritage	
Does the research involve the usage of cultural heritage resources, such as humans, flora, fauna, their material remains, tangible and intangible cultural achievements or sites protected due to their cultural value?	NO
9. Abuse and dual use	
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	NO
Does your research output have the potential for malevolent/criminal/terrorist abuse?	NO

Description of the measures taken to ensure that the research will be carried out in compliance with the rules of good scientific practice in the given field/discipline. Information on any permissions already issued or description of how the relevant requirements will be fulfilled [in English]

Declaration	
I hereby declare that: - if any approvals, opinions or permits of competent authorities/committees are required for the research, I shall obtain them beforehand; - I am aware of my obligation to provide the NCN with the approvals, opinions and permits required for the project with the annual and final reports; - I am also aware that if a research project is carried out without the required approvals, opinions and permits, there is a possibility that it will not be settled and the funds will have to be returned in their entirety or in part.	YES

RESEARCH TASKS [in Polish and in English]

No.	Name of the research task	Entities
1	Modelowanie konstrukcji z wykorzystaniem oprogramowania ETABS Modelling of structures using ETABS software	• Gdansk University of Technology
2	Opracowanie elementów konstrukcyjnych oraz ich konstruowanie Development drawing shop of the structural elements and constructing the structural elements	• Gdansk University of Technology
3	Wdrożenie sprzętu rejestrującego dane i wykonanie testu sprawdzającego w celu sprawdzenia całkowitego stanu Implementing the data recording equipment and performing checking test for controlling total condition	• Gdansk University of Technology
4	Weryfikacja czujników i rejestratorów danych Verifying the sensors and data recorders	• Gdansk University of Technology
5	Wykonywanie właściwych testów eksperymentalnych Performing experimental tests	• Gdansk University of Technology
6	Analiza wyników Analysis of the results	• Gdansk University of Technology

7	Przygotowanie zbioru danych dla algorytmów uczenia maszynowego Preparing dataset for machine learning algorithms	• Gdansk University of Technology
8	Implementacja transformacji falkowej w celu utworzenia skalogramów ze zbioru danych Implementing wavelet transform to create scalograms from dataset	• Gdansk University of Technology
9	Weryfikacja wyników uczenia i testowania zbiorów danych Verifying results of training and testing datasets	• Gdansk University of Technology
10	Zaproponowanie modelu predykcyjnego opartego na uczeniu maszynowym do szacowania reakcji sejsmicznych Proposing machine learning-based prediction model for estimating seismic responses	• Gdansk University of Technology
11	Badanie metody retrofitu na uszkodzonej konstrukcji Testing retrofitting method on damaged structure	• Gdansk University of Technology

SIMILAR RESEARCH TASKS

Is the PI applying for funding of the research tasks included in this proposal also from other sources?	NO
Is the PI currently working on or has he/she completed research tasks similar to the tasks included in this proposal?	NO
PI is	THE AUTHOR OF THE PROJECT DESCRIPTIONS

Entities

Gdansk University of Technology	
Is the entity applying for funding of the research tasks included in this proposal also from other sources?	NO

INTERNATIONAL COOPERATION

Is the project carried out as international cooperation?	YES
Countries	• Iran (Islamic Republic of)

Foreign research institutions - Iran (Islamic Republic of)

No.	Entity
1	Imam Khomeini International University

Description of advantages of international cooperation [in English]
International cooperation with the esteemed Professor (Associate) Benyamin Mohebi, affiliated with the Faculty of Engineering and Technology, Imam Khomeini International University, Qazvin, Iran, offers significant benefits for the application. He has professional research experience on damage index in RC structures, École Polytechnique Fédérale de Lausanne (EPFL University, IMAC), Lausanne, Switzerland. June-November 2010. He is involved in many international research projects, most of which have been published as papers. In addition, he is a famous structural designer in the seismic-prone areas, and he has done numerous retrofitting projects that will help the research team with his experience. This collaboration provides access to a wealth of knowledge and expertise in earthquake engineering, particularly in the context of wavelet transform techniques, which are crucial for analyzing and interpreting seismic data. His experience in wavelet transform can greatly enhance the programming aspects of the project, ensuring precise and effective data processing and analysis. Moreover, having two papers with him in the field of wavelet-based damage-sensitive features can bring more benefit for the research team. His involvement in the consultant process of the experimental tests will provide invaluable insights and guidance, fostering a more robust and comprehensive understanding of the seismic behavior of buildings. Moreover, this partnership facilitates a cross-cultural exchange of innovative methodologies and best practices, contributing to the advancement of seismic research and the development of more resilient structural designs. The international cooperation underscores a commitment to global scientific collaboration, aiming to improve safety standards and mitigate the risks associated with seismic activities worldwide.

RESEARCH TEAM

1. Neda Asgarkhani, PI	
Entity	Gdansk University of Technology
Scope of work [in English]	Project manager Design and constructional of structures Methodology and investigation Machine learning methods Data managment Writing and preparing the paper

2. Robert Jankowski, Mentor	
Entity	Gdansk University of Technology
Scope of work [in English]	Supervisor Methodology Writing, reviewing, and editing the application and manuscript

3. Wykonawca_1, Co-Investigator	
Entity	Gdansk University of Technology
Scope of work [in English]	Designing the models Assembling the frames Working with operating devices Seismic performance control Implementing monitoring devices Controlling the shaking table test Application of actuator and loading protocol Software engineering Programming code and machine learning method Implementing CWT and CNNs methods
Required professional qualifications [in English]	Farzin Kazemi is currently a four-year PhD student in Earthquake Engineering at Gdańsk University of Technology, Gdańsk, Poland. His academic interests focus on machine-learning prediction models, optimization algorithms, and the design and retrofitting of buildings. He is familiar with OpenSees, Abaqus, Python, and MATLAB, and has qualified skills in working with experimental devices, an experimental background to improve the accuracy of tests,and experimental ability for performing the shaking table tests. During his PhD program, he published 55 articles and conference papers, with collaborations from South Korea, the USA, New Zealand, Australia, Oman, Libya, the UK, Iraq, Türkiye, Iran, and Italy. He also experienced a six-month internship at University College London (UCL), London, UK, and another seven-month internship at the University of Naples “Federico II”, Naples, Italy. He started an internship program at the National Technical University of Athens (NTUA), Athens, Greece, for a period of eight months. Throughout his PhD program, he has been the recipient of multiple scholarships from Gdańsk University of Technology.

PI

mgr inż. Neda Asgarkhani	
Entity	Gdansk University of Technology

PhD	
Is the Principal Investigator a PhD holder?	NO
PhD student	
Does the Principal Investigator participate in a doctoral programme?	YES

Academic disciplines (according to the Classification of fields and disciplines of science and disciplines of the arts)		
No.	Code and name	Academic disciplines (according to the Classification of fields and disciplines of science and disciplines of the arts)
1	2.7 - civil engineering, geodesy and transport	Main scientific discipline

Personal data	
Name	Neda
Middle name	
Surname	Asgarkhani
PESEL	91102115745
Date of birth (yyyy-mm-dd)	1991-10-21
Gender	Female
Citizenship	Iran (Islamic Republic of)

Contact information	
Phone Number	880368346
Email	neda.asgarkhani@pg.edu.pl
Electronic delivery box ESP (ePUAP)	

Address	
Country	Poland
Voivodeship	pomorskie
Postcode	80-226
Town/City	Gdansk
Street, Street No., Apartment No.	Romualda Traugutta 115a

Address for correspondence	
Country	Poland
Voivodeship	pomorskie
Postcode	80-226
Town/City	Gdansk
Street, Street No., Apartment No.	Romualda Traugutta 115a

Employment	Not currently employed

MENTOR

prof. dr hab. inż. Robert Jankowski	
Entity	Gdansk University of Technology

Personal data	
Name	Robert
Middle name	
Surname	Jankowski
PESEL	68122601075
Date of birth (yyyy-mm-dd)	1968-12-26
Gender	Male
Citizenship	Poland

Contact information	
Email	robert.jankowski@pg.edu.pl

Researcher's electronic identifier	
Researcher's electronic identifier	0000-0002-6741-115X
Identifier's type	ORCID

Declaration by the PI Mentor	
File name	NCNMod_OSWIADCZENIA_OPIEKUNA_NAUKOWEGO_pl_osf-1.pdf

TEAM MEMBERS' SURVEYS [in English]

PRINCIPAL INVESTIGATOR
mgr inż. Neda Asgarkhani

ACADEMIC AND RESEARCH CAREER

Information on Education, Academic Degrees/Titles, and Employment

I am currently a PhD student in Earthquake Engineering at Gdańsk University of Technology, Gdańsk, Poland. My academic interests focus on seismic performance and risk assessment, machine-learning prediction models, and design and retrofitting of buildings. Throughout my coursework, I have built a strong foundation in engineering principles and design methodologies and have gained proficiency in software such as OpenSees, Abaqus, Python, and MATLAB. This academic background has equipped me with the skills necessary to advance in the field of earthquake engineering.

Research Stays at Home and Abroad

During my PhD program, I have engaged in research collaborations with prominent scientists from South Korea, the USA, New Zealand, Australia, the UK, Iraq, Iran, and Italy. These collaborations have resulted in several joint publications and have significantly contributed to the breadth and depth of my research experience. I also completed a seven-month internship at the University of Naples “Federico II”, Naples, Italy. I started internship program at National Technical University of Athens (NTUA), Athens, Greece for a period of eight months. These research stays have facilitated extensive knowledge exchange and have enhanced my research capabilities through exposure to diverse methodologies and perspectives.

Lectures and Presentations

Over the past three years, I have presented my research at 21 conferences held in various countries. These conferences have provided platforms for extending cooperation and sharing my findings with the global academic community. Notably, three of these conferences were ranked A and awarded 140 points, underscoring the significance and impact of the research presented. My presentations have covered topics related to seismic performance, risk assessment, and advanced machine learning techniques in earthquake engineering.

Prizes and Awards

Throughout my PhD program, I have been the recipient of multiple scholarships from Gdańsk University of Technology. These scholarships recognize my academic excellence and research contributions. The financial support has enabled me to focus on my research endeavors and to participate in international conferences, further enriching my academic experience.

- Erasmus+ at Gdańsk University of Technology (May 2025)
- Nitrogenium Supporting Excellence in Publishing – 2025 (January 2025)
- Nitrogenium Supporting Excellence in Publishing – 2024 (January 2024)
- Polish National Agency for Academic Exchange (NAWA) internship- Supporting mobility abroad for the best doctoral students (June 2024)
- Miniatura (National Science Centre), as team member, Project manager: Dr. Natalia Lasowicz
- Francium Supporting Outstanding Doctoral Candidates - IDUB program 2024 (October 2024)
- Francium Supporting Outstanding Doctoral Candidates - IDUB program 2023 (October 2023)
- NAWA Scholarships for the Best Doctoral Students with International Cooperation- (April 2024)
- PROM Program-International scholarship exchange for doctoral students - (March 2025)
- PROM Program-International scholarship exchange for doctoral students - (March 2023)
- Polonium International Doctoral Fellowships - IDUB program 2022 - (November 2022)

Other Significant Achievements

I have published 32 articles in peer-reviewed journals and have six additional papers currently under revision. These publications reflect the quality and scope of my research, which spans various aspects of earthquake engineering and machine learning applications. The high volume of published work demonstrates my commitment to advancing knowledge in the field and contributing to the academic community. We performed two experimental investigations to propose a novel bracing system and steel shear wall system for retrofitting moment-resisting frames. Additionally, experimental tests have been performed, and some results have been submitted to journals for publication.

Other Key Information Impacting the Evaluation of the Academic and Research Career

My research outputs, coupled with extensive international collaboration and active participation in prestigious conferences, highlight my dedication to the field of earthquake engineering. The scholarships and awards I have received further attest to my academic and research capabilities. My proficiency in programming languages and advanced methodologies, along with a solid foundation in engineering principles, positions me well to make significant contributions to the field. My efforts are aimed at developing innovative approaches for designing and retrofitting buildings to enhance their seismic resilience, ultimately ensuring greater safety and durability. For this purpose, we proposed a novel double-stage yield steel slit damper-buckling restrained brace as passive energy dissipative system that improves the ability of the buckling-restrained brace (BRBs). The innovative system is published, and numerical models are under evaluation for future studies.

PUBLICATION RECORD

1. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Optimization-based stacked machine-learning method for seismic probability and risk assessment of reinforced concrete shear walls* (**2024**), paper, Expert Systems with Applications, 124897
   Total number of citations (without self-citations): 70
   Open Access: no, DOI https://doi.org/10.1016/j.eswa.2024.124897
   Publication status: published

2. Neda Asgarkhani, Farzin Kazemi, Anna Jakubczyk-Gałczyńska, Benyamin Mohebi, Robert Jankowski, *Seismic response and performance prediction of steel buckling-restrained braced frames using machine-learning methods* (**2025**), paper, Engineering Applications of Artificial Intelligence, 107388
   Total number of citations (without self-citations): 98
   Open Access: no, DOI https://doi.org/10.1016/j.engappai.2023.107388
   Publication status: published

3. Neda Asgarkhani, Farzin Kazemi, Robert Jankowski, *Machine learning-based prediction of residual drift and seismic risk assessment of steel moment-resisting frames considering soil-structure interaction* (**2023**), paper, Computers and Structures, 107181
   Total number of citations (without self-citations): 78
   Open Access: no, DOI https://doi.org/10.1016/j.compstruc.2023.107181
   Publication status: published

4. Neda Asgarkhani, Mansoor Yakhchalian, Benyamin Mohebi, *Evaluation of approximate methods for estimating residual drift demands in BRBFs* (**2020**), paper, Engineering Structures, 110849
   Total number of citations (without self-citations): 70
   Open Access: no, DOI https://doi.org/10.1016/j.engstruct.2020.110849
   Publication status: published

5. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Machine learning-based seismic fragility and seismic vulnerability assessment of reinforced concrete structures* (**2023**), paper, Soil Dynamics and Earthquake Engineering, 107761
   Total number of citations (without self-citations): 156
   Open Access: no, DOI https://doi.org/10.1016/j.soildyn.2023.107761
   Publication status: published

6. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Machine learning-based seismic response and performance assessment of reinforced concrete buildings* (**2023**), paper, Archives of Civil and Mechanical Engineering, 94
   Total number of citations (without self-citations): 145
   Open Access: yes, DOI https://doi.org/10.1007/s43452-023-00631-9
   Publication status: published

7. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Predicting seismic response of SMRFs founded on different soil types using machine learning techniques* (**2023**), paper, Engineering Structures, 114953
   Total number of citations (without self-citations): 70
   Open Access: no, DOI https://doi.org/10.1016/j.engstruct.2022.114953
   Publication status: published

8. Farzin Kazemi, Neda Asgarkhani, Torkan Shafighfard, Robert Jankowski, Doo-Yeol Yoo, *Machine-Learning Methods*

for Estimating Performance of Structural Concrete Members Reinforced with Fiber-Reinforced Polymers (**2024**), paper, Archives of Computational Methods in Engineering, 571–603
Total number of citations (without self-citations): 50
Open Access: yes, DOI https://doi.org/10.1007/s11831-024-10143-1
Publication status: published

9. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Probabilistic assessment of SMRFs with infill masonry walls incorporating nonlinear soil-structure interaction* (**2023**), paper, Bulletin of Earthquake Engineering, 503-534
Total number of citations (without self-citations): 42
Open Access: no, DOI https://doi.org/10.1007/s10518-022-01547-0
Publication status: published

10. Farzin Kazemi, Neda Asgarkhani, Natalia Lasowicz, Robert Jankowski, *Development and experimental validation of a novel double-stage yield steel slit damper-buckling restrained brace* (**2024**), paper, Engineering Structures, 118427
Total number of citations (without self-citations): 22
Open Access: yes, DOI https://doi.org/10.1016/j.engstruct.2024.118427
Publication status: published

ARTISTIC ACHIEVEMENTS

n/a

NCN-FUNDED RESEARCH

n/a

OTHER RESEARCH PROJECTS

n/a

RESEARCH ACHIEVEMENT

I developed and experimentally validated a novel double-stage yield steel slit damper-buckling restrained brace (SSD-DYB) that has improved both seismic performance capacity of bracing system and total weight of device. The novel bracing system has a better adjustment method that can include a wider range of seismic intensity measures, which will be suitable for seismic-prone regions. The investigation led to a publication with title of "Development and experimental validation of a novel double-stage yield steel slit damper-buckling restrained brace".

MENTOR
prof. dr hab. inż. Robert Jankowski

ACADEMIC AND RESEARCH CAREER

Qualifications / scientific degrees:
1992 - University of Sheffield (UK), BSc Course in Civil Engineering.
1993 - Gdansk University of Technology (Poland), MSc in Civil Engineering.
1997 - University of Tokyo (Japan), PhD in Civil Engineering.
2007 - Gdansk University of Technology (Poland), DSc (habilitation) in Civil Engineering.
2014 - President of Poland, Title of Professor in Technical Sciences.

Employment:
1993 - 1994 - Gdansk University of Technology (Poland), Assistant.
1994 - 1997 - University of Tokyo (Japan), PhD student.
1998 - 2010 - Gdansk University of Technology (Poland), Assistant Professor.
2010 - 2018 - Gdansk University of Technology (Poland), Associate Professor.
2018 - - Gdansk University of Technology (Poland), Professor.

Foreign stays:
10.1991 - 06.1992 University of Sheffield (UK), BSc studies
03.1993 University of Roskilde (Denmark), study visit
10.1994 - 09.1997 University of Tokyo (Japan), PhD studies
05.2009, 03.2010, 03.2011, 03.2012, 04.2013 Vilnius University of Applied Engineering Sciences (Lithuania), conducting lectures
09.2009 University of Malta (Malta), conducting lectures
02.2011, 02.2012, 03.2013 .H. Kempen University College (Belgium), conducting lectures
04.2011 Copenhagen University College of Engineering (Denmark), conducting lectures
09.2014 University of Padua (Italy), conducting lectures

Cooperation with foreign institutions - joint publications:
Hirosaki University (Japan), Hong Kong Polytechnic University (Hongkong, China), Helwan University (Egypt), Lund University (Sweden), King Abdulaziz University (Saudi Arabia), Gulf University (Bahrain), University of Dammam (Saudi Arabia), Shiraz University of Technology (Iran), Semnan University (Iran), Delta University for Science and Technology (Egypt), Tanta University (Egypt), University of Florida (USA), University of Tokyo (Japan), University of Porto (Portugal), University of Raparin (Iraq), Tishk International University (Iraq), Universiti Sains Malaysia (Malesia)

Cooperation with foreign institutions - joint PhD thesis:
Tanta University (Egypt), Mansoura University (Egypt), Semnan University (Iran)

PUBLICATION RECORD

1. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski , *Machine learning-based seismic fragility and seismic vulnerability assessment of reinforced concrete structures* (**2023**), paper, Soil Dynamics and Earthquake Engineering, 107761
   Total number of citations (without self-citations): 156
   Open Access: no, DOI https://doi.org/10.1016/j.soildyn.2023.107761
   Publication status: published

2. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski , *Predicting seismic response of SMRFs founded on different soil types using machine learning techniques* (**2023**), paper, Engineering Structures, 114953
   Total number of citations (without self-citations): 70
   Open Access: no, DOI https://doi.org/10.1016/j.engstruct.2022.114953
   Publication status: published

3. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski , *Machine learning-based seismic response and performance assessment of reinforced concrete buildings* (**2023**), paper, Archives of Civil and Mechanical Engineering, 94
   Total number of citations (without self-citations): 145
   Open Access: yes, DOI https://doi.org/10.1007/s43452-023-00631-9
   Publication status: published

4. Neda Asgarkhani, Farzin Kazemi, Anna Jakubczyk-Gałczyńska, Benjamin Mohebi, Robert Jankowski , *Seismic response and performance prediction of steel buckling-restrained braced frames using machine-learning methods* (**2024**), paper, Engineering Applications of Artificial Intelligence, 107388
Total number of citations (without self-citations): 95
Open Access: no, DOI https://doi.org/10.1016/j.engappai.2023.107388
Publication status: published

5. Neda Asgarkhani, Farzin Kazemi, Robert Jankowski , *Machine learning-based prediction of residual drift and seismic risk assessment of steel moment-resisting frames considering soil-structure interaction* (**2023**), paper, Computers and Structures, 107181
Total number of citations (without self-citations): 80
Open Access: no, DOI https://doi.org/10.1016/j.compstruc.2023.107181
Publication status: published

6. Farzin Kazemi, Neda Asgarkhani, Robert Jankowski, *Optimization-based stacked machine-learning method for seismic probability and risk assessment of reinforced concrete shear walls* (**2024**), paper, Expert Systems with Applications, 124897
Total number of citations (without self-citations): 70
Open Access: no, DOI https://doi.org/10.1016/j.eswa.2024.124897
Publication status: published

7. Farzin Kazemi, Benjamin Mohebi, Robert Jankowski , *Predicting the seismic collapse capacity of adjacent SMRFs retrofitted with fluid viscous dampers in pounding condition* (**2021**), paper, Mechanical Systems and Signal Processing, 107939
Total number of citations (without self-citations): 80
Open Access: yes, DOI https://doi.org/10.1016/j.ymssp.2021.107939
Publication status: published

8. Farzin Kazemi, Neda Asgarkhani, Natalia Lasowicz, Robert Jankowski, *Development and experimental validation of a novel double-stage yield steel slit damper-buckling restrained brace* (**2024**), paper, Engineering Structures, 118427
Total number of citations (without self-citations): 20
Open Access: no, DOI https://doi.org/10.1016/j.engstruct.2024.118427
Publication status: published

9. Farzin Kazemi, Neda Asgarkhani, Torkan Shafighfard, Robert Jankowski, Doo-Yeol Yoo, *Machine-Learning Methods for Estimating Performance of Structural Concrete Members Reinforced with Fiber-Reinforced Polymers* (**2025**), paper, Archives of Computational Methods in Engineering, 32
Total number of citations (without self-citations): 50
Open Access: yes, DOI https://doi.org/10.1007/s11831-024-10143-1
Publication status: published

10. Farzin Kazemi, Robert Jankowski, *Machine learning-based prediction of seismic limit-state capacity of steel moment-resisting frames considering soil-structure interaction* (**2023**), paper, Computers and Structures, 106886
Total number of citations (without self-citations): 78
Open Access: no, DOI https://doi.org/10.1016/j.compstruc.2022.106886
Publication status: published

ARTISTIC ACHIEVEMENTS

n/a

NCN-FUNDED RESEARCH

n/a

OTHER RESEARCH PROJECTS

Title: **Dynamics of soil - experimental and analytical modelling of settlement and liquefaction**

Registration number: B/T02/2010/38

Source(s) of funding: Ministry of Science and Higher Education

Ammount of funding: **400,000 PLN**

Entity's name: **Institute of Hydroengineering PAS, Gdańsk University of Technology**

Start date (yyyy-mm-dd): **2010-10-01,** End date (yyyy-mm-dd): **2015-09-30**

List of the most important publications resulting from the project:
Sawicki A., Kulczykowski M., Jankowski R.: Estimation of stresses in a dry sand layer tested on shaking table, Archives of Hydro-Engineering and Environmental Mechanics, Vol.59, No.3-4, pp. 101-112, 2012. Sawicki A., Jankowski R., Kulczykowski M., Świdziński W.: Modeling the dynamics of a soil layer on a seismic table, XIII Symposium "Seismic and Paraseismic Influences on Buildings" [XIII Symposium "Seismic and Parasseismic Influences on Structures"], [CD-ROM], pp. 1-16, Kraków, November 22-23, 2012. Sawicki A., Kulczykowski M., Świdziński W., Jankowski R.: Modeling the dynamics of a soil layer on a seismic table, Inżynieria Morska i Geotechnika [Marine Engineering and Geotechnics], book 34 , no.6, pp.527-534, 2013.

Title: **Experimental and numerical study on behaviour of steel tanks under earthquakes and mining tremors**

Registration number: N N506 121240

Source(s) of funding: Ministry of Science and Higher Education

Ammount of funding: **248,000 PLN**

Entity's name: **Gdańsk University of Technology**

Start date (yyyy-mm-dd): **2011-05-13,** End date (yyyy-mm-dd): **2015-11-12**

List of the most important publications resulting from the project:
Burkacki D., Jankowski R.: Experimental study on steel tank model using shaking table, Civil and Environmental Engineering Reports, Vol.14, No.3, pp.37-47, 2014. Burkacki D., Jankowski R.: Experimental study on models of cylindrical steel tanks under mining tremors and moderate earthquakes, Earthquakes and Structures, Vol.17, No.2, pp.175-189, 2019. Burkacki D., Wójcik M, Jankowski R.: Numerical investigation on behaviour of cylindrical steel tanks during mining tremors and moderate earthquakes, Earthquakes and Structures, Vol.18, No.1, pp.97-111, 2020. Burkacki D., Jankowski R.: Response of cylindrical steel tank under stochastically generated non-uniform earthquake excitation, AIP Conference Proceedings, Vol. 2239, pp.020004, 2020.

Title: **Optimal technology for microseismic monitoring in processes of hydraulic fracturing**

Registration number: BG1/GASŁUPMICROS/13

Source(s) of funding: National Center for Research and Development

Ammount of funding: **2,400,000 PLN**

Entity's name: **PGNiG, AGH University of Science and Technology, Gdańsk University of Technology, Oil and Gas Institute**

Start date (yyyy-mm-dd): **2013-10-01,** End date (yyyy-mm-dd): **2017-06-30**

List of the most important publications resulting from the project:

Antoszkiewicz M., Kmieć M., Szewczuk P., Szkodo M., Jankowski R.: The processing procedure for the interpretation of microseismic signal acquired from a surface array during hydraulic fracturing in Pomerania region in Poland, Procedia Computer Science, Vol.108, pp.1722-1730, 2017. Antoszkiewicz M., Kmieć M., Szewczuk P., Szkodo M., Jankowski R.: Microseismic monitoring of hydraulic fracturing - data interpretation methodology with an example from Pomerania, Proc. of 10th International Conference “Environmental Engineering”, pp.1-7, Vilnius, Lithuania, 27-28 April 2017. Kmieć M., Antoszkiewicz M., Szewczuk P., Szkodo M., Jankowski R.: Planning, configuration and usefulness of microseismic monitoring on Eastern-Europe platform - example from East Pomerania, Proc. of 10th International Conference “Environmental Engineering”, pp.1-7, Vilnius, Lithuania, 27-28 April 2017. Antoszkiewicz M., Kmieć M., Szkodo M., Jankowski R.: Reverse modelling of microseismic waves propagation for the interpretation of the data from hydraulic fracturing monitoring in Poland, Proc. of 17 International Multidisciplinary Scientific GeoConference, pp.1-6, Albena, Bulgaria, 27 June - 6 July, 2017. Kmieć M., Antoszkiewicz M., Jankowski R., Szkodo M.: Matched filter approach for microseismic signal processing of real data from east Pomerania shale gas, Proc. of 17 International Multidisciplinary Scientific GeoConference, pp.1-8, Albena, Bulgaria, 27 June - 6 July, 2017. Kmieć M., Antoszkiewicz M., Jankowski R., Szkodo M.,: Microseismic event detection using different algorithms on real data from patch array geophone grid from eastern Pomerania fracturing job, Proc. of 17 International Multidisciplinary Scientific GeoConference, pp.1-8, Albena, Bulgaria, 27 June - 6 July, 2017.

RESEARCH ACHIEVEMENT

The most important scientific achievement concerns the non-linear viscoelastic model of earthquake-induced structural pounding that gained recognition among other researchers, and in some articles it is quoted as: 'Jankowski's model' or 'Jankowski's formula'. Moreover, I recognized as professional expert in methods of modelling of structural pounding during earthquakes, and introduced some novel approaches to model, design, and retrofit the seismic pounding effects on bridges and buildings. The most novel approaches for retrofitting have been proposed based on machine learning models to facilitate those retrofitting strategies.

PERSONNEL COSTS AND SCHOLARSHIPS

Personnel costs and scholarships		
No.		
1	Name	mgr inż. Neda Asgarkhani
	Nature of contribution to the project	PI
	Entity	Gdansk University of Technology
	Type of employment	additional salary
	Project-related remuneration period [in months]	12
	Total salary cost on grant [PLN]	12,000
2	Name	prof. dr hab. inż. Robert Jankowski
	Nature of contribution to the project	Mentor
	Entity	Gdansk University of Technology
	Type of employment	no remuneration
	Project-related remuneration period [in months]	0
	Total salary cost on grant [PLN]	0
3	Name	Wykonawca_1
	Nature of contribution to the project	Co-Investigator
	Entity	Gdansk University of Technology
	Type of employment	additional salary
	Project-related remuneration period [in months]	12
	Total salary cost on grant [PLN]	6,000

RESEARCH EQUIPMENT

OTHER DIRECT COSTS

No.	Other direct costs	
1.	Name / description [in English]	Material needed for steel frames
	Category	Materials and small equipment
	Entity	Gdansk University of Technology
	Total cost [PLN]	14,550
	Calculation and merit-based justification for the purchase [in English]	Purchasing materials related to the designed structures according to the shop drawing. Steel frames consist of following structural members: steel beams and columns that will be made from a thin steel plate that will create I-shaped cross-section.
2.	Name / description [in English]	Construction of steel frames
	Category	Outsourced services
	Entity	Gdansk University of Technology
	Total cost [PLN]	13,350
	Calculation and merit-based justification for the purchase [in English]	Constructing the structural members, connections, beams, and columns according to the details. Assembling structures on shaking table according to the numbers of case studies
3.	Name / description [in English]	Material needed for steel connections
	Category	Materials and small equipment
	Entity	Gdansk University of Technology
	Total cost [PLN]	4,250
	Calculation and merit-based justification for the purchase [in English]	Purchasing materials according to connection types and designed structures based on the shop drawing. Steel frames consist of different connection types.
4.	Name / description [in English]	Material needed for connections bolts
	Category	Materials and small equipment
	Entity	Gdansk University of Technology
	Total cost [PLN]	7,200
	Calculation and merit-based justification for the purchase [in English]	Purchasing materials according to connection types and designed structures based on the shop drawing with two types of regular and shape memory alloy bolts. Steel frames consist of different connection types and different connection bolts.

OPEN ACCESS

Entity's name	Indirect costs of OA (%)	TOTAL [PLN]
1. Gdansk University of Technology	2.00	1,146

OTHER INDIRECT COSTS

Entity's name	Other indirect costs (%)	TOTAL [PLN]
1. Gdansk University of Technology	20.00	11,470

STATE AID

1. Gdansk University of Technology	
Does the requested funding constitute state aid?	NO
PI and authorised representatives of the entity are familiar with the state aid rules.	YES

TOTAL COSTS OF THE ENTITIES

Gdansk University of Technology	
Indirect costs of OA (%)	2.00
Other indirect costs (%)	20.00
	Total [PLN]
Direct costs, including:	57,350
- personnel costs	18,000
- research equipment/device/software costs	0
- Other direct costs	39,350
Indirect costs, including:	12,616
- indirect costs of OA	1,146
- other indirect costs	11,470
Total costs	69,966

TOTAL COSTS

	Total [PLN]
Direct costs, including:	57,350
- personnel costs	18,000
- research equipment/device/software costs	0
- Other direct costs	39,350
Indirect costs, including:	12,616
- indirect costs of OA	1,146
- other indirect costs	11,470
Total costs	69,966

DATA MANAGEMENT PLAN [in English]

1. Data description and collection or re-use of existing data
How will new data be collected or produced and/or how will existing data be re-used?
New data will be generated during experimental research and numerical analyses. Experimental data will be collected by PCs directly connected to the research equipment. Test procedures, measurement conditions and settings will be collected by the person implementing the project. The nature of the data collected varies. These are the results of measurements of accelerations, damages and displacements during experimental measurements of steel structures. Data on the structural characteristics of buildings are also collected: fundamental period, damage state, damaged floor, and number of stories. In the next stage, the data is analyzed and transformed for the needs of the Machine Learning model.
What data (for example the types, formats, and volumes) will be collected or produced?
The data and documentation will be deposited in recommended formats. Data will be stored in accordance with prevailing standards and practice. Currently, quantitative data for the statistical software packages and documentation is preserved using XLS, SPF, DOC and PDF. The size of a single file will not exceed 20MB, however, the total disk space for all data is 2GB.
2. Documentation and data quality
What metadata and documentation (for example methodology or data collection and way of organising data) will accompany data?
Quantitative data will be divided into subfolders corresponding to subsequent stages of analysis; file names will include the name of the analysis and the date it was prepared. Selected data will be made available via an open research data repository MOST Wiedzy Open Research Data Catalog (common name Bridge of Data) and described in accordance with commonly used metadata standards. The author will be identified and authorized by an ORCID number.
What data quality control measures will be used?
The structure will be tested several times and the results obtained will be compared and verified based on probabilistic methods. Data with insufficient reliability will be disclosed and will not be collected, and the test will be repeated, if necessary.
3. Storage and backup during the research process
How will data and metadata be stored and backed up during the research process?
The data created and collected in "raw" form and as a result of analysis or post-processing will be stored on the work computer of the Gdańsk University of Technology and the shared One Drive workspace under the Office 365 A1 for faculty license. All data from the measurement units will also be stored on the control computers. The backup process will be performed monthly and the backup files will be stored on an external hard drive and One Drive shared workspace under the Office 365 A1 for faculty license.
How will data security and protection of sensitive data be taken care of during the research?
Only project members will have access to the data; only selected project members will be able to save data. To share data with colleagues, a disk space (matrix) on the intranet managed by the Gdańsk University of Technology and protected by passwords will be used. All data will be backed up throughout the duration of the project.
4. Legal requirements, codes of conduct
If personal data are processed, how will compliance with legislation on personal data and on data security be ensured?
Research data collected during the project will not constitute personal data.
How will other legal issues, such as intelectual property rights and ownership, be managed? What legislation is applicable?

Ownership and management of all intellectual property related to the Project remains with the members of the research team and the Gdańsk University of Technology in accordance with Polish law and Resolution of the Senate of the Gdańsk University of Technology No. 117/2021/XXV of 19 May 2021. Data and results will be published in the open-access model under one of the CCBY or CC0 licenses.
5. Data sharing and long-term preservation
How and when will data be shared ? Are there possible restrictions to data sharing or embargo reasons?
Some of the data will be published in the open research data repository Bridge of Data repository. The selected data will be made available at the time of publication of a scientific article on the proposed research. Some of the data will be published in scientific journals, which may also require publication of raw data.
How will data for preservation be selected, and where will data be preserved long-term (for example a data repository or archive)?
Good practice for digital preservation requires that an organization address succession planning for digital assets. Principal investigator has a commitment to designate a successor in the unlikely event that such a need arises. The data set will be stored in the Bridge of Data repository. The repository is CoreTrustSeal certified, which means that it has established good preservation and dissemination practices. Data deposited in the repository will be automatically categorized for long term storage, without expiration date. Moreover, all data not selected for sharing will be stored by PI for at least 10 years after the project is finished and access to them will be possible on direct request with the PI consent.
What methods or software tools will be needed to access and use the data?
The data will be shared in open formats, so recipients will not need specialized software.
How will the application of a unique and persistent identifier (such us a Digital Object Identifier (DOI)) to each data set be ensured?
Data sets made available in the Bridge of Data repository will be assigned a DOI number.
6. Data management responsibilities and resources
Who (for example role, position, and institution) will be responsible for data mangement (i.e the data steward)?
Open Science Competence Center (pg.edu.pl/openscience) - established by Gdańsk University of Technology will be responsible for DMP and storing and disseminating data included in the Bridge of Data repository. The head of research (mgr. Neda Asgarkhani) will be responsible for assessing the procedures and overall data quality.
What resources (for example financial and time) will be dedicated to data management and ensuring the data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?
Each member of the research team is expected to follow data collection and storage guidelines. The project manager will monitor the implementation of the data management facility and, if necessary, make adjustments during the project.

ADMINISTRATIVE DECLARATIONS

DECLARATIONS BY THE PI

I hereby declare that:

1. the research tasks specified in this proposal are not and have not been funded from the NCN resources and/or from other sources;
2. should I apply for or receive funding of the research tasks specified in this proposal from another source than the NCN, I shall:
   a) in the event that funding is received from the NCN:
      - resign from applying for funding from another source

      or
      - notify the authorised representative of the entity acting as the applicant of my resignation from funding of research tasks allocated by the NCN Director or

   b) in the event that funding is received from another source:
      - notify the authorised representative of the entity acting as the applicant of my resignation from applying for funding under this call of proposal organised by the NCN

      or
      - resign from accepting funding from other source;
3. should the proposal be recommended for funding, the results generated during the research project shall be evaluated and published in a journal/journals of international impact;
4. should the proposal be recommended for funding, I agree to have the project abstract for the general public published on the National Science Centre's website alongside the information on the call's results;
5. I have read the rules according to which the decision of the NCN Director is delivered;
6. I agree to have the application verified using anti-plagiarism software and the contents of the application placed in the software database;
7. I have read the Code of the National Science Center on Research Integrity and Applying for Research Funding and undertake to use it;
8. In the event that funding is granted, I will reside in Poland for at least 50% of the project duration period and be available to the participating entity pursuant to the Regulations on awarding funding for research tasks funded by the National Science Centre as regards research projects.

Acceptance of declarations: YES

DECLARATIONS BY THE HEAD OF THE ENTITY / AUTHORISED REPRESENTATIVE

I hereby declare that:

1. the research tasks specified in this proposal are not and have not been funded from the NCN resources and/or from other sources;
2. should I apply for or receive funding of the research tasks specified in this proposal from another source than the NCN, I shall:
   a) in the event that funding is received from the NCN:
      - resign from applying for funding from another source

      or
      - resign from funding of research tasks allocated by the NCN Director or

   b) in the event that funding is received from another source:
      - resign from applying for funding under this call of proposal organised by the NCN

      or
      - resign from accepting funding from other source;
3. should the research project be awarded funding, acting on behalf of the entity I represent, I shall:
   a) include the research project in the financial plan of the entity;
   b) employ the project's principal investigator in compliance with the proposal and principles set out for the call;
   c) employ investigators necessary to conduct the research project in compliance with the proposal and principles set out for the call;
   d) provide the conditions required for the completion of the research, including access to laboratory/office premises and research equipment required for the completion of the research;
   e) provide the project with administrative and accounting assistance;
   f) supervise the completion of the research project and proper disbursement of project monies;
4. should the proposal be recommended for funding, I agree to have the project abstract for the general public published on the National Science Centre's website alongside the information on the call's results;
5. I have read the rules according to which the decision of the NCN Director is delivered;
6. I agree to have the application verified using anti-plagiarism software and the contents of the application placed in the software database; and
7. I have read the Code of the National Science Center on Research Integrity and Applying for Research Funding and undertake to use it;
8. The entity I represent is not under receivership, in liquidation or subject to bankruptcy proceedings.

Acceptance of declarations: YES

PERSONAL DATA PROTECTION

INFORMATION ON PERSONAL DATA PROCESSING

The National Science Centre with its headquarters in Krakow (30-312), at ul. Twardowskiego 16, is the controller of your personal data. You can contact the Data Protection Officer at iod@ncn.gov.pl. Your personal data will be processed for the purpose of:

a) evaluation of the funding proposal for a research project,
b) supervision, financial and accounting operations, audits during and after the project, evaluation of implementation and settlement of the funding agreement if funding is awarded to the project, and
c) evaluation of the NCN's tasks, reporting, dissemination of information on NCN calls for proposals throughout the scientific community.

You can read the disclosure requirements on our website at: https://www.ncn.gov.pl/dane-osobowe?language=en.