FBU-DAE 2022
2 (2) : 123-130

GENERATING DATA OF AN IMPACT-LOADED REINFORCED CONCRETE SLAB VIA GANS

DARBE YÜKÜ ETKİSİNDEKİ BETONARME DÖŞEME VERİLERİNİN GANS İLE ÜRETİLMESİ

R. Tuğrul ERDEM*, Engin GÜCÜYEN**, Aybike ÖZYÜKSEL ÇİFTÇİOĞLU***

ABSTRACT

Reinforced concrete (RC) slabs are significant members in the structural system of a building. Although RC slabs are designed under the effect of static dead and live loads, they could be exposed to low velocity impact loading during their service periods. In this study, behavior of a simply supported RC slab under sudden impact effect is experimentally investigated in the first place. For this purpose, a drop weight test setup and essential measurement devices such as accelerometers, dynamic load cell, optic photocells, and data logger are utilized in impact experiments. In the numerical analysis part, a new method is proposed which uses the Generative Adversarial Networks (GANs) for generating the synthetic data of RC slab. GANs are a type of deep learning algorithm that goes beyond the standard supervised or unsupervised learning techniques. They are a type of generative model in which two networks compete against each other to generate data that is as close to an authentic, natural dataset as possible. One network is called the generator and takes in raw inputs. The other network is called the discriminator, which takes in the generated outputs and tries to identify them as fake or not. The major goal of this study is to create a considerable volume of data for dynamic analysis using GANs based on the outcomes of a small number of physical experiments using RC slab. The numerical analysis findings show that our model is capable of generating tabular synthetic data that properly represent the RC slab's actual behavior. This can be a valuable tool for engineers who need to do dynamic analysis on RC slabs since it allows them to generate large amounts of data for input into their analysis with a small number of physical experiments.

Anahtar Kelimeler: GANs, Impact, Slab, Test setup

ÖZET

Betonarme döşemeler bir binanın taşıyıcı sisteminde önemli elemanlardır. Betonarme döşemeler statik ölü ve hareketli yüklerin etkisi altında tasarlanmalarına rağmen hizmet ömürleri boyunca düşük hızlı darbe yüklerine maruz kalabilirler. Bu çalışmada öncelikle basit mesnetli betonarme bir döşemenin ani darbe etkisi altındaki davranışı deneysel olarak incelenmiştir. Bu amaçla, darbe deneylerinde ağırlık düşürme testi düzeneği, ivmeölçer, dinamik yük hücresi, optik fotosel ve veri kaydedici gibi temel ölçüm cihazları kullanılmaktadır. Sayısal analiz bölümünde, betonarme döşemenin sentetik verilerini üretmek için Çekişmeli Üretici Ağları (GANs) kullanan yeni bir yöntem önerilmiştir. GAN's, standart denetimli veya denetimsiz öğrenme tekniklerinin ötesine geçen bir tür derin öğrenme algoritmasıdır. Bunlar, mümkün olduğu kadar özgün, doğal bir veri kümesine en yakın verileri üretmek için iki ağın birbiriyle rekabet ettiği bir tür üretici modeldir. Bir ağ üretici olarak adlandırılır ve ham girdileri alır. Diğer ağ, üretilen çıktıları alan ve bunların sahte olup olmadığını belirlemeye çalışan ayırıcı olarak adlandırılır. Bu çalışmanın ana amacı, betonarme bir döşemenin az sayıda gerçekleştirilen fiziksel deneylerinin sonuçlarına dayalı olarak dinamik analiz için GANs ile önemli miktarda veri oluşturmaktır. Sayısal analiz bulguları, modelimizin betonarme döşemenin gerçek davranışını düzgün bir şekilde temsil eden sentetik veriler üretebildiğini göstermektedir. Bu durum, az sayıda fiziksel deney ile analizlerine girdi için fazla miktarda veri üretmelerine izin vereceğinden, RC döşemeler üzerinde dinamik analiz yapması gereken mühendisler için değerli bir araç olabilir.

Keywords: GANs, Darbe, Döşeme, Test düzeneği

Geliş Tarihi/Received: 25 Şubat 2022
Kabul Tarihi/Accepted: 7 Mart 2022

Araştırma Makalesi/Research Article

*
İnşaat Mühendisliği Bölümü, Manisa Celal Bayar Üniversitesi, Manisa / Türkiye

Civil Engineering, Manisa Celal Bayar University, Manisa / Turkey

ORCID: 0000-0002-8895-7602

**
İnşaat Mühendisliği Bölümü, Manisa Celal Bayar Üniversitesi, Manisa / Türkiye

Civil Engineering, Manisa Celal Bayar University, Manisa / Turkey

ORCID: 0000-0001-9971-8546

***Sorumlu yazar
İnşaat Mühendisliği Bölümü, Manisa Celal Bayar Üniversitesi, Manisa / Türkiye

Civil Engineering, Manisa Celal Bayar University, Manisa / Turkey

ORCID: 0000-0003-4424-7622

aybike.ozyuksel@cbu.edu.tr

1. INTRODUCTION

Concrete formed of cement, coarse and fine aggregate, water, and chemical additives if necessary. Due to its functional advantages such as durability and compressive strength, concrete is commonly used in construction works. However, tensile strength of concrete is very low. To overcome this problem, steel bars are placed in the tensile regions of the concrete elements. Thus, RC structural members are obtained.

RC slabs are planar structural elements, and they are utilized to cover areas in the buildings. RC slabs are designed in one way or two ways due to the configuration of the steel bars. Vertical loads are transmitted to beams and vertical structural members as shear walls and columns by slabs. In addition, lateral dynamic loads are also distributed by RC slabs to vertical members in the structural system.

Impact loading is a sudden dynamic loading type whose effect may be very high in a short span of time. Even though studies have been performed about the effect of static and dynamic loads on structural members, there aren't many studies about impact loading in the literature due to the difficult laboratory conditions and numerical solutions. However, especially low velocity impact loading may effect structural members during their service periods (Yilmaz et al., 2022; Yilmaz et al., 2020). Examples of impact incidents can be given as vehicle collisions, sudden rock falls, crane accidents, and explosion based shock waves (Erdem, R. T., 2021).

Researchers have developed test setups to investigate the responses and failure modes of the structural members under impact effect (Hummeltenberg et al., 2011; Iqbal et al., 2019; Othman & Marzouk, 2015; Yilmaz et al., 2019; Zineddin & Krauthammer, 2007). Besides, several measurement devices have also been used in impact experiments. Drop weight test setup is widely used to implement impact loading on test specimens in the literature (Kumar et al., 2018; Xiao et al., 2017; Yilmaz et al., 2021). The regulations in "ASTM E-23" have defined test devices and impact limits for experimental studies (E23-00, 2002).

Civil engineering experiments are often costly and time consuming, making large amounts of data difficult to produce. This is the reason why research projects usually only focus on a small number of samples. However, it's important that a lot of data is collected in order to be able to make accurate conclusions about a project. One way to address this issue is with synthetic data generation (Navidan et al., 2021). Synthetic data follows the same patterns as real-world phenomena but does not have any of the underlying details that could lead to a deviation in model performance. Another advantage of using synthetic data is that it is easier to scale up in order to look at more complex, higher-level phenomena (Mozo et al., 2022).

Deep learning has been used to develop artificial intelligence applications in different fields such as engineering, computer vision, and medical diagnosis (Rather & Bala, 2020, 2021). With the advancements of deep-learning technology, "GAN" has become an important tool for generating synthetic data (Goodfellow et al., 2014; LeCun et al., 2015). Deep learning, a type of machine learning algorithm that can be used to extract information from data sets, has become an increasingly popular topic of research in the last few years (Khalilpourazari et al., 2021; Naser, 2019; Naser & Alavi, 2021). GANs are neural networks consisting of two parts: the generator, which produces samples from the latent space of the model; and the discriminator, which accepts the samples produced by the generator and provides ground truth labels to distinguish real samples from generated ones (Grnarova et al., 2019; Hsu et al., 2020). They are helpful because they save time and resources that would otherwise be spent collecting expensive or time-consuming data. "TVAE" (Tabular Variational Autoencoder) (Xu et al., 2019) is a type of GAN architecture where the generator and discriminator share parameters. It takes a different approach in training the network, making use of variational autoencoders which are able to learn how to reconstruct high-dimensional data from lower-dimensional inputs.

Based on the outcomes of a limited number of RC slab experiments, a new deep learning approach has been introduced for obtaining a huge number of new data without experimenting. TVAE model of GANS has been utilized to create 5000 synthetic data of RC slab under sudden impact vibration. The generated data has been then used to compare with the real-time recorded response of RC slab under sudden impact vibration and analyze the performance of the TVAE-generated data model.

2. IMPACT EXPERIMENTS

In the experimental part of the study, the RC slab specimen having 700x700x100 mm dimensions is produced in the first place. After lubrication of the mold, 5 steel bars with 15 mm distances are placed in each direction of the slab. While diameter is 6 mm, yield strength value is 420 MPa for the steel bars. In addition, concrete cover is taken to be 20 mm.

After 28 days curing period, the specimen has been placed in the test setup and input impact energy is applied due to the constant values of drop height and mass of the hammer. Measurements have been taken by test devices for each drop and transferred to the computer. Crack propagation has also been observed during experimental study.

Cement, gravel, sand, and water are mixed in the production of concrete. Table 1 presents the material quantities for 1 m3 concrete. Concrete mix is produced by a concrete mixing machine in the laboratory Vibration is performed after pouring concrete into the mold of the specimen.

Table 1. Material amounts

Material	Amount (kg)	Weight (%)
Cement (42.5 R)	350	14.6
Gravel (0-15 mm)	950	39.8
Sand (0-5 mm)	900	37.6
Water	190	8.0

A drop weight test setup that is developed to implement impact loading on the test specimens is utilized in the experimental program as presented in Figure 1. Dynamic behaviors and responses of several materials and structural members are investigated in a similar way (Erdem, 2014; Erdem & Berberoğlu, 2021).

Figure 1. Test setup

A striker in the vertical direction also called as hammer that is produced from high strength steel material is used to implement impact loading on the specimen. Drop height and mass of the hammer can be adjusted in the test setup before performing impact experiments. Wheel shaped elements produced from castermid material provide the connection between the hammer and slides of the test setup as presented in Figure 2. Base platform of the test setup with 1000x1000x200 mm dimensions is placed on the ground. This platform with a weight of 500 kg is manufactured from steel plates.

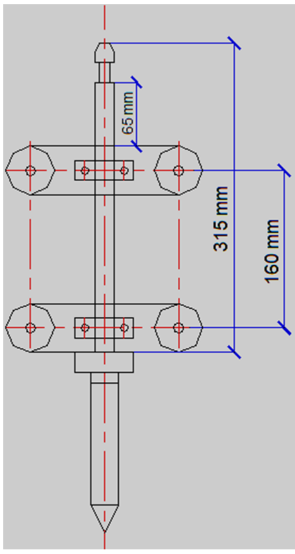

Figure 2. The hammer

A total of 4 piezoelectric accelerometers are used to measure the acceleration values. These accelerometers are symmetrically placed from 150 mm and 250 mm distances from impact point. For this purpose, brass devices and mechanical anchors are mounted on the top surface of the RC slab. The accelerometers with a working temperature between -18 and 65 oC have the capacity to measure the vibrations without any loss.

To determine the impact load values on the specimen, a dynamic load cell whose maximum measurement range is 88.96 kN has been utilized during the experimental study. This load cell is fixed in the edge section of the hammer. Thus, impact load values are measured for all drop movements of the hammer.

Drop durations and numbers are obtained by optic photocells that are located on the right side of the test setup. These values can be seen in the electronic part of the test setup. Another assignment of the optic photocells is enabling the locking mechanism. In this way, the second load effect on the specimen is prevented after the rebound movement of the hammer.

Low noise coaxial cables are utilized to provide the connection between the measurement devices and the data logger. So, all measured values are collected by the data logger. Finally, all measured data are evaluated in the computer environment and acceleration-time and impact load-time graphs are generated.

A neoprene rubber layer with 5 mm thickness and a steel loading plate having 10 mm thickness are placed on the middle of the specimen where impact loading is implemented. So, local fracture is prevented, and impact loading is properly transferred to the specimen. Two sides of the specimen are fixed to the test setup by using steel support devices. Test specimen with measurement devices is seen in Figure 3.

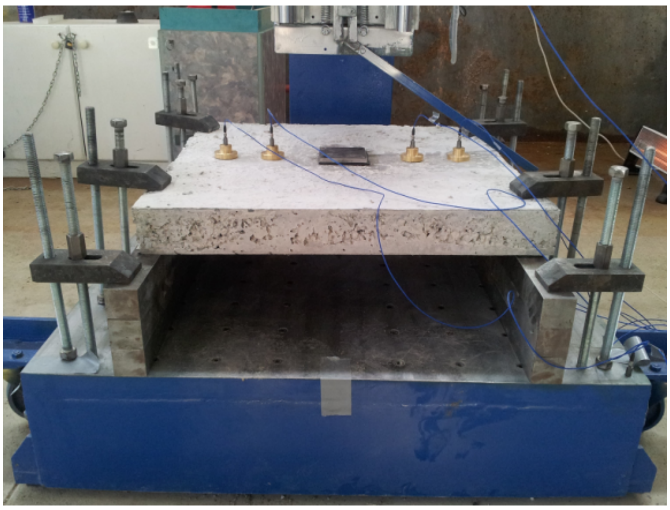
Figure 3. Test specimen

The mass and the drop height of the hammer are taken as 8.5 kg and 900 mm respectively. So, impact experiments have been performed for a constant level of input energy (8.5x9.81x0.9 = 75.05 joule). Besides, damage development of the specimen has been observed during experimental study. Cracks have been marked on the tension side of the RC slab as given in Figure 4.

Figure 4. Cracks on the specimen

The experimental study has been finished after applying a total of 38 drops on the specimen. Similar values are obtained by the measurement devices in the last drops of the hammer. Maximum acceleration values from 150 and 250 mm distances of impact point with impact load values are seen in Table 2.

Table 2. Experimental results

Drop No	Accelerations (m/s^2) 150 mm	Accelerations (m/s^2) 250 mm	Impact Load (kN)	Drop No	Accelerations (m/s^2) 150 mm	Accelerations (m/s^2) 250 mm	Impact Load (kN)
1	4813	4011	37,6	20	3726	2765	33,7
2	4791	4032	37,3	21	3648	2821	33,3
3	4764	3918	37,4	22	3527	2667	33,4
4	4781	3846	37	23	3583	2705	33
5	4604	3875	37,2	24	3491	2553	33,2
6	4632	3594	36,8	25	3439	2581	32,8
7	4518	3689	36,5	26	3472	2516	32,2
8	4437	3543	36,6	27	3367	2427	32,5
9	4408	3477	36,1	28	3308	2491	32,4
10	4426	3426	36,3	29	3254	2409	32
11	4291	3358	35,2	30	3168	2388	31,8
12	4325	3261	35,6	31	3127	2337	31,2
13	4195	3224	35,5	32	3083	2305	31,4
14	4163	3174	35,1	33	3054	2251	31,1
15	4057	3038	34,4	34	3006	2274	30,9
16	3918	3093	34,6	35	2981	2238	30,6
17	3961	3007	34,1	36	2944	2194	30,4
18	3826	2949	34,2	37	2937	2163	30,5
19	3771	2914	34,5	38	2905	2147	30,2

As mass and drop height values are constant in the impact experiments, similar drop durations are obtained by optic photocells. Average drop duration is determined as 462 msec. To give an example, time histories of maximum acceleration and impact load values for the first drop of the hammer are shown in Figure 5.

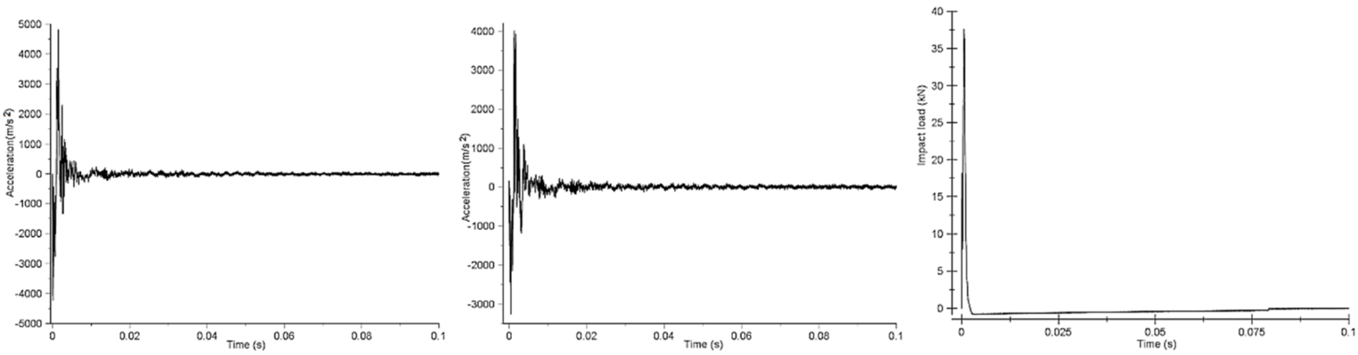

Figure 5. Experimental graphs

3. NUMERICAL ANALYSIS

It is challenging to generate synthetic data that is similar to that of real-world processes. In particular, it is difficult to obtain a large number of samples from a process with the cost and time required. In this section, the authors have introduced how GANs can be used to automate the process of generating synthetic data in civil engineering experiments. To generate 5000 synthetic slab data, 5000 iterations of the TVAE model in “Python” have been performed with the acceleration and impact load values collected from 38 experiments on an actual reinforced concrete slab as input data. TVAE model has been verified by comparing experimental and synthetic slab values. Table 3 compares real and synthetic slab data statistically. It is clearly seen that the synthetic data generated by TVAE is statistically similar to data obtained from real slab experimental data in terms of minimum values, maximum values, mean values, and standard deviations.

Table 3. Statistics of real and synthetic slab data

	Real Beam Samples			Synthetic Beam Samples		
	Max acceleration (150 mm)	Max acceleration (250 mm)	Impact Load (kN)	Max acceleration (150 mm)	Max acceleration (250 mm)	Impact Load (kN)
Min	2905	2147	30.2	2935	2170	30.2
Max	4813	4032	37.6	4647	3821	37.2
Mean	3807.92	2938.45	33.91	3843.92	2956.55	34.09
St Dv	618.68	584.24	2.28	574.20	477.01	2.00

When the cumulative sums of each feature of real and synthetic slabs are compared in Figure 6, the generated data appear to be realistic and capture all of the features of the experimental data.

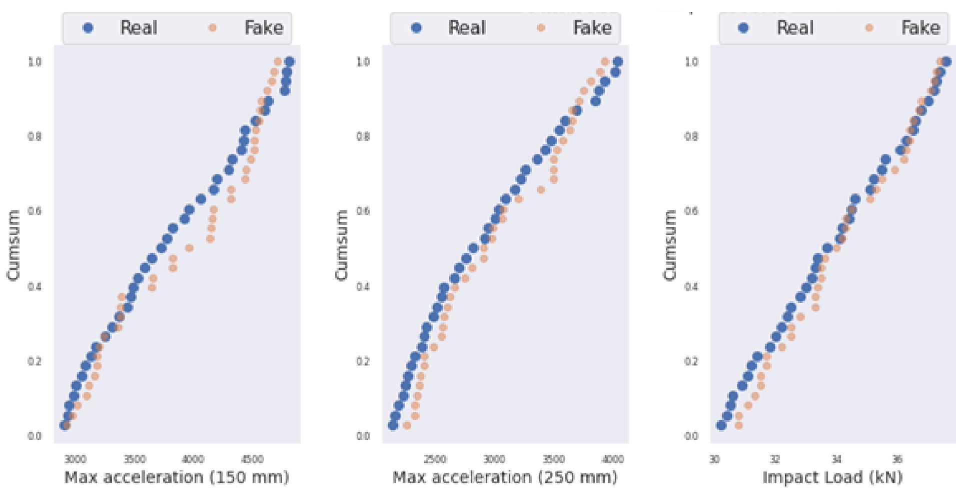

Figure 6. Comparison graphs of cumulative sums for each feature of real and synthetic data

The results demonstrate that the GANs TVAE model can be used to generate realistic synthetic data for RC slabs.

4. CONCLUSIONS

RC slabs are widely used in the building industry and may be affected by sudden impact loading during their service lives. Even though impact loading occurs in a short span of time, its effect could be destructive. Thus, dynamic behavior of structural members under impact effects has become more important. This study aims to evaluate the response of the RC slab under the effect of low velocity impact. In line with this objective, both experimental and numerical studies have been carried out.

A test setup with measurement devices has been used during experimental study. Test specimen has been subjected to impact loading and measurements have been taken for each drop of the hammer. Afterward, time dependent values have been evaluated in the computer environment. The cracks have been followed on the specimen and impact experiments have been finished when similar values are measured by accelerometers and dynamic load cell.

Accelerometers have been fixed on the RC slab for two different positions. Bigger acceleration values have been obtained from accelerometers which are closer to the impact point. In addition, dynamic load cell has measured the impact loading on the specimen for each drop. Maximum acceleration and impact load values have been obtained for the first drop movement of the hammer. These values tend to decrease as the cracks have become to occur on the specimen.

Since traditional data collecting methods are typically costly and time-consuming, 5000 synthetic data have been generated through using the GANs TVAE model over a small number of data gathered from experiments on an RC slab under impact load. 5000 iterations of the TVAE model have been performed using the acceleration and impact load values gathered from 38 experiments of the real slab sample, and 5000 synthetic slab data that are compatible with the input data have been generated. In terms of minimum, maximum, mean, and standard deviation values, it is obvious that the synthetic slab data created is close to the data collected from the real slab test data. This demonstrates that the GANs TVAE model can be used to generate realistic synthetic data for RC slabs. In the future, the authors intend to examine the application of GANs to generate realistic synthetic data for various RC structures. Besides, GANS will be used to simulate other engineering problems in the further studies.

REFERENCES

E23-00, A. (2002). Standard test methods for notched bar impact testing of metallic materials. ASTM International.

Erdem, R. T. (2021). Dynamic responses of reinforced concrete slabs under sudden impact loading. Revista de La Construcción, 20(2), 346–358.

Erdem, R. T. (2014). Prediction of acceleration and impact force values of a reinforced concrete slab. Computers and Concrete, 14(5), 563–575.

Erdem, R. T. & Berberoğlu, M. (2021). Prediction of impact results on cement based mortar slabs. Romanian Journal of Materials, 34(9), 1517–1534.

Goodfellow, I. J., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., Courville, A. & Bengio, Y. (2014). Generative Adversarial Networks.

Grnarova, P., Levy, K. Y., Lucchi, A., Perraudin, N., Goodfellow, I., Hofmann, T. & Krause, A. (2019). A domain agnostic measure for monitoring and evaluating GANs. Advances in Neural Information Processing Systems, 32(NeurIPS).

Hsu, C.-C., Zhuang, Y.-X. & Lee, C.-Y. (2020). Deep Fake Image Detection Based on Pairwise Learning. In Applied Sciences (Vol. 10, Issue 1). https://doi.org/10.3390/app10010370

Hummeltenberg, A., Beckmann, B., Weber, T. & Curbach, M. (2011). Investigation of Concrete Slabs under Impact Load. Applied Mechanics and Materials, 82. https://doi.org/10.4028/www.scientific.net/AMM.82.398

Iqbal, M. A., Kumar, V. & Mittal, A. K. (2019). Experimental and numerical studies on the drop impact resistance of prestressed concrete plates. International Journal of Impact Engineering.

Khalilpourazari, S., Khalilpourazary, S., Özyüksel Çiftçioğlu, A. & Weber, G.-W. (2021). Designing energy-efficient high-precision multi-pass turning processes via robust optimization and artificial intelligence. Journal of Intelligent Manufacturing, 32(6), 1621–1647. https://doi.org/10.1007/s10845-020-01648-0

Kumar, V., Iqbal, M. A. & Mittal, A. K. (2018). Study of induced prestress on deformation and energy absorption characteristics of concrete slabs under drop impact loading. Construction and Building Materials, 188(Complete), 656–675. https://doi.org/10.1016/j.conbuildmat.2018.08.113

LeCun, Y., Bengio, Y. & Hinton, G. (2015). Deep learning. Nature, 521(7553), 436–444. https://doi.org/10.1038/nature14539

Mozo, A., González-Prieto, Á., Pastor, A., Gómez-Canaval, S. & Talavera, E. (2022). Synthetic flow-based cryptomining attack generation through Generative Adversarial Networks. Scientific Reports, 12(1), 2091. https://doi.org/10.1038/s41598-022-06057-2

Naser, M. Z. (2019). Heuristic machine cognition to predict fire-induced spalling and fire resistance of concrete structures. Automation in Construction, 106, 102916. https://doi.org/10.1016/J.AUTCON.2019.102916

Naser, M. Z. & Alavi, A. H. (2021). Error Metrics and Performance Fitness Indicators for Artificial Intelligence and Machine Learning in Engineering and Sciences. Architecture, Structures and Construction. https://doi.org/10.1007/s44150-021-00015-8

Navidan, H., Moshiri, P. F., Nabati, M., Shahbazian, R., Ghorashi, S. A., Shah-Mansouri, V. & Windridge, D. (2021). Generative Adversarial Networks (GANs) in networking: A comprehensive survey & evaluation. Computer Networks, 194, 108149. https://doi.org/https://doi.org/10.1016/j.comnet.2021.108149

Othman, H. & Marzouk, H. (2015). An experimental investigation on the effect of steel reinforcement on impact response of reinforced concrete plates. International Journal of Impact Engineering, 88. https://doi.org/10.1016/j.ijimpeng.2015.08.015

Rather, S. A. & Bala, P. S. (2020). Swarm-based chaotic gravitational search algorithm for solving mechanical engineering design problems. World Journal of Engineering, 17(1), 97–114. https://doi.org/10.1108/WJE-09-2019-0254

Rather, S. A. & Bala, P. S. (2021). Lévy flight and chaos theory-based gravitational search algorithm for mechanical and structural engineering design optimization. Open Computer Science, 11(1), 509–529. https://doi.org/doi:10.1515/comp-2020-0223

Xiao, Y., Li, B. & Fujikake, K. (2017). Behavior of reinforced concrete slabs under low-velocity impact. ACI Structural Journal, 114(3), 643–658. https://doi.org/10.14359/51689565

Xu, L., Skoularidou, M., Cuesta-Infante, A. & Veeramachaneni, K. (2019). Modeling Tabular data using Conditional GAN. Advances in Neural Information Processing Systems.

Yılmaz, T., Anil, Ö. & Erdem, R. T. (2022). Experimental and numerical investigation of impact behavior of RC slab with different opening size and layout. Structures, 35, 818–832.

Yılmaz, T., Kıraç, N., Anil, Ö., Erdem, R. T. & Kaçaran, G. (2020). Experimental Investigation of Impact Behaviour of RC Slab with Different Reinforcement Ratios. KSCE Journal of Civil Engineering, 24(1), 241–254. https://doi.org/10.1007/s12205-020-1168-x

Yilmaz, T., Kiraç, N. & Anil Ö. (2019). Experimental investigation of axially loaded reinforced concrete square column subjected to lateral low-velocity impact loading. Structural Concrete, 20(4), 1358–1578. https://doi.org/10.1002/suco.201800276

Yilmaz, M. C., Mercimek, Ö., Ghoroubi, R., Anil Ö. & Gültop, T. (2021). Investigation of support type effect on plastic hinges in RC beam under impact load. Structural Concrete, 22(4), 2049–2069. https://doi.org/10.1002/suco.202000649

Zineddin, M. & Krauthammer, T. (2007). Dynamic response and behavior of reinforced concrete slabs under impact loading. International Journal of Impact Engineering, 34, 1517–1534.