Research Status of 1-D Soil Layers Seismic Response

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Abstract. The local site effect of vibration propagation during earthquakes is usually considered by one-dimensional site response analysis, while the ground motion of the site is the result of the combined effect of the source, the propagation path and the local site conditions. In the study, the influence of ground motion input, soil layer properties and analysis methods need to be considered. Based on a large number of related literatures, this paper briefly summarizes the research status of seismic response of one-dimensional soil layer sites through the determination of bedrock ground motions, soil dynamic constitutive models, and analysis methods. In the future, the development of seismic response of soil sites is prospected and summarized.

1. Introduction
The analysis of soil layer seismic response is one of the important contents in the research field of geotechnical earthquake engineering. Since the 1970s, seismic engineers and geotechnical engineers at home and abroad have begun research in this field and have achieved a series of valuable research results. The earlier research in this area was Wood [1-2]. When collating the seismic damage data of the San Francisco earthquake, he first realized that the site conditions had an impact on the ground motion. Therefore, people began to pay attention to the research on the impact of site conditions on earthquake ground motion. Duck [3] analyzed the collected data and found that there is a certain relationship between the site conditions and the degree of earthquake damage. Wiggins[4] applied this research earlier using numerical methods. In 1964, he began to quantitatively analyze the relationship between ground pieces and ground motion from strong earthquake records.

With the continuous deepening of theoretical research on soil seismic response analysis technology and the continuous development of test technology, the seismic response analysis technology of soil layer has also been continuously developed and perfected, various methods have been developed. For example linear elastic analysis methods and non-linear integration methods, linear total stress method and nonlinear finite element methods. The methods have been developed from simple to complex. This paper discusses and summarizes one-dimensional aspects from the determination of bedrock ground motions, soil dynamic constitutive models, and analytical methods.

2. Determination of bedrock ground motion
The site ground motion is the result of the combined action of the source, propagation path and local site conditions. As input parameters for analysis, the determination of bedrock ground motion is particularly important. Wang Yuqing had summarized three methods to obtain bedrock ground motion: (1)selecting deep well bedrock records;(2)appropriately adjusting bedrock ground motion;(3)use artificial seismic waves that meet the design response spectrum.
At present, the method using bedrock records is more mature than other methods, and the existing strong earthquake records cannot meet the needs of engineering and research. This requires adjustment of the actual bedrock ground motion. Method, by multiplying the recorded ground motion by an appropriate scale to make the amplitude and the period of excellence meet the calculation requirements. Although the scale method is simple and clear in use, it has certain limitations on the scaling ratio. Wenqi Du [5] gave a scale limit range of 3-5 times for general use by studying a large amount of ground motion data, but since the ground motion records used in the analysis are all selected from the western United States, no general research has been performed. Therefore, the use of the proportional method of ground motions at different stations remains to be studied.

At present, the methods for simulation of strong vibrations can be divided into three categories: seismic methods and engineering methods.

2.1 Seismological methods
Based on different source models, propagation functions, and site models, the seismological methods are divided into deterministic, stochastic, and hybrid methods.

The deterministic method is to represent the ground motion as a convolution of the source function and the Green's function, which is based on the representation theorem of Aki et al. [6] Deterministic methods can better simulate low-frequency ground motions, but it is difficult to describe high-frequency ground motions. The stochastic methods are mainly divided into two categories: the empirical Green's function method based on small earthquake records and the random vibration method based on Gaussian band-limited white noise. Both methods can better simulate high-frequency ground motions. The random vibration method can well fit the actual recorded response spectrum characteristics, but there is a certain gap in the fitted waveform.

In order to simulate wide-band ground motions, Kamae Proposed to use Green's function method to simulate low-frequency ground motions and random methods to simulate high-frequency ground motions, and then used the mixed wide-band small earthquake time history as an empirical Green function to synthesize large earthquake time history method. Irikura [7] proposed the idea of predicting future ground motions using the empirical Green function method, summarized the general steps, and simulated a large number of ground motions. This method combines the advantages of the Green's function method and the stochastic method, and is the main method in current seismological methods.

At present, the understanding of the complexity of the source and the propagation medium is not complete, so there is still some uncertainty in the seismic method, and its accuracy needs to be improved. In general, seismic methods have clear physical meaning and are one of the main directions for the development of ground motion simulation.

2.2 Engineering method
The engineering method emphasizes the mathematical description of ground motion parameters, which is the empirical statistical relationship between stochastic process theory and ground motion parameters. As early as 1947, Housner proposed the use of random pulse superposition to simulate ground motions. However, this process is assumed to be unreasonable, So Kanai improved the stationary random process method and proposed a filtered white noise model. In order to reflect the non-stationary nature of the ground motion, Bolotin proposed to multiply the stationary Gaussian process by the envelope function to simulate the ground motion. Based on Bolotin, Scanlan proposed the use of triangular series to simulate strong ground motion, this method can consider the probability of occurrence and the seismic intensity background of bedrock ground motion and can be widely used to this day. In order to solve the problems of fitting accuracy and convergence, many scholars have improved this. Hu Yanxian improved the method of modifying the amplitude spectrum so that the frequency component near the control point of the response spectrum can be distinguished during the fitting, which speeds up the convergence speed and improves the fitting accuracy. Zhai Ximei proposed to use the method of joint modification of power spectrum and amplitude spectrum to improve the fitting accuracy of response spectrum and target spectrum in triangle series method.
simulation. Cheng Wei proposed a method of directly fitting the response spectrum to avoid the error caused by the target spectrum to power spectrum conversion.

The engineering method is affected by the target response spectrum and the intensity envelope function, so it has certain uncertainty. At the same time, the seismic wave fitted by this method lacks the completely non-stationary characteristics of natural ground motion. The engineering method is simple in theory and easy to apply, at present, the engineering method is still the main method for synthesizing artificial ground motion in engineering construction.

3. Dynamic Constitutive Model

The earliest development of the soil dynamic constitutive model is the linear elastic model. During this period, the soil was considered as a linear elastic material. After the online elastic model, non-linear elastic models appeared, such as Duncan-Chang model. With the understanding of soil nonlinearity, various dynamic constitutive models have emerged, which can be divided into viscoelastic models and elastoplastic models.

3.1 Viscoelastic model

The viscoelastic model introduces a viscous term into the elastic model, which can consider the energy dissipation characteristics of the soil under dynamic loading. The viscoelastic model is divided into an equivalent linear model and the Masing type.

3.1.1 Equivalent Linearization Model

The equivalent linearization model is based on the equal overall dynamics effect, and uses equivalent shear modulus and damping ratio to replace the shear modulus and damping ratio under all strain amplitudes to transform the nonlinear problem into linear. The problem is solved in the frequency domain using the principle of superposition[8]. For example, Hardin Drnevich model[9], Ramberg Osgood model, hyperbolic model, etc.

In recent years, many scholars have improved the equivalent linear model. Chen Guoxing introduced the idea of segmentation to reduce the "virtual resonance effect" produced by the equivalent linear model. The combination of equivalent linearization thought and stochastic theory is another direction for the development of equivalent linearization models. In this regard, Wu Zaiguang, Lin Ye, and Koreatown have done a lot of work. Chen Yuan et al. Also established site earthquakes that consider geotechnical nonlinearity Dynamic random numerical simulation method. In addition, the equivalent linearization model has also made breakthroughs in the calculation of soft and frozen soils.

The equivalent linearization model is a breakthrough achievement. It has a simple concept, few calculation parameters, and a simple form. It is widely used in engineering. But after all, it is a simplified method, and it also exposes some shortcomings, such as unreasonable calculation results when strong earthquakes or soft soil layers, and large calculation errors at high frequencies.

3.1.2 The Masing Model

The difference between the Masing model and the equivalent linearization model is that the Masing model directly gives specific expressions of the dynamic stress-strain relationship according to different loading, unloading, and reloading conditions. Is the backbone curve, and then the soil hysteresis curve equation is constructed according to Masing's law. Since the Masing model was proposed in 1926, many scholars have improved and developed Masing-type nonlinear models, such as the Pyke model[10]; Iwan model[11]; Wang Zhiliang, etc., introduced damping ratio degradation coefficients and proposed generalized Masing models. In addition, Li Xiaojun proposed a "dynamic skeleton curve" model based on the Masing model; Qi Wenhao and others constructed a UE model suitable for asymmetric loads according to Masing's law; Zheng Datong developed the Iwan model A new model that can consider work hardening and work softening is proposed.

At present, the viscoelastic model is one of the mainstream dynamic constitutive models. Its simple
form and easy-to-measure parameters play an important role in the current seismic response analysis of soil layers. However, it has many deficiencies, such as the failure to consider the strain accumulation of the soil, the influence of the stress path, and the problem of strain softening.

3.2 Elastoplastic model

Many scholars have established many elastoplastic models based on different yield conditions, flow rules, and hardening laws. Li Xiaojun summarized the elastoplastic model, and divided the elastoplastic model into a single yield surface model, a multiple yield surface model, a boundary surface model, an internal time model, a rate model, a nonlinear incremental model, and an empirical relationship model.

The single yield surface model was first developed in the late 1960s. Its stress-strain characteristics are determined by the position of the soil stress state relative to the yield surface. Considering the hysteretic characteristics of the stress-strain relationship of the soil, concepts such as homosclerosis and kinematic hardening have also been introduced into plastic single yield surface models, such as the hat model proposed by Shen Zhujiang and others.

Because the single-yield-surface model is difficult to reflect the continuous change of soil stress-strain, Iwan proposed a multi-yield-surface model in 1967. The multi-yield surface model reflects the nonlinear hysteresis of the soil through the movement of the yield surface and the isotropic expansion rule. Compared with the single-yield surface model, it can more reasonably simulate the continuous soil stress-strain obtained from the experiment alternative relation. At the same time, plastic multi-yield surface models have emerged. The main differences are the shape of the boundary surface and its moving rules, and the study methods of the hardening modulus field.

After the multi-yield surface model, Bardet et al. Proposed a boundary surface model, which includes a single-sided model and a two-sided model. The two-sided theory was first proposed independently by Dafalias and Krieg. Later, Mroz [77] and others used this theory to describe the constitutive characteristics of soils under round-trip loads and established their own plastic models. The boundary surface model can better simulate the response of soil under dynamic action.

4. Analysis method of site seismic response

Site seismic response analysis methods are mainly random vibration analysis methods and deterministic dynamic analysis methods. At present, the analysis of random seismic response is immature and there is still a certain distance to apply it to engineering practice. The deterministic method still occupies a dominant position in the application. The earlier deterministic method is the linear elastic wave analysis method, which considers that the soil stress-strain relationship changes linearly. With the accumulation of actual seismic observation data and the in-depth study of soil dynamic characteristics, the equivalent linear method and nonlinear method have been gradually developed.

4.1 Equivalent linearization method

The equivalent linearization method appeared earlier and is widely used at home and abroad. It uses the relationship between dynamic shear modulus, damping ratio and strain to determine the equivalent dynamic shear modulus and damping through multiple linear calculations. The ratio and the strain level corresponding to the equivalent parameter are matched with the effective strain level under the action of the earthquake, thereby transforming the dynamic solution of the complex nonlinear system into a frequency domain iterative solution of the wave equation. Seed[8] first proposed the equivalent linearization method and compiled the corresponding program SHAKE. The proposed equivalent linearization method is a breakthrough in seismic response to soil layers. The method is simple, easy to understand, and easy to operate. Application and promotion. However, the traditional equivalent linearization method also has many problems that are difficult to overcome. The more serious problem is that when the amplitude of the soil strain is large, the calculated high-frequency components of the ground motion are usually lower than the actual strong vibration observations. Based on the above
problems, different scholars have proposed various frequency-dependent equivalent linearization methods. Sugito et al. Used frequency-dependent equivalent shear strain to replace the equivalent shear strain originally calculated with a fixed coefficient (such as 0.65), and then equivalent The effective linearization method was improved; Yoshida further analyzed that the high-frequency frequency response magnification calculated by SHAKE was lower than the actual one, and divided the frequency into three sections. Each frequency section used a different formula to calculate the equivalent shear strain; Kausel et al. Equivalent linearization does not consider the influence of high-frequency and small-vibration components, so a relationship between equivalent shear strain and frequency is suggested; Jiang Tong et al. Used a spectral smoothing method to fit the standardized strain spectrum curve to obtain the frequency correlation. New method.

The introduction of the equivalent linearization method is a major breakthrough in the analysis of site seismic response, which has extremely important significance. However, this method converts complex non-linear problems into approximate solutions to linear problems. Problems still occur during the use, such as Problems such as infinite loop phenomena, weak sites, and unreasonable calculations under large earthquakes. In order to improve and improve the existing methods, traditional iterative methods can be replaced by introducing new stable algorithms.

4.2 Nonlinear methods

In addition to determining the appropriate constitutive model, the nonlinear method also includes solving dynamic equations and establishing artificial boundary conditions.

4.2.1 Solving the equation of soil motion

The numerical calculation methods of the motion equation mainly include the finite element method and the finite difference method. The finite difference method has strict requirements on the mesh shape of the solution domain, so the finite element method is commonly used.

Kim et al. Proposed a direct finite element method that can consider the anisotropy of the soil and the transmission conditions of any boundary shape, and Song et al. Combined the advantages of the finite element method and the boundary element method and proposed a mapping boundary finite element method. Also known as the uniform infinitesimal finite element method. Li Xiaojun combined with an explicit differential numerical integration method to provide a method for analyzing the nonlinear seismic response of soil layers. Methods: Liao Heshan et al. Studied the nonlinear seismic response of the soil layer based on the one-dimensional composite strain wave theory and the characteristic line difference method. Jin Xing et al. Proposed an explicit finite element method for nonlinear analysis of seismic response of horizontally layered sites based on the incremental form of the discrete dynamic balance equation of Li Xiaojun’s integral format.

At present, the finite element method is often used, but it also has limitations. The more the finite element mesh is divided, the larger the calculation amount. Therefore, many scholars are still looking for a high-precision, unconditionally stable algorithm.

4.2.2 Establishing boundary conditions

At present, the most commonly used boundary conditions are global artificial boundary, approximate local artificial boundary, and local artificial boundary. Among them, the local artificial boundary conditions are more stable and have a smaller amount of calculation when applied to the nonlinear calculation of complex media, which is convenient to implement.

Local artificial boundary conditions have multiple forms of boundary expression. The viscous boundary was first proposed by Lysmer. It is a boundary condition with low accuracy, which is only the first-order calculation accuracy, but the processing method is simple, the physical concept is clear, and it is widely used in engineering. Smith et al. Proposed and developed superimposed boundaries. It mainly solves the wave problem by superposing the solutions of two problems, fixed boundary and free boundary, which will increase the amount of calculation. Wolf et al. Proposed a double asymptotic Higdon boundary by combining the double asymptotic boundary and the Higdon boundary and
developed a viscoelastic boundary. Liao Zhenpeng et al. Proposed and developed a local artificial boundary of the first-order transmission formula, and demonstrated its reliability in the time domain.

These boundaries are easily combined with finite element methods. Among them, the viscoelastic boundary itself is relatively stable and easy to implement, but the accuracy is poor; the transmission boundary is complicated and there are stability problems. Therefore, although many artificial boundary conditions have appeared, there is no recognized optimal method currently affected by stability, accuracy, and ease of implementation.

5. Conclusion
At present, the seismic response analysis methods of soil sites have developed more maturely. However, a lot of work is still needed to truly and reasonably calculate site seismic responses. Starting with the key issues, the research status of the seismic response analysis of the soil layer site is briefly described, and the future research directions are proposed.

1. The best way to determine the bedrock ground motion is to use the measured bedrock ground motion as input, but the number of records currently available is relatively small. Among the methods for considering the simulation of ground motion, the seismological method can consider the physical nature and is worthy of vigorous development.

2. None of the existing soil dynamic constitutive models can completely reflect the nonlinear dynamic characteristics of soils. Therefore, it is still the direction of future efforts to build a soil dynamic constitutive model that is practical, easy to measure and accurate.

3. The equivalent linearization method has some limitations in practical applications. In order to solve this problem, in-depth study of the time-domain nonlinear method is a better development direction. For example, the establishment of high-precision, high-efficiency boundary conditions and the search for a stable solution algorithm.

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