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SMART METHOD RECOMMENDATIONS FOR THE DETECTION OF POST-EARTHQUAKE DAMAGES IN RC BUILDINGS

Gamze Doğan[1], Musa Hakan Arslan[2a], Alper İlki[2b]

[1]Konya Technical University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering
gdogan@ktun.edu.tr
[2a]Konya Technical University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering
mharslan@ktun.edu.tr
[2b]Istanbul Technical University, Faculty of Civil Engineering, Department of Civil Engineering
ailki@itu.edu.tr

Abstract

In Turkey, which is located on an active seismic zone, the existing old reinforced concrete (RC) buildings have been extensively and severely damaged in the past earthquakes. In this context, in the event of a possible earthquake such as the 6 February 2023 Kahramanmaraş earthquakes (Mw=7.7 and 7.6), it is extremely important to conduct the damage assessment promptly and in an objective/homogenous way. Although there are advanced methods developed for the assessment of post-earthquake damages to buildings in Turkey, there may often be differences/subjectiveness in the damage decisions based on the experience of the assessment staff and the psychological factors in the field. In this respect, introduction of intelligent decision support systems that will accelerate and harmonize the decision-making process of the engineers/technical staff involved in damage assessment activities after earthquakes may be very beneficial. In this study, firstly, information about the preliminary studies on the use of smart systems in structural engineering problems was given. Afterwards, smart software developed to be used in post-earthquake damage assessment of reinforced concrete buildings were compared according to their success/accuracy rates. In the evaluation, it has been seen

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that pre-trained deep learning models have a very high success in predicting post-earthquake damages in reinforced concrete structures.

Keywords: Convolutional Neural Networks, Deep learning, Damage, Earthquake, Reinforced Concrete.

1 INTRODUCTION

Detection of damage to structures quickly and accurately after severe earthquakes is extremely important in terms of life safety and economic losses. This issue is one of the main topics that should always be on the agenda of governments, especially in countries such as Turkey, whose lands are in an active seismic area and unfortunately frequently severe earthquakes occur (Kocaeli, 1999, Van, 2011, Elazığ 2020, İzmir 2020, Kahramanmaraş, 2023).

The fact that a significant part of the building stock in Turkey was built without complying with the codes causes the damages to become widespread during earthquakes [1-4]. The most obvious example of such a tragedy was seen after 6 February 2023 Kahramanmaraş earthquakes (M_W=7.7 and 7.6, respectively). According to the official records, this earthquake, which was effective in 11 big cities in Turkey and caused the collapse or severe damage of nearly 300,000 buildings, is estimated to cause a financial loss of 100 billion dollars in the Turkish economy.

Especially after earthquakes, damage assessment campaigns need to be conducted promptly and accurately. There are many conventional techniques in the literature for post-earthquake damage assessment [5-9]. The main purpose of these techniques is to classify and report the damage in a standard way. Often, an evaluation is made on the basis of the global damage of the structure considering the classification of the damages on the structural elements such as columns, beams and shear walls [10-12].

Apart from these methods, there are also innovative examples that damage detection/assessment can be done with artificial intelligence-based smart systems, especially in the last ten years. In most of these methods, the crack widths and orientations are determined based on the surface images of elements, and the damage classification is made based on image data.

The method proposed by İlki et al. [13, 14] is one of the conventional methods used after the recent earthquakes in Turkey (i.e. after İzmir (2020), Elazığ (2020) and Kahramanmaras (2023) earthquakes. Although the method is quite simple to use and a lot of live and on-line training options were provided by the relevant Ministry, Chamber of Civil Engineers and the Turkish Catastrophe Insurance Pool, there were problems in decisions of damage assessors in some cases, where the damage assessment staff was not sufficiently experienced/knowledgeable.

This clearly shows that an automatic and intelligent decision support system in post-earthquake damage assessment is vitally important. In particular, an artificial intelligence supported software that may accelerate the decision-support processes of the technical staff working in the field and enable them to make more accurate decisions. In this study, the basic working principles of an intelligent software that is being developed to be used in the damage assessment of RC buildings after an earthquake are explained.

2 SMART METHODS FOR STRUCTURAL ENGINEERING

Intelligent systems are the process of imitating human-specific features by machines and putting these imitated behaviors into practice. The transformation of people's brain activities and decision-making mechanisms into applications with computers has revealed the concept of "Artificial Intelligence". Many artificial intelligence applications developed in recent years have produced technologies that will facilitate human life. Machine learning (ML) is an important sub-branch of artificial intelligence, in which data can learn and make predictions in line with the information learned through some mathematical and statistical operations. The ML method can basically be used for regression and classification operations. The ML algorithm learns and makes logical predictions with the help of the data entered in the regression models. In classification models, on the other hand, it is possible to determine which categorical class the data belongs to. Image processing (IP) is inspired by the way the human eye sees and perceives images. However, image processing method is used to transfer the objects existing in nature to the computer environment. Deep learning (DL), as a sub-branch of machine learning, which is one of the areas of artificial intelligence that has attracted a lot of attention in recent years; It is the general name of the algorithm class designed to perform the analysis of data with the increasing number of data, learning and speech recognition, object recognition from various images, making predictions, etc. There are many new technological developments in the deep learning approach, especially in the field of computer vision. Artificial neural networks (ANN) are a branch of artificial intelligence that is created by using the structure of the human brain and is similar to the working principle of neural networks in the brain. Contrary to classical classification methods, fuzzy logic (FL) produces results that are somewhat fast and somewhat slow on concepts such as fast-slow, cold-hot, which are clearly distinguished, and in this respect, it is likened to real world problems.

A lot of work has been done on intelligent systems (in recent years, mostly with deep learning methods) in structural engineering, with an increasing momentum in the last decade. Applications developed with machine learning, artificial neural networks, deep learning, fuzzy logic, image processing algorithms have also found a place in the field of structural engineering. In Table 1, artificial intelligence studies in the field of structural engineering are given in the literature. The studies first started with crack detection applications on the concrete surface and were developed with the detection of structural damages. Numerous studies have been carried out especially in the field of post-earthquake structural damage determination, pre-earthquake structural performance determination, determination of crack width in structural damages, classification of damages and structural health monitoring. The Voswiever figure, which consists of the topics on the use of smart methods in the field of structural engineering on the “Web of Science resource”, is given in Figure 1.

As can be seen from these studies in the literature, the use of smart methods in the field of structural engineering has become widespread in the last 10 years. In the studies, solutions were found to important problems in the field of structural engineering with artificial intelligence techniques. In particular, classification and detection problems on image data and estimation problems on numerical engineering data are solved. In particular, studies developed in recent years on the automatic detection of structural damage after earthquakes with smart methods are very important.

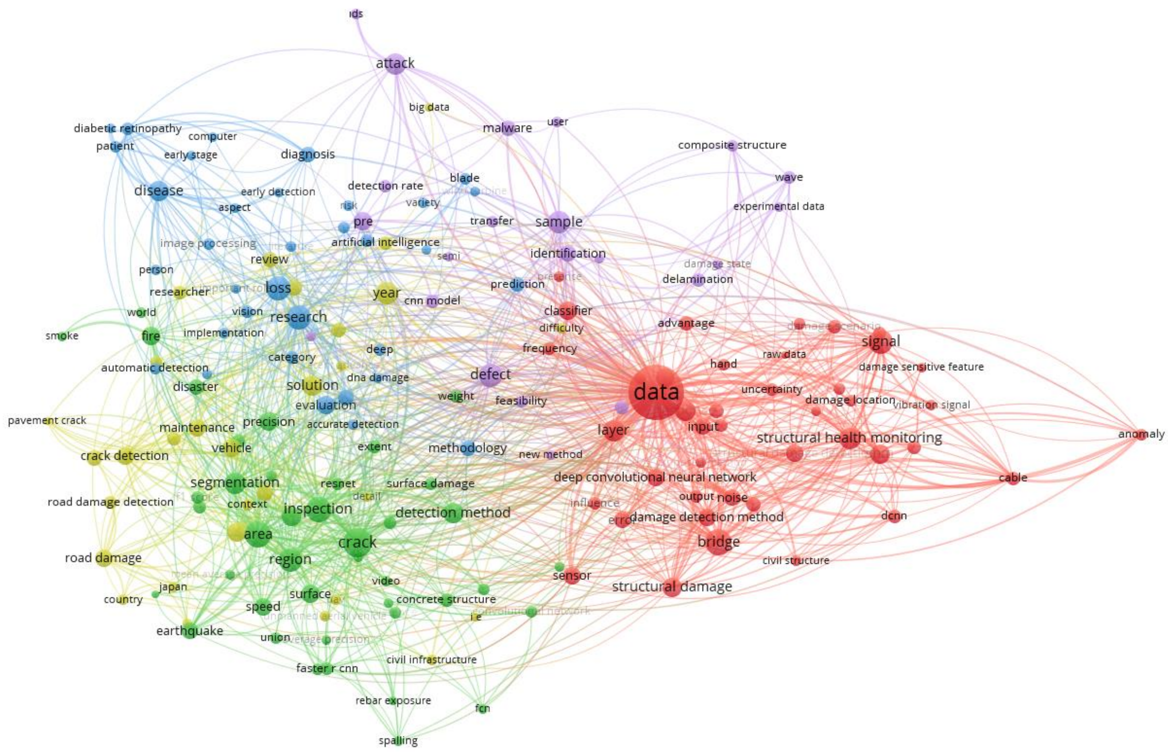

Figure 1: Vosviewer for smart methods in structural engineering (Web of Science results).

Application	Reference	Smart Methods
Structural Health Monitoring	Worden and Manson, 2016 [15]	ML
	Gui et al., 2017 [16]	ML
Classification of Buildings affected by the Earthquake	Mangalathu and Burton, 2019 [17]	DL
Bridge Damage Severity Measurement	Chun et al., 2015 [18]	ANN
Damage Detection and Crack Prediction in Bridges	Valença et al., 2017 [19]	IP
	Neves et al., 2018 [20]	ML
	Mangalathu et al., 2019 [21]	ML
	Okazaki et al., 2020 [22]	ML
Determination of Concrete Surface Cracks	Choudhary and Dey, 2012 [23]	IP
	Lee et al., 2013 [24]	IP
	Cha et al., 2017 [25]	DL
	Gopalakrishnan et al., 2017 [26]	DL
Prediction of Bending Moment of RC Slabs Under the Influence of Earthquake	Özbayrak, 2019 [27]	ANN
Modelling of Cracked Beams	Mazanoğlu and Kandemir, 2017 [28]	ANN
Estimation of Seismic Performance of Existing RC Buildings	Arslan et al., 2015 [29]	ANN
Damage Type Determination for RC Struc-	Cha et al., 2017 [30]	DL

ture		
Evaluation of Structural Safety After Earthquake	Allali et al., 2018 [31]	FL
	Zhang et al., 2018 [32]	ML
Earthquake Damage Estimation	Mohaneselvi and Hemapri-ya, 2019 [33]	FL
Structural Damage Estimation	Santos et al., 2016 [34]	ML
	Rafiei and Adeli, 2017 [35]	ML
	Avcı et al., 2017 [36]	DL
	Suryanita et al., 2017 [37]	ANN
	Lin et al., 2017 [38]	DL
	Bilici, 2017 [39]	IP
	Karameşe, 2018 [40]	IP
	Abdeljaber et al., 2018 [41]	DL
	Pathirage et al., 2018 [42]	DL
	Avcı, 2019 [43]	IP

Table 1: Literature studies on the use of smart methods in structural engineering.

3 ASSESSMENT OF POST-EARTHQUAKE DAMAGES IN RC BUILDINGS

3.1 Code Approaches and Traditional Methods

For the damage assessment of low-medium-rise buildings after an earthquake, there are several technical documents for assessing damage levels [5-7]. In addition to examining the buildings from outside, the damage assessment methods given in the technical documents require a visual inspection-based inspection from inside the building on the structural members. According to the technical documents, the structural damage depends on the type of damage (shear, flexure, or shear + flexure), residual crack width (w), and whether there is a possible compression damage (such as cover crushing, cover spalling, buckling of reinforcement or core crushing). In all methodologies, the evaluation is based on the determination of a global Seismic Damage Index (SDI) based on the distribution of damaged structural members, type of damage and level of damage on the most damaged floor of the building (usually basement or ground floors). In addition, the methods given in JBDPA [5] and FEMA 306 [7] aims to estimate to what extent the apparent earthquake damage affects the global performance of the existing building system.

In a country like Turkey with high seismic activity and always at risk of earthquakes, the problem of assessment of damage to buildings after an earthquake becomes very important. For fast and practical damage assessment, Ilki et al. [13, 14] have developed a unique methodology. According to this methodology, the damage assessment process is an observational determination as the other application examples in the world. In this method, the global damage level of the building is decided according to the damage formation mechanisms in structural members, especially in the column and shear wall elements. In the application of such methods by the damage assessors in the field, a decision support software may be invaluable towards reduction of mistakes and increase the pace of damage assessment practice.

3.2 Smart Methods for Damage Detection

Several studies have been conducted in the literature, on whether smart software can be used in damage detection/assessment and successful results have been reached. In the studies of damage determination with smart systems, evaluation is made based on damage images, and in this context, image processing [44-46] and deep learning applications [47-49] are used more frequently. Deep learning applications, which are relatively new methods in the literature, were firstly applied in the field of structural engineering after 2017. Deep learning as a computer vision application has brought solutions to problems in areas such as damage detection and health monitoring in buildings [50-52]. Further effort of researchers is necessary in order to provide a basis for damage assessment studies, which have become chaotic especially after major earthquakes. For the determination of structural damage in RC buildings, Arenada et al.; Shan et al., 2016; Feng et al., 2017, Gao & Mosalam, 2018; Dung, 2019, Doğan et al., 2020 [53-58] studies have been pioneering studies in this field. Similarly, Miyato et al., 2018; Ji et al., 2020; Ghosh et al., 2020; Sayedi & Liang, 2021; Miao et al., 2021 [59-63] developed deep learning algorithms for RC element-based damage detection. In addition, it has also been important to detect the cracks on the structural elements [64, 65]. In Table 2, studies developed by applying smart methods used in automatic damage detection after earthquakes in the literature are presented. The table shows the approximate success rate of the methods used in the studies in the application of damage identification/separation/classification.

Studies	Researchers	Success rate (%)
Post-earthquake Evaluation of Buildings	Nahata et al., 2019 [66]	92.0
Damage Classification	Pan and Yang, 2020 [67] Ogunjinmi et al., 2022 [68]	81.0 87.0
Image Based Structural Damage Recognition	Gao and Mosallam, 2018 [56]	90.0
Concrete Spalling and Crack Inspection	Yang et al., 2017 [69]	93.0
Post-Disaster Inspection of RC Systems	Liang, 2019 [70]	99.0
Seismic Damage Assessment of Buildings	Xiong et al., 2020 [71]	89.0
Crack Detection	Yang et al., 2018 [72] Dais et al., 2021 [73] Silva and Lucena, 2018 [74]	98.0 91.6 92.0
Concrete Crack Assessment	Kim and Cho, 2019 [75]	76.0
Post-earthquake and Corrosion Damage Detection	Doğan et al., 2023 [76]	90.6
Automatic Image Classification of Seismic Damages	Patterson et al., 2018 [77]	88.3
Automatic Seismic Damage Identification from Images of RC Columns	Xu et al., 2018 [78]	94.4
Multi-Class Damage Detection for Post-Disaster Autonomous Reconnaissance	Mondal et al., 2019 [79]	60.8
Structural Damage Detection	Feng et al., 2019 [80]	96.8
Automated Post-earthquake Inspections	Hoskere et al., 2018 [81]	91.1
Structural Crack Detection	Ye et al., 2019 [82]	93.6
Determination of Post-Earthquake Damage Levels of Reinforced Concrete Columns	Doğan et al., 2020 [58]	80.0

Table 2: Damage detection studies with smart methods.

As can be seen from the studies in Table 2, smart methods developed based on post-earthquake damage images and providing automation in damage assessment processes achieve an average of 89% success in damage assessment and classification processes. In studies, the performance metric is usually chosen as “accuracy value”. It is understood from the table above that the application of artificial intelligence technology integrated with seismic damage assessment is a hot topic of current research. In particular, it is seen that Surface crack patterns and geometric properties of RC members are the main indicators of the type of damage in a significant part of the studies. Therefore, image processing-based damage assessment to be made on the surface images of RC members and methods based on deep learning has become quite popular. This result shows that it is possible to carry out observational damage assessment practice in buildings after earthquakes with applications developed using artificial intelligence methods. This shows that it is quite important to develop a practical decision-support system which can be used after severe earthquakes where damage assessment should be conducted promptly. The main motivation of all these methods outlined above is the classification or detection of damage on concrete and reinforced concrete elements. However, the development of software that uses the methods which accepted in the literature and in the codes will be more beneficial for the use of technical personnel who conduct damage assessment after earthquakes.

4 CONCLUSIONS

Especially after the recent destructive earthquakes in Turkey (6 February 2023 Kahramanmaraş earthquakes (Mw=7.7 and 7.6)) it has been seen once again that accurate and prompt assessment and classification of damages of buildings is extremely important.

In this study, smart system applications developed in the literature are mentioned in the detection of cracks and damages in concrete and reinforced concrete. Especially the high success rates of the studies in damage detection or classification show that smart systems can be an important tool in damage assessment studies in the coming years.

It was pointed out that the software to be developed based on the traditional post-earthquake damage assessment methods used in the literature may fill an extremely important gap in practice. Similar opinions have also been reported by other researchers in the literature. It is reported that especially pre-trained deep learning-based methods can detect and classify building damages with great success in an article of the authors, which is currently under preparation.

In data based smart systems, it is obvious that the number of qualified data is the most important parameter in the development of algorithms. After that, it is predicted that the success rates of the software developed by the authors for their ongoing studies, especially with the data obtained from the last earthquakes, will increase remarkably. With the achievement of a satisfactory level in the success of the algorithm, it is aimed to transform the software into a mobile application and to expand its use after earthquakes.

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