EXPERIMENTAL SIMULATION OF FOREST ECOSYSTEM RESTORATION BY A QUASI-STATIC METHOD

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Abstract. For a forest ecosystem severely damaged by an earthquake, it is necessary to experimentally simulate and analyze the forest ecosystem restoration process and investigate the forest ecosystem self-restoration ability. The finite element strength reduction method in the quasi-static method is used to calculate the slope static safety factor of the forest ecosystem, with the connection of the plastic zone and the non-convergence of the calculation results set as the judgment criteria for stability imbalance. When the sliding body has suddenly increased displacement with the plastic zone connected, it means imbalanced slope of the forest ecosystem in the area, and the forest ecosystem restoration ability should be analyzed. The simulated experimental environment was set up by constructing an open-top box, and the observation time was set to 14 months. Experimental simulation revealed that with the passage of time, the final number of the experimental forest ecosystem species was about twice that of the initial number. The final aboveground biomass and underground biomass were about three times of the original, and the soil microbial biomass carbon contents at soil depths of 10 cm - 20 cm and 20 cm - 30 cm were 187.64 w/mg•g-1 and 147.62 w/mg•g-1, respectively, at most, after 14 months. That was, the experimental forest ecosystem is amid gradual restoration at a relatively fast speed.
Keywords: *quasi-static method, stability, forest, ecosystem, restoration, experimental simulation*

Introduction

Forests provide the basis for the survival and development of human beings and various organisms (Liu et al., 2020). With rich species diversity, complex ecological processes and ecological structures, a forest is the most stable gene pool and organic carbon reservoir in nature (Feng et al., 2016). Forest ecosystems can improve the world's ecological environment and maintain ecological balance, thus greatly affecting the survival and development of human beings (Sobol et al., 2020). Investigation and analysis found that China's existing forest area ranks fifth in the world, with a size of about 1.593 × 108 hm^2. Nonetheless, compared with the world average, our forest coverage percent is low, so is our unit area forest stock and per capita forest area (Wu et al., 2022). The study of forest ecosystem carries great practical significance for protecting forests and natural environment (Umravia and Solanki, 2021).

At present, sudden, highly destructive and large-scale earthquakes have a great impact on the forest ecosystem. For example, the "5·12" Wenchuan 8.0 earthquake disaster in 2008 had a huge impact on the forests of Guangyuan City. The city's forest land was damaged by 50700 hm^2, more than 4600 wild animals died, and some protected plants were submerged by mountains or interrupted by rolling stones. At the same time, the earthquake will cause many secondary disasters, which will cause semi

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natural environmental problems and damage the stability of the forest ecosystem. Taking the Wenchuan earthquake as an example, it triggered mountain fractures, mud rock flows, landslides and collapses, causing massive damage to vegetation, forest structure, serious water and soil loss, and the disaster area is facing a new ecological security crisis (Liu et al., 2016; Yan et al., 2022; Zhang and Gao, 2020). Under poor stability of the forest ecosystem, a relatively loose geological structure with a high degree of landscape fragmentation will form in the forest, which will seriously affect the forest ecosystem development and therefore residents' life and living environment near the forest ecosystem (Zhang et al., 2020). Hence, it is necessary to analyze the post-earthquake slope stability of the forest ecosystem, and judge whether the current forest ecosystem is destroyed from the slope stability degree of the forest ecosystem (Mao et al., 2017). When the forest ecosystem is severely damaged, simulation experiments should be conducted to analyze the forest ecosystem restoration process, investigate the forest ecosystem self-restoration ability, analyze the forest ecosystem restoration time through the analysis results and then determine whether artificial interference should be added to facilitate the forest ecosystem restoration. In order to accurately analyze the self-recovery of the forest ecosystem after the earthquake, this paper analyzes the slope stability of the forest ecosystem from a quasi-static perspective. The finite element strength reduction method of quasi-static method is used to calculate the static safety factor of forest ecosystem slope, and the connection of plastic zone and the non-convergence of calculation results are taken as the judgment criteria of stability imbalance. When the displacement of the sliding body increases suddenly along with the connection of the plastic belt, it means that the slope of the forest ecosystem in this area is unbalanced, and the restoration ability of the forest ecosystem should be analyzed. The simulation experiment environment was established by building an open top box, and the observation time was set as 14 months.

Slope stability analysis of forest ecosystem based on quasi-static method

Calculation principle

By consulting the relevant literature, it is found that the main function of the quasi-static method is to simplify the earthquake action, convert it into a constant inertial force in the vertical or horizontal direction, calculate the inertial force according to the finite element strength reduction method or the limit equilibrium method, thus calculating the slope static safety factor of the forest ecosystem (Huang et al., 2021). In real life, the seismic acceleration has a certain direction, so the seismic force in different directions should be fully considered when calculating the seismic force. An effective calculation method in the numerical analysis method is the finite element strength reduction method. Compared with the limit equilibrium method, this method more comprehensively and fully considers the relationship between the stress-strain of forest land and the slope stress state of the forest ecosystem, which can accurately calculate the forest ecosystem slope stability.

The finite element strength reduction method is to first reduce the shear strength parameters of the slope rock and soil mass of the forest ecosystem and then stop doing so when the forest ecosystem slope reaches the ultimate failure state. The finite element calculation results are used to calculate the strength reserve safety factor of the sliding surface and the forest ecosystem slope (Gao et al., 2021; Wang et al., 2020). The equation for calculating the strength reduction safety factor is as follows:

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$$k = \frac{n + \alpha \tan\theta}{\omega} = \frac{n}{\omega} + \alpha \frac{\tan\theta}{\omega} = n^{'} + \alpha \tan\theta^{'} \quad \text{(Eq.1)}$$

where *n* is the cohesion of the geotechnical materials in the forest ecosystem, θ is the internal friction angle of the geotechnical materials in the forest ecosystem, *n'* is the cohesion of the geotechnical materials in the forest ecosystem after strength reduction, $\theta^{'}$ is the internal friction angle of the geotechnical materials in the forest ecosystem after strength reduction, ω is the slope angle and α is the natural weight of the rock and soil. The cohesion and internal friction angle of the geotechnical materials in the forest ecosystem after the strength reduction can be calculated from *Equation 1* (Zhang and Li, 2020). The solution results are shown in *Equation 2:*

$$\begin{cases} n^{'} = \dfrac{n}{\omega} \\ \tan\theta^{'} = \dfrac{\tan\theta}{\omega} \end{cases} \quad \text{(Eq.2)}$$

The strength reduction safety factor is a kind of strength reserve safety factor. In actual life, the strength reduction factor can represent the safety factor of the entire sliding surface of the forest ecosystem. That is, it can accurately reflect the stability of the entire sliding surface (Ma et al., 2020; Wu et al., 2020).

Selection of yield criterion

Ansys finite element analysis software was used to simulate and analyze the two-dimensional plane of the forest ecosystem. The two-dimensional adoption criterion is the criterion adopted under the M-C (Mohr-Coulomb) criterion. Considering the high degree of matching between D-P (Drucker-Prager) criterion and M-C criterion under the plane strain condition, the D-P criterion was selected as the yield criterion, and the expansion angle was calculated according to non-correlated flow law (Sobol et al., 2020; Xie et al., 2020). The calculation formulas for the expansion angle and the constants related to the cohesion and internal friction angle are as follows:

$$\begin{cases} \phi = \dfrac{\theta}{2} \\ \beta = \dfrac{\sin\theta}{3} \\ l = n\cos\theta \end{cases} \quad \text{(Eq.3)}$$

where β and l represent constants, which are mainly related to the cohesion and internal friction angle of geotechnical materials in forest ecosystem.

Failure mechanism of slope instability

When judging and analyzing the slope instability and failure degree of the forest ecosystem, whether the forest ecosystem slope is damaged can be detected from the three perspectives of rupture surface, potential sliding mass displacement, medium force and displacement (Lu et al., 2016). The slope instability of the forest ecosystem can be

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judged by checking whether the rupture surface is connected or not. At the same time, whether the forest ecosystem slope is damaged can be judged by detecting the displacement increase amplitude in potential sliding mass of the forest ecosystem. Finally, the degree of neutrality and displacement convergence can be detected to determine the slope stability of forest ecosystem according to the convergence degree (Zeng et al., 2016). In this paper, the judgment is mainly based on whether the plastic zone is connected and whether the calculation results are non-convergent. The slope stability of the forest ecosystem is judged according to the judgment results. In case of unstable slope of the forest ecosystem, the forest ecosystem is unbalanced. At this time, the forest ecosystem needs self-restoration. Simulation experiments should be conducted to analyze the self-restoration ability of the forest ecosystem, and then judge from the detection results whether it is necessary to artificially restore the forest ecosystem, thus improving the forest ecosystem stability, and then perfecting the natural environment through a stable forest ecosystem (Zhuang et al., 2017).

Simulation experiments

Stability analysis

In the case of poor stability of forest ecosystem after earthquake, the restoration process of forest ecosystem can be simulated through experiments to predict the restoration efficiency and time of forest ecosystem. Therefore, it is necessary to analyze the slope stability of the forest ecosystem in the selected area first. This paper mainly takes the forest ecosystem in the western margin of the Sichuan Basin as an example to analyze the forest ecosystem slope stability. In the analysis process, Ansys was used to build a finite element model of the forest ecosystem slope in the northeast region. The constructed model is shown in *Figure 1*.

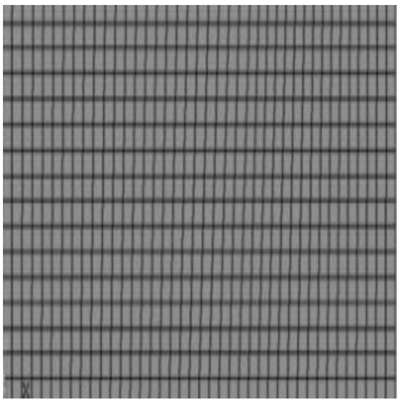

Figure 1. *Two-dimensional finite element model*

After the model construction, the method proposed herein was used to calculate the strength reduction safety factor, and then establish the horizontal displacement cloud map and plasticity cloud map of the forest ecosystem slope under the strength reduction safety factor, as shown in *Figure 2.* After the completion of the model construction, the method proposed in this paper is used to calculate the strength reduction safety factor, and the horizontal displacement nephogram and plastic nephogram of the forest ecosystem slope under the strength reduction safety factor are established, as shown in *Figure 2.*

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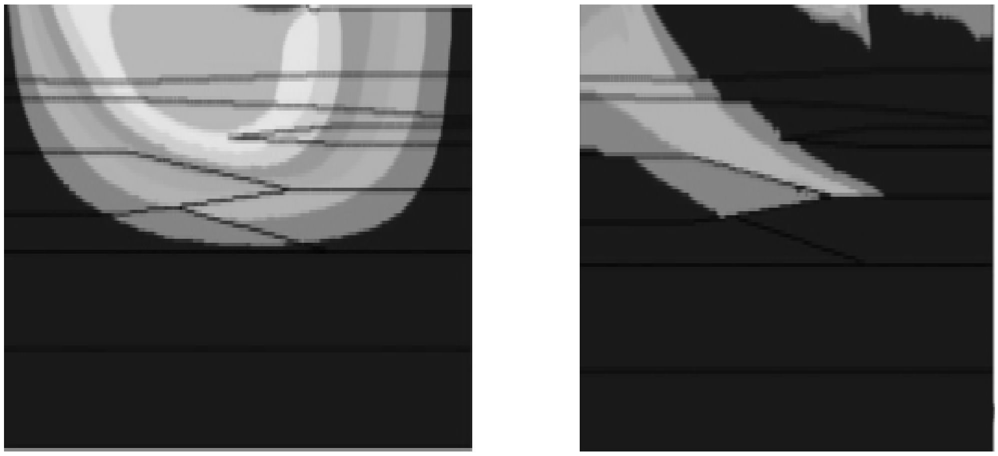

Figure 2. *(a) Horizontal displacement cloud map and (b) equivalent plasticity cloud map*

Figure 2 shows that the calculation results in this area lack convergence, the sliding body has suddenly increased displacement, and the plastic zone is connected, indicating that the forest ecosystem has poor slope stability. Simulation experiments should be conducted to simulate the forest ecosystem restoration process. The simulation is specifically as follows.

Simulation experiment of restoration

Overview of the study area

The western margin of the Sichuan Basin includes the Wenchuan earthquake-stricken area. The Wenchuan earthquake-stricken area consists of Wenchuan County, Pingwu County and an County. The earthquake-stricken area is gradually elevated from east to west. The climate change in the earthquake-stricken area is relatively obvious, the water system is highly developed, various lakes and wetlands have been formed, and the forest ecosystem is relatively rich. In this paper, samples were randomly selected from the forest ecosystem in this area for simulation experiments. The sample plot selection process is as follows.

Sample plot setting

The sample plots with consistent slope and aspect were selected from this area, about 20 m × 20 m in dimension. In order to reduce the difference from other external environmental factors, the sample plot should be located in a relatively independent open area. Open-top boxes were built in open spaces with the following method. First, a square pit of about 3.2 m × 3.2 m × 1 m was dig underground. Bricks were used to build walls around the pit. With the ground as a reference plane, the wall was 20 cm higher than the ground. First, the pit was filled with gravel, then cement was paved on top of the gravel, and finally tiles were paved at the bottom and around the pit. Details are shown in *Figure 3.*

The open-top box repaired according to the above steps has good leak-proof function, and the inner diameter of the open-top box is 3 m × 3 m × 0.8 m. The water outlet holes were built on the top and bottom of the open-top box, with one on the upper and lower sides each. The surface runoff and soil infiltration water was collected through the water outlet holes. After the open-top box was built, soil was added to the

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open-top box. The soil of the selected area was collected and filled according to the corresponding soil layer. That is, the soil of the same level was filled to the same level. On this basis, the restoration process of simulated forest ecosystem was observed, and the observation time of forest ecosystem restoration was set to 14 months to analyze the restoration process. The analysis results are as follows.

a b c

Figure 3. *The construction process of the simulation experiment platform. (a) After hollowing out the soil. (b) The finished open-top box. (c) Open-top box after planting*

Changes in vegetation quantity characteristics

When experimentally simulating the forest ecosystem restoration process, the changes in the vegetation quantity characteristics in the forest ecosystem should be analyzed, mainly from the two aspects of community quantity characteristics and biomass change characteristics of the community plant functional groups. The altimeter was mainly used to measure the community in the test, and the biomass was estimated by establishing the regression equation between biomass and easily measurable indicators. The analysis results are as follows.

Table 1 shows that with the continuous advancement of time, the forest ecosystem restoration community displays good restoration ability, with the number of species, aboveground biomass and underground biomass continuously increasing in the community. The number of species, above ground biomass and underground biomass was $19.68 \pm 1.64 \rho/g \cdot m^2$, $441.94 \pm 32.22 \rho/g \cdot m^2$ and $1296.92 \pm 63.93 \rho/g \cdot m^2$ respectively at the most. The final number of forest ecosystem species was about twice that of the initial number, the final aboveground biomass and underground biomass were about three times of the original. That is, the forest ecosystem is amid gradual restoration at a fast speed. At the same time, *Table 2* shows that the biomass variation amplitude varies depending on different plant functional groups in the community. Where, Poaceae and broad-leaved herb changed greatly, while Cyperaceae did not change, indicating that the phytoremediation abilities vary depending on different species in the forest ecosystem.

Soil microbial biomass carbon

Soil microbial biomass carbon is the most active part of soil organic carbon in forest ecosystem, which has an important impact on the dynamic process of soil organic carbon. This paper mainly analyzes the changes of microbial biomass carbon at different soil layers of 0 cm-10 cm, 10 cm-20 cm and 20 cm-30 cm in soil depths. The image in *Figure 4* shows soil microbial biomass carbon changes with time at the same soil depth.

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Table 1. *Community quantity characteristics*

Time (month)	1	2	3	5	7	9	11	14
Coverage (%)	50.13±1.18	53.14±1.62	57.89±1.23	65.42±1.56	70.18±1.76	76.24±2.01	80.16±2.15	85±2.59
Height (cm)	21.3456	23.5962	25.6871	31.2651	34.3681	37.6589	39.2415	41.3256
Species	6.27±1.39	8.26±1.54	9.13±1.65	11.74±1.43	13.25±1.36	15.36±1.25	17.21±1.43	19.68±1.64
Aboveground biomass (ρ/g•m^2)	182.73±24.17	201.36±26.91	245.68±28.25	296.36±30.59	343.69±62.91	387.94±32.26	401.62±32.31	441.94±32.22
Underground biomass (ρ/g•m^2)	454.91±57.19	502.36±50.46	567.58±55.36	635.49±59.87	859.46±61.25	989.75±65.28	1093.56±62.31	1296.92±63.93
Index	2.2045	2.2102	2.2198	2.2246	2.2357	2.2469	2.2671	2.7293
Pielou index	0.8321	0.8425	0.8514	0.8671	0.8972	0.9026	0.9338	0.9627

Table 2. *Biomass variation characteristics of community plant functional groups*

Time/Month	1	2	3	5	7	9	11	14
Poaceae	195.18±11.07	201.46±13.25	225.68±13.31	264.79±13.91	291.26±15.72	315.49±16.82	345.28±18.59	368.22±19.24
Cyperaceae								69.37±16.32
Broad-leaved herb	61.45±8.84	85.69±8.64	99.81±7.63	125.48±7.49	141.84±7.31	176.31±7.68	190.36±7.36	210.88±7.47
Community biomass	182.73±24.18	201.36±26.18	256.91±26.73	291.76±27.69	347.28±29.16	395.25±30.36	412.87±31.39	440.95±32.34

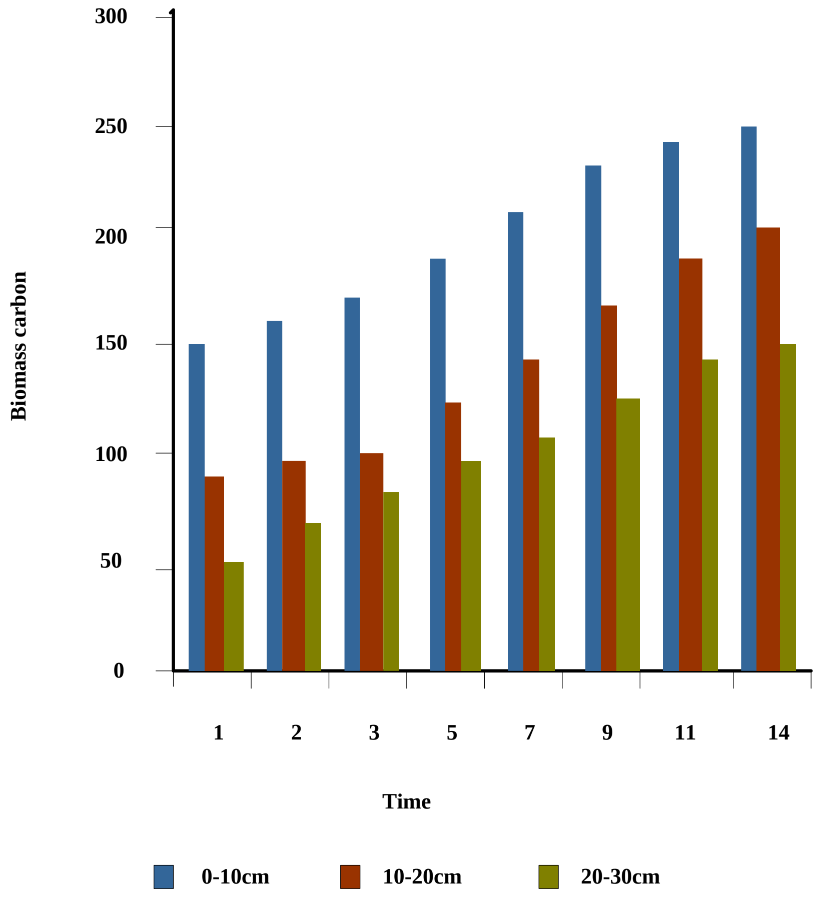

Figure 4. *Changes of biomass carbon content with time*

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Figure 4 shows that the soil microbial biomass carbon content at different soil depths gradually increases over time. In the 14th month of the simulation experiment, the soil microbial biomass carbon content reaches the highest at different soil depths. The soil microbial biomass carbon contents at soil depths of 0 cm-10 cm, 10 cm-20 cm and 20 cm-30 cm are 251.49 w/mg•g-1, 187.64 w/mg•g-1 and 147.62 w/mg•g-1, respectively at the most, indicating that the forest ecosystem is in a state of self-restoration. At the same time, the figure reveals certain differences in soil microbial biomass carbon content at different soil depths. The main reason is that there are certain differences in plant root mass at different soil depths.

Soil enzyme activity

Regarding status of soil nitrogen supply and soil urease activity in the forest ecosystems, the supply of soil available phosphorus can be determined by the alkaline phosphatase activity. The soil physiochemical characteristics during the forest ecosystem restoration were analyzed, with the analysis results shown in *Table 3.*

Table 3. *Soil physicochemical characteristics*

Time	1	2	3	5	7	9	11	14
Bulk density (ρ/g•m2)	1.17±0.05	1.19±0.07	1.23±0.08	1.29±0.09	1.35±0.09	1.39±0.11	1.49±0.10	1.56±0.11
Soil water content (%)	10.41±0.41	12.56±0.58	15.68±0.73	18.73±0.82	19.28±1.14	21.56±1.13	24.68±1.12	26.08±1.19
PH value	6.36±0.03	6.47±0.03	6.69±0.02	6.82±0.04	6.95±0.03	7.12±0.04	7.58±0.03	7.76±0.04
Soil organic matter (w/g•kg-1)	65.12±3.78	71.48±4.36	79.69±4.98	85.46±5.277	90.18±5.74	93.17±5.67	97.28±5.24	105.64±5.79
Total nitrogen (w/g•kg-1)	1.17±0.11	1.39±0.15	1.48±0.19	1.67±0.21	1.79±0.22	1.84±0.23	1.97±0.23	2.23±0.24
Available nitrogen (w/g•kg-1)	9.71±1.19	10.48±1.18	11.57±1.31	13.25±1.37	15.24±1.46	16.28±1.513	18.79±1.59	19.29±1.57
Total phosphorus (w/g•kg-1)	0.53±0.11	0.58±0.14	0.61±0.13	0.66±0.15	0.70±0.16	0.74±0.19	0.80±0.21	0.82±0.21
Available phosphorus (w/g•kg-1)	2.87±0.18	2.96±0.221	3.01±0.21	3.31±0.25	3.75±0.24	4.01±0.23	4.57±0.25	4.86±0.28

According to *Table 3,* each value of soil physiochemical characteristics increases significantly with time. At the14th month of the simulation experiment, each value of soil physiochemical characteristics reaches the maximum value, indicating that the soil physicochemical characteristics of the forest ecosystem are constantly improving with good forest ecosystem self-restoration ability.

The above is the whole process of experimental simulation of forest ecosystem restoration using this method. In order to further prove the effectiveness and importance of this design method, the existing literature methods of Wang et al. (2020) and the method of Ma et al. (2020) are compared with this method to test the accuracy of experimental simulation of changes in vegetation quantitative characteristics of different methods. The results are as shown in *Figure 5.*

It can be seen from *Figure 5* that at the beginning, the prediction accuracy of vegetation quantitative characteristics change of different methods is high, but the accuracy of this method is the highest, 97%. Moreover, with the increase of the simulation experiment time, the accuracy of the method in this paper remains at about

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97%, while the other two methods, with the increase of the test time, have increased the uncertainty, leading to a gradual decline in the accuracy, which is only 80% and 85% respectively. It can be seen that the method in this paper has higher accuracy, better prediction effect and certain application value.

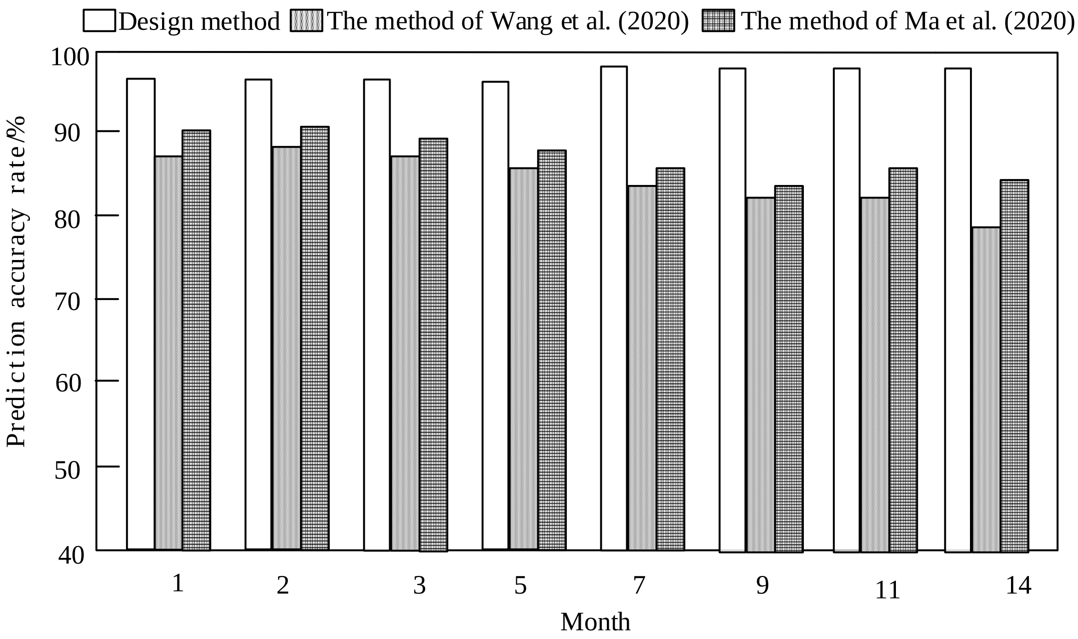

Figure 5. *Comparison of simulation effects of different methods*

Discussion

The above is the whole process of experimental simulation and analysis on the restoration process of forest ecosystem using quasi-static method. The following conclusions can be drawn through simulation experiments.

(1) With the passage of time, the forest ecosystem restoration community showed a good recovery ability, and the number of species, aboveground biomass and underground biomass in the community were increasing. The maximum species, aboveground biomass and underground biomass were 19.68 ± 1.64 respectively $\rho/g\cdot m^2$, 441.94±32.22 $\rho/g\cdot m^2$ and 1296.92 ± 63.93 $\rho/g\cdot m^2$. The final quantity of forest ecosystem species is about twice of the initial quantity, and the final aboveground biomass and underground biomass are about three times of the original quantity. That is to say, the forest ecosystem is gradually recovering at a rapid speed. And there are some differences in soil microbial biomass carbon content in different soil depths. The main reason is that there are some differences in the quality of plant roots in different soil depths. Finally, the soil physical and chemical characteristics increased significantly with time. In the 14 months of the simulation experiment, the soil physical and chemical characteristics reached the maximum, indicating that the soil physical and chemical characteristics of the forest ecosystem were continuously improved, and the forest ecosystem had a good self-recovery ability.

(2) In addition, comparing the method in this paper with the other two methods, it can be concluded that the test accuracy of the design method is higher, with an average accuracy of more than 97%, which is far higher than the other two methods, and the

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experimental simulation effect is more stable. This is because the method in this paper uses the finite element strength reduction method in the quasi-static method to calculate the static safety factor of the slope of the forest ecosystem. The connection of the plastic band and the non-convergence of the calculated results are taken as the criteria for judging the stability imbalance, which improves the analysis effect of the experimental simulation.

Conclusions

Since the ecosystem forms the basis of sustainable regional economic and social development, the research focus of the post-earthquake ecological environment is the forest ecosystem restoration status. In order to study the post-earthquake self-restoration status of forest ecosystem, this paper analyzes the slope stability of forest ecosystem from the perspective of quasi-statics. The poor slope stability of forest ecosystem means that the forest ecosystem is seriously damaged by earthquake. At this time, experimental simulation should be carried out to analyze the process of forest ecosystem restoration. Through the experimental simulation analysis, it is found that the experimental forest ecosystem has a good recovery ability after the earthquake. That is, the post-earthquake experimental forest ecosystem can quickly restore balance without external interference.

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REFERENCES

[1] Feng, J. G., Ding, L. B., Wang, J. S., Yao, P. P., Yao, S. C., Wang, Z. K. (2016): Case-based evaluation of forest ecosystem service function in China. – Chinese Journal of Applied Ecology 27(5): 1375-1382.

[2] Gao, G., Cao, J., Hu, K., Xu, T., Zhang, Y. (2021): Application of nuclear magnetic resonance (NMR) spectroscopy to lacustrine kerogen geochemistry: Paleogene Dongpu Sag, China. – Energy & Fuels 35(2): 1234-1247.

[3] Huang, R., Li, L., Cao, Q., Gao, Y., Luan, T. (2021): Transient simulation model and process simulation analysis of fast cut back process in thermal power plant. – Journal of Physics: Conference Series 1754(1): 012144.

[4] Liu, Y., Chen, B. Z., Chen, J., Xu, G. (2016): Applicability of evapotranspiration simulation model of Qianyanzhou forest ecosystem. – Chinese Bulletin of Botany 51(2): 226-234.

[5] Liu, J., Chen, S., Yang, M., Hu, J., Fang, Y. (2020): Research on the reliability verification and key parameter optimization of numerical simulation of a gas explosion. – Energy Sources Part A Recovery Utilization and Environmental Effects (7): 1-17.

[6] Lu, Y. L., Bo, J. S., Chen, X. R., Wang, L., Lu, T. (2016): Simplified calculation of seismic quasi-static stability of seepage slopes. – Water Power 42(1): 29-33.

[7] Ma, Z. Q., Wang, H. M., Yang, F. T., Fu, X. L., Fang, H. J., Wang, J. H., Dai, X. Q., Kou, L., Zhao, Bo. (2020): Based on long-term observation and research, support the restoration and sustainable development of forest ecosystem in subtropical red soil hilly area. – Journal of the Chinese Academy of Sciences 35(12): 1525-1536.

[8] Mao, X. G., Chen, W. Q., Hu, S., Liu, J. (2017): Simulation and analysis of net primary productivity in Harbin based on ecological process model. – Journal of Northeast Forestry University 45(7): 55-60.

[9] Sobol, A. N., Bogdan, A. V., Uskov, A. E., Denisenko, E. A. (2020): Methodology for simplified calculation of filter parameters of static power converters. – IOP Conference Series: Earth and Environmental Science 488(1): 012040.

[10] Umravia, N. B., Solanki, C. H. (2021): Comparative study of existing cement fly ash gravel pile and encased stone column composite foundation. – IOP Conference Series: Materials Science and Engineering 1197(1): 012002.

[11] Wang, W. J., Han, B. L., Zheng, H., Ouyang, Z. Y. (2020): Change and simulation of ecosystem pattern in Guangdong Hong Kong Macao Greater Bay Area. – Journal of Ecology 40(10): 3364-3374.

[12] Wu, X., Feng, X., Shen, D. (2020): Research on multi-factor regression estimation model of above-ground carbon storage in forest park. – ICGDA 2020: 2020 3rd International Conference on Geoinformatics and Data Analysis.

[13] Wu, H., Yue, Q., Guo, P., Xu, X., Huang, X. (2022): Improving the aquacrop model to achieve direct simulation of evapotranspiration under nitrogen stress and joint simulation-optimization of irrigation and fertilizer schedules. – Agricultural Water Management 266: 107599.

[14] Xie, Y.C., Zhang, S. X., Lin, B., Zhao, Y. J., Hu, B. Q. (2020): Based on the relationship between supply and demand of ecosystem services, the spatial division of county land ecological restoration in Guangxi. – Journal of Natural Resources 35(1): 217-229.

[15] Yan, S. Y., Li, J. Y., Wang, Y. H., Zheng, X. (2022): Evolution and simulation of social ecological system vulnerability in shallow mountainous towns: a case study of Pinggu. – Beijing Journal of Ecology 42(17): 6912-6921.

[16] Zeng, C., Xu, G. S., Zhang, S. W., Wang, T. (2016): Application of force-displacement hybrid control method in quasi-static test of large-scale multifunctional test loading system. – Journal of Vibration and Shock 35(7): 161-166.

[17] Zhang, C., Gao, Y. (2020): Analysis of the force characteristics of the Chinese wooden dou-gong brackets in the ming dynasty. – IOP Conference Series: Earth and Environmental Science 598(1): 012004.

[18] Zhang, Y., Li, Y. (2020): Willingness to pay for tourism ecological compensation and its influencing factors — Taking the best spring in the world in ji'nan as an example. – IOP Conference Series: Earth and Environmental Science 615(1): 012046.

[19] Zhang, L., Jun, L. I., Peilin, G. E. (2020): Discussion on plants of soil and water conservation research in Jiangxi Province. – IOP Conference Series: Earth and Environmental Science 565: 012018.

[20] Zhuang, Y. Z., Huang, F. Y., Qian, H. M., Xiong, Z. H. (2017): Pseudo-static test research on mechanic behavior of PHC piles with soil-pile interaction. – China Journal of Highway and Transport 30(4): 42-51.

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