SEISMIC WAVES SELECTION FOR STRUCTURAL SEISMIC DESIGN BASED ON DEEP LEARNING

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Abstract

Seismic wave selection is the first step in building structure seismic analysis, which is very important for seismic analysis results. Because at present there are mainly modal decomposition response spectrum method and various time history analysis method for structure seismic analysis. However, with the continuous development of society, economy, science and technology and the rapid expansion of population, the number of high-rise, super-high-rise buildings and buildings with complex shapes is increasing rapidly, the modal decomposition response spectrum method that can only achieve the maximum response of the structure has been far from meeting the demand. What's more, although some time-history analysis methods widely used can understand the structural response of the whole earthquake and meet the requirements of complex high-rise structures in detail, their calculation results are largely dependent on the selection of seismic waves due to the limitations of their assumptions. So how to choose the right seismic wave is one of the key points of seismic analysis of building structure. As for the problem of how to choose seismic wave, there are two main requirements to be satisfied when selecting seismic wave input at present. The first is to select some parameters of the input seismic wave that are consistent with the location of the building. The parameterization mainly includes soil type, seismic intensity, seismic intensity parameters, predominant period and response spectrum. Secondly, the three elements of seismic activity should be satisfied, that is, the spectrum characteristics of selected seismic waves and the duration of seismic acceleration time-history curve should meet certain requirements. It is inefficient and difficult to select natural self - seismic waves which satisfy these conditions. Automatic wave selection algorithm with high efficiency and strong universality is becoming more and more important and feasible in the era of big data. In this paper, a deep learning network, convolutional neural network (CNN), is used to select seismic waves. Based on an actual structure, 40 seismic waves from Pacific Earthquake Engineering Research Center (PEER) are classified and screened. And compared with 100 seismic waves selected by PEER. It is proved that convolutional neural network has the ability of seismic wave selection. Furthermore, the results obtained with CNN are less discrete. More suitable for building seismic design. So it can be said that several seismic waves can be given for training CNN network, so as to find suitable seismic waves in other seismic wave Banks. It also lays a foundation for extracting new and better seismic wave selection parameters through CNN visualization in the future.

Keywords: Seismic waves selection, Convolutional neural network (CNN), Deep learning

1. Introduction

The theory of seismic design of structures involves the knowledge of seismology, structural engineering and other disciplines. Its contents can be summarized into four parts: ground motion input, structural modeling, structural response analysis and seismic design principles. The first step of seismic design is to determine the design ground motion, reasonable ground motion input is the necessary condition to ensure the design results are correct. With the emergence of more and more complex structures and high-rise structures, dynamic time-history analysis has become the main means of seismic design. In dynamic time-history analysis engineering, artificial waves or natural waves corresponding to the site of the building are generally input. However, artificial waves cannot completely simulate the original ground motion and reflect the real characteristics of the earthquake. Although natural waves can do these things, it is very difficult to find the natural waves that can completely reflect the environment of the construction site because of too many influencing factors and the limited number of recorded natural waves. At present, there are three kinds of methods to select seismic waves at home and abroad. First, based on the seismic information of the site, the suitable ground motions are selected and then adjusted according to the methods. Asce-7, the aseismic design code of the United

States, requires that when selecting the seismic wave input, the MCE of the site should be obtained according to the seismic risk analysis, and then the seismic wave parameters such as magnitude and epicenter distance should be deduced according to the MCE. Finally, the seismic wave should be selected according to these parameters[1]. The European code stipulates that natural waves, artificial waves and simulated waves may be used for ground motion input, in which the natural waves shall conform to the corresponding source mechanism and site conditions[2]. Cornell[3] et al. proposed vector-type multidimensional intensity index considering spectral shape, and defined spectral shape parameter. Mousavi[4] et al. improved the spectral parameters on the basis of Cornel, so that the seismic waves selected by the parameters can better simulate the collapse of structures. These first methods are more intuitive, but because of the lack of real strong earthquake records in many areas, it is difficult to select the seismic wave input. What's more, it is not necessary to conduct seismic risk analysis for general buildings, which will increase the calculation amount of designers. The second kind of method is to use the design response spectrum as the target spectrum to match the wave selection process, which not only considers the dynamic characteristics of the structure itself, but also considers the influence of site factors. This is the method currently used in China's seismic standard. The problem with this method is how to choose the seismic waves that match the response spectrum of the target. A popular method is to control a number of periodic points or intervals within which the selected seismic waves reach the appropriate conditions. However, the seismic waves selected in this way often differ greatly from the target response spectrum in the non-control segment. Pu Yang[5] et al. compared the four methods of site wave selection, site characteristic periodic wave selection, dual-band wave selection and response spectrum area selection, and the results showed that the seismic waves selected according to the dual-band wave selection have the smallest discrete type in time-history analysis. Naeim[6] et al. used genetic algorithm to continuously optimize amplitude modulation coefficient, and selected the best 7 seismic waves from thousands of seismic databases. The response spectrum of the selected seismic waves had the smallest dispersion and mean square deviation with the response spectrum of the target. However, this algorithm is prone to local optimization and non-convergence. In this paper, a method of wave selection based on convolutional neural network (CNN) is proposed. In this method, the seismic waves with the target response spectrum given in real time are used for training, so that the CNN network can know which seismic waves are needed and which are not. Then, the trained network is applied to seismic wave selection. The results show that the dispersion of seismic waves is small. It is helpful for the structural design of buildings that need small discrete seismic wave input. A third type of method is to study structures that are particularly important or dangerous and require the most adverse vibrations. This research direction is not considered in this paper.

2. Establishment of seismic wave data sets

From the Pacific Earthquake Engineering Research Center (PEER), this paper downloaded 100 seismic waves as the seismic wave data set for the following Research data set. These waves are selected by means of the built-in wave selector of PEER, whose kernel is the method of controlling key points and overall average error. The selected target response wave is shown in the Fig.1.

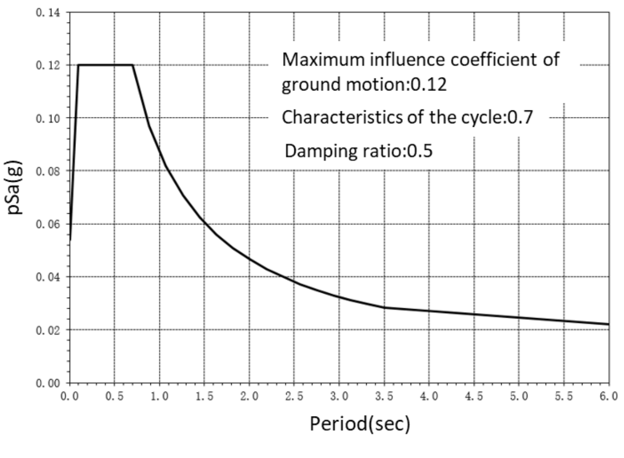

Fig.1. Target response spectrum

In the figure, the maximum impact coefficient of ground motion is determined according to the true value of 6 degrees in the Chinese seismic code. The characteristic cycle is also determined according to the site category of the Chinese code. Assume that the damping ratio of the structure is 0.5. It can be seen from these three indicators that the response spectrum not only reflects the characteristics of the building site, but also reflects the characteristics of the structure.

After wave selection by using the target response spectrum with PEER, we obtained 100 seismic waves. The following figure shows the response spectrum of 100 seismic waves and their average response spectrum, and the comparison with the target response spectrum.

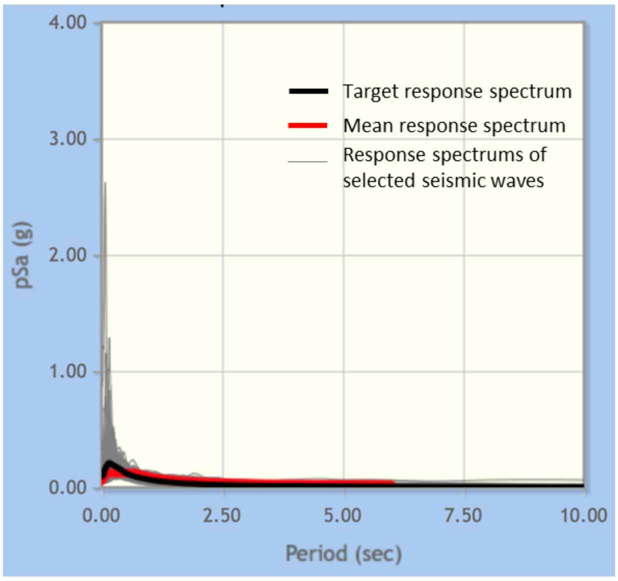

Fig.2. The response spectrum of all records

As can be seen from figure 2, although the response spectrum of the selected seismic waves is close to that of the target on average, their response spectra are far apart. Although this is very conducive to the study of ground motion, but for the engineering design, the response spectrum is too large is unfavorable. This is also a common problem in controlling response spectrum variables or parameter methods. But this problem, for the use of CNN wave selection method, does not exist.

3. Structure and training of neural networks

This paper adopts the existing mature CNN network structure, AlexNet[7]. Its structure is shown in the figure below.

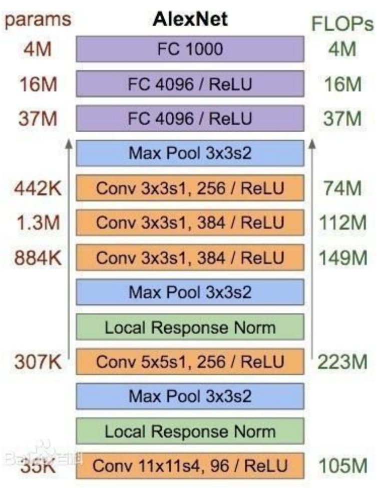

Fig.3. The structure of AlexNet

AlexNet has a very good effect on image classification. It can also take advantage of its structure and use two GPUs for computation at the same time, which improves the speed of CNN. However, seismic waves are not a picture. To preserve the physical properties of seismic waves as completely as possible, cut it into a picture. The short-time Fourier transform is used to transform seismic waves into a picture with amplitude, period, and frequency information. A seismic wave is selected as an example in Fig. 4 to show the process of the short-time Fourier transform.

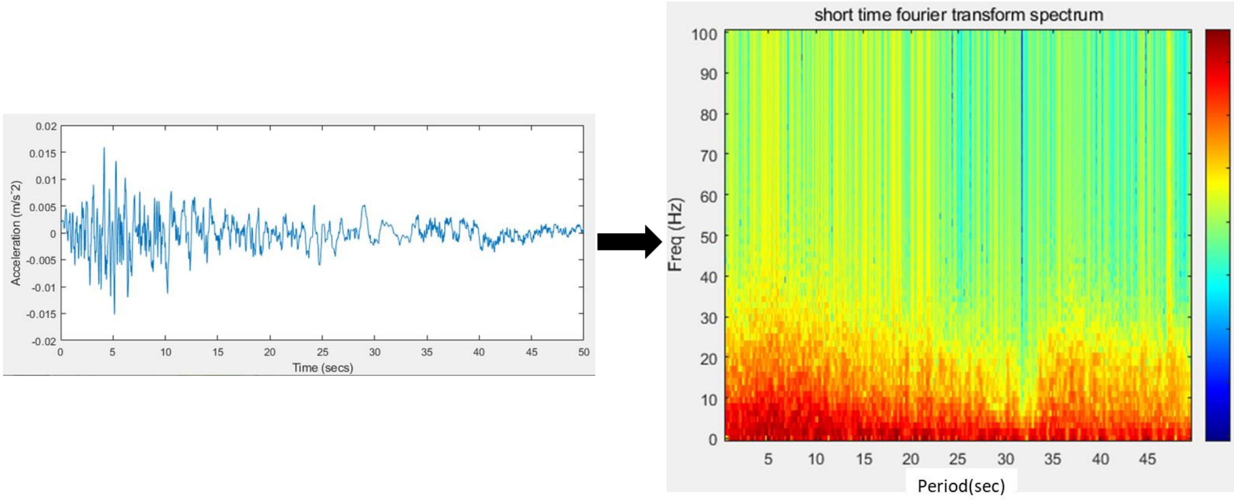

Fig.4. The process of the short-time Fourier transform

These generated images serve as input to the neural network. Selection and rejection are the outputs of neural networks. In other words, input a picture obtained by seismic wave transformation to determine whether the seismic wave should be selected.

For the training of the network, 14 seismic waves were artificially selected from the 100 waves, whose response spectrum was close to the target response spectrum, while the remaining 84 seismic waves were not selected. Among them, 9 seismic waves can be selected and 51 seismic waves cannot be selected as the training set. The remaining seismic waves were used as test sets, namely 5 seismic waves that could be selected and 35 that could not be selected, to check whether the trained neural network could correctly select the correct 5 seismic waves from the 40 waves. It is worth noting that the test set is not included in the training set. In other words, the neural network does not know how many ground motions in the test set match the response spectrum of the target.

4. The result of the selected wave

AlexNet is successful in selecting five seismic waves that can be selected, while discarding the other 35. The response spectra of selected seismic waves are compared as shown in the figure below.

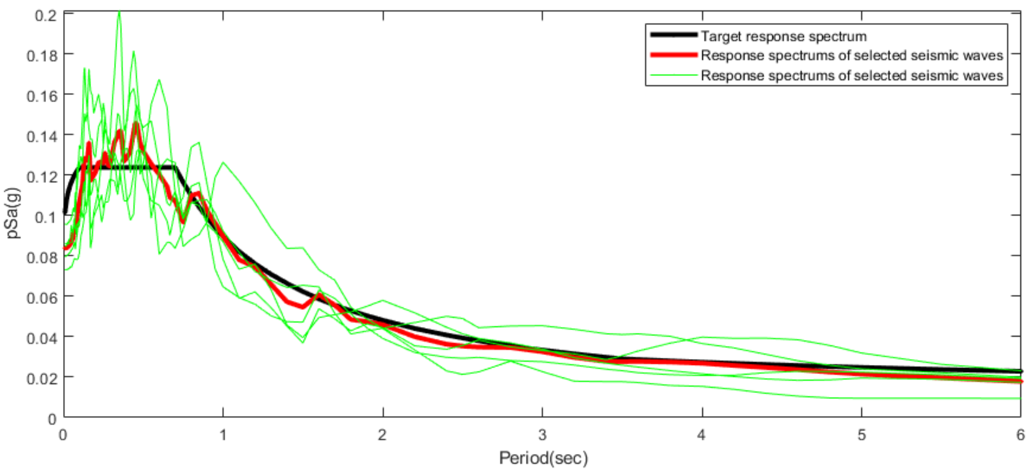

Fig.5. The response spectrum of 5 selected seismic waves

From Fig 5, it can be seen that the response spectrum of the five seismic waves selected by the neural network is basically close to the response spectrum of the target, and the deviation is much smaller than that obtained by using the built-in program of PEER, that is, the method of controlling parameters. After training, CNN can also select the seismic waves that are close to the response spectrum of the target quickly and automatically. This example proves the feasibility of seismic wave selection by CNN to some extent.

5. Conclusion

In this paper, a new idea of using CNN network to select ground motion wave is proposed, and its feasibility is demonstrated by a simple example. The results are less discrete than those obtained by traditional methods and more suitable for building seismic design. Several seismic waves can be given for training CNN network, so as to find suitable seismic waves in other seismic wave Banks. However, this method is also limited by the size of the training set and the range of the artificially selected training set. Further research is needed. Furthermore, it also lays a foundation for extracting new and better seismic wave selection parameters through CNN visualization in the future.

References

[1] "ASCE 7-2010 Minimum design loads for building and other sturctures[s] " *Restion: American Society of Civil Engineers,* 2010.

[2] Z. A. Lubkowski and X. Duan, "EN1998 Eurocode 8: Design of structures for earthquake resistance," *Dictionary Geotechnical Engineering/wörterbuch Geotechnik,* vol. 144, pp. 55-60, 2001.

[3] C. C. A. Baker J W "Spectral shape, epsilon and record selection[J]," *Earthquake Engineering & Structural Dynamics,* vol. 35(9), 2006.

[4] A. Azarbakht, M. Shahri, and M. Mousavi, "Reliable estimation of the mean annual frequency of collapse by considering ground motion spectral shape effects," *Bulletin of Earthquake Engineering,* vol. 13, 2014.

[5] 杨溥, 李英民, and 赖明, "结构时程分析法输入地震波的选择控制指标," *土木工程学报,* vol. 33, pp. 33-37, 2000.

[6] F. Naeim, A. Alimoradi, and S. Pezeshk, "Selection and Scaling of Ground Motion Time Histories for Structural Design Using Genetic Algorithms," *Earthquake Spectra,* vol. 20, pp. 413-426.

[7] A. Krizhevsky, I. Sutskever, and G. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks," *Advances in neural information processing systems,* vol. 25, 2012.

