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Parameter Identification and Damage Diagnosis of Marine Engineering Structures Based on Deep Learning

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Abstract: In the field of offshore engineering, the number of offshore platforms is increasing with the development of the offshore oil industry. During the working period, it is not only affected by seawater impact and pile foundation scouring, but also affected by marine debris, biological attachment, corrosion, etc., and extreme weather such as typhoons and earthquakes will also have an impact. Therefore, it is unavoidable during use. will be damaged. In order to ensure safety during platform services and effectively prevent serious accidents, it is necessary to conduct regular tests and safety assessments during platform services. In this paper, the offshore platform is taken as an example of numerical analysis, the ABAQUS finite element analysis software is used to establish the structural model of the marine platform, the structural parameters of the marine engineering are identified through the deep CNN(CNN), and the damage conditions of single-component damage and multi-component damage are simulated calculate. The results show that the CNN has anti-noise ability for damage assessment of marine engineering structural parameters, completes the localization and quantitative solution of damage, and achieves a certain DD(DD) effect.

1. Introduction

At present, more and more offshore platforms are in the middle and late stages of service. Due to the special working conditions, the platform structure is prone to different types and degrees of damage. These local damages may lead to instability and damage to the overall structure of the offshore platform. It reduces the structural bearing capacity of the offshore platform and threatens the normal operation of the offshore platform [1]. In order to avoid the structural damage of the offshore platform during the service work, an effective DD method is necessary, which is of great significance to ensure the safety of the platform staff and protect the marine environment.

So far, many researches have proposed methods for parameter identification and DD of marine engineering structures. For example, some studies first demonstrated the application of the BSS model to structural dynamics, incorporating the BSS model into the field of structural modal identification, but did not explicitly consider the connection between the modal extension theorem and the BSS model used in operational modal analysis [2]. Afterwards, some scholars proposed a damage identification method based on CP-BSS combined with improved support vector machine for the structure of offshore platform, studied the basic principle of principal component analysis in depth, and gave the steps of applying CP-BSS to damage identification of offshore platform. Using the theory of support vector machine, the damage identification of the offshore platform model is carried out, and the reliability and robustness of the algorithm are verified [3]. In some studies, the intelligent bionic algorithm is combined with the dynamic damage identification theory to locate and identify different types of damages on offshore platforms, which provides ideas for this method to identify different types of damages [4]. Some scholars have proposed a quantitative diagnosis method of Multi-BPNN, and numerically simulated the cracks of different lengths and angles in the central weld of the offshore platform, effectively predicting the length and angle of the cracks [5]. Although there are many methods for diagnosing damage of marine engineering structures, there are very few methods based on deep learning. Therefore, it is necessary to further explore the application of deep learning in DD.

This paper firstly introduces the basic concepts of structural parameter identification and DD, then proposes a structural damage identification method based on CNN, then establishes the structural model of the marine platform, and finally uses the CNN to carry out single structure and multi-dimensional marine platform analysis. Component structure simulation DD, analyzing the simulation results of the structural DD calculation example of the offshore platform working condition.

2. Structural Parameter Identification and DD

2.1. Identification of Structural Parameters

So far, modal analysis techniques and finite analysis techniques have been widely used in structural dynamics research. Vibration-based modal parameter identification is widely used in ships, marine engineering, vehicles, aerospace and other fields, and has been widely discussed by domestic and international academic circles [6]. In the field of engineering, structures such as offshore platforms and buildings are considered, and the identification method is used to determine the structural dynamic parameters of the vibration test data. The monitoring method based on vibration response is easy to operate and can comprehensively monitor the health status without interfering with its operation [7]. By transforming the modal coordinates and decoupling the vibration system, the modal parameters can be solved. These parameters determine the dynamic characteristics of the structure. The modal parameters can be used to modify the design model and verify its design feasibility. In addition, the structural model can be tested regularly. According to the determined model parameters, vibration control, model adjustment, and DD are performed to keep the structure intact [8-9].

2.2. Structural DD

There are generally static and dynamic methods for damage identification. The test period is very long for the static method, and the actual operation is complex, and real-time monitoring is difficult. In addition, when the structure has a small disturbance, it is very difficult to identify the static method [10]. The dynamic identification method is not only efficient but also not easily restricted by other factors. It is suitable for the real-time characteristics of structural health monitoring and has been widely used.

Structural DD is a theory and method for evaluating structural physical damage based on some typical characteristics. These properties (features) include physical parameters, modes, and derived physical quantities [11]. Damage identification consists of four stages. At present, many methods usually only realize the two stages of judging the occurrence of damage and judging the damage location, and rarely can accurately judge the two stages of determining the degree of damage and assessing the lifespan [12-13].

3. Simulation Experiment

3.1. Method of CNN for Structural Damage Location Recognition

The CNN adds convolution operation on the basis of the BP neural network, performs feature extraction in the convolutional layer, aggregates the feature maps output by the convolutional layer in the pooling layer, and comprehensively extracts the extracted data in the fully connected layer. features and input them into the classifier [14]. Figure 1 shows the structure of the CNN. The deep CNN method does not require any preparatory information of the system to be identified, and its neuron output needs to undergo nonlinear processing, and the nonlinear processing unit can be called an activation function [15].

$$f_1(x) = \frac{1}{e^{-x}+1} \tag{1}$$

$$f_2(x) = \frac{e^{x}-e^{-x}}{e^{x}+e^{-x}} \tag{2}$$

Among them, $f_1(x)$ and $f_2(x)$ represent the output values of the Sigmoid function and the Tanh function, respectively, and x is the input signal.

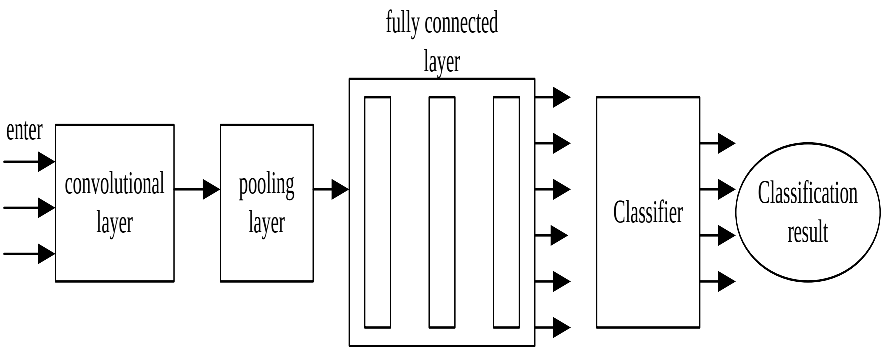

Figure 1. CNN Architecture

When using the CNN to identify the damage position of the structure, the network is first trained with the known training samples to test the network performance, and the characteristics of various damage modes are fully learned through the network and stored in the form of weights. Then, input the features of the damage pattern to be identified into the network. The selected network input should ensure that different damage patterns have good class separability, which can ensure that the training of the CNN is easier to converge and can Reduce the probability that the training result falls into the local minimum, and finally identify the location of structural damage according to the network output [16-17].

3.2. Numerical Simulation of Offshore Platform DD

Offshore platforms are essential and important engineering facilities for marine resource exploration, collection and transportation, observation, navigation, construction and other workflows, and are one of the main tools for human exploration of the ocean, whether it is the development of marine oil and gas resources or the exploitation of marine minerals. , are all completed by the equipment carried by the application platform [18-19].

In this paper, an offshore platform is taken as an example of numerical analysis, and the calculation is carried out in the finite element model according to the representative damage conditions of different positions and different degrees. In order to verify the diagnostic effect of the CNN, the ABAQUS finite element analysis software was used to establish the structural model of the offshore platform, and the simulation calculations were carried out for different working conditions of single-component damage and multi-component damage.

4. Analysis of Simulation Results

4.1. Identification of Structural Parameters of Marine Engineering

The numerical model of the offshore platform simulates the structural frequency response function for the DD of each damage condition of the structure. Considering the influence of noise on the CNN, 5%, 10%, 15%, and 20% of noise are added to the structural frequency response function respectively. . Using the two-step identification method, establish a sub-network net1 to perform the first-step identification of unit 1 and unit 2, and establish a sub-network net2 to perform the second-step identification of unit 3 and unit 4. The output layer of the sub-network net1 adopts two neurons, and the output layer of the sub-network net2 adopts a rectangular arrangement. The results of CNN recognition are shown in Table 1. It can be seen that with the increase of the noise level of the test data, the correct rate of CNN's recognition of the structural damage of the offshore platform gradually decreases. Noise has a certain influence on the evaluation of structural damage degree, but it is all within the allowable range, so this method can evaluate the damage of marine engineering structural parameters, and has a certain anti-noise ability.

Table 1. Structural damage identification results with noise (%)

	5%	10%	15%	20%
1	100	98.6	94.2	87.3
2	98.5	97.1	95.4	91.6
3	100	92.8	83.7	76.9
4	93.3	85.4	72.8	66.5

It can be seen that the two-step identification method is also applicable to the damage identification of complex structures. When there are similar patterns in the sample, the one-step recognition method will cause errors in the recognition of individual patterns. In the past, it was attributed to insufficient number of neurons or insufficient network input. Usually, the method of increasing the number of neurons or increasing the network input was used to solve this problem. The two methods not only greatly increase the scale of the network, but also increase the difficulty of network training, and often the effect is not ideal. This is because it is neither economical nor necessary to attempt to discern subtle differences between individual similar patterns through an overall network. Using the two-step identification method, most of the patterns can be correctly identified on the premise that the overall network is small. For individual patterns that are prone to misidentification, a smaller sub-network can be used for identification; at this time, the sub-network plays a role in The function of the "magnifying glass" improves the correct recognition rate of each pattern on the one hand, and reduces the complexity of the main network on the other hand.

4.2. DD Results of Marine Engineering

(1) DD effect of a single structural component

This simulation is aimed at the situation where one or more damages occur on a single component of the offshore platform, and tests the ability of the DD method to identify damage in the local structure. Condition 1 and Condition 2 form a contrast, simulating a single damage situation with different damage levels, different damage types and different damage types in a single component. Case 3 simulates a situation where a single component has multiple damages, and the damage degree is compared with cases 1 and 2 to verify the sensitivity of damage degree estimation.

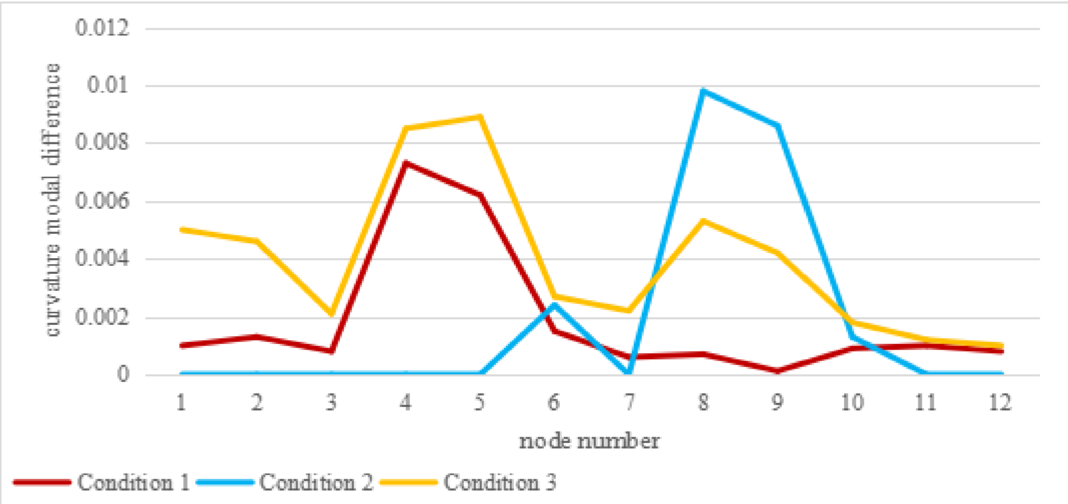

Figure 2. Damage location results of offshore platforms

When a single component is damaged, the curvature mode at the node position of the damaged element will change abruptly, and the damage position can be located according to this property. As shown in Figure 2, in case 1, the modal difference of curvature at nodes 4 and 5 has a sudden change, and the damage of the corresponding 4 structural elements can be judged. In the same case 2 and 3, the modal difference of curvature at nodes 8 and 9 can be judged. The value changes obviously, and according to this, it is judged that the damaged unit positions are units 4 and 8. Comparing the 4 units of working conditions 1 and 3, and the 5 units of working conditions 2 and 3, the larger the damage index, the higher the mutation peak value, which can reflect the severity of the damage degree to a certain extent. For different working conditions, the peak value of the sudden change in curvature is different, so it cannot be used as the basis for estimating the damage degree.

Table 2. Single-component DD results

	Damage index (%)	Relative error(%)
Condition 1	15.36	2.77
Condition 2	18.92	3.21
Condition 3	11.43	3.15

As shown in Table 2, the damage degree diagnosis results of damaged units in working conditions 1, 2 and 3 are obtained, and the damage indexes of three working conditions are obtained. According to the results, the damage indexes of working conditions 1, 2, and 3 are 15.36%, 18.92%, and 11.43%, respectively, and the relative error range of the damage characteristic indexes is about 3%. This shows that for the damage under different working conditions, the application of CNN to solve the damage of a single component of the offshore platform can ensure a certain accuracy in the diagnosis effect.

(2) DD effect of multiple structural parts

Overall structural analysis becomes more complex when damage occurs at different locations on the offshore platform. In this paper, in order to verify the feasibility of the DD method, three kinds of damage conditions are simulated and calculated. Case a and case b are used to compare the single damage and multi-damage cases, and case c is used to verify the sensitivity of the DD method to the degree of damage.

Table 3. Multi-component DD results

	Damage index (%)	Relative error(%)
Condition a	13.45	5.64
Condition b	17.69	4.83
Condition c	14.72	5.78

The calculation results of the damage degree of the damaged units in the three working conditions are shown in Table 3. According to the damage conditions under different working conditions, the damage degree of the multi-component damage position of the offshore platform is obtained. The damage indexes of the working conditions a, b, and c are respectively: 13.45%, 17.69%, 14.72%, the relative error range is within 6%, and it has a certain sensitivity to the degree of damage. Compared with the damage of a single component, the diagnostic error is larger. The CNN has a certain accuracy in the estimation of the damage degree of the marine platform.

5. Conclusion

Marine engineering structures have long been operating in harsh marine environments, and their health during service is in the vital interests of all parties. Factors such as environmental corrosion, material aging, and long-term influence of loads will cause structural damage, which will reduce the ability of the structure to resist external influences, and inevitably lead to a decline in the safety of structural performance. Taking practical and effective DD methods for this, and taking effective countermeasures quickly when damage occurs, is of great significance to ensuring the safety of workers and protecting the marine environment. The numerical simulation results of the offshore platform in this paper show that the method based on the CNN realizes the identification of the parameters of the marine engineering structure, and the DD of the single damage and multi-damage conditions of the structure is performed, and the diagnosis effect is good.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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