Numerical Simulation of the Combined Slope Protection Effect of Live Stump and Bamboo Anchor

Yang Hui
Central South Forestry University: Central South University of Forestry and Technology
Yingbo Zhu (1767033243@qq.com)
Central South Forestry University: Central South University of Forestry and Technology
Yong Liu
Guangdong Zhongye Shanhe Construction Engineering Co.Ltd
xueliang Jiang
Central South University of Forestry and Technology
Riwen Deng
Guangdong Zhongye Shanhe Construction Engineering Co.Ltd
Li Huang
Guangdong Zhongye Shanhe Construction Engineering Co,Ltd
Peng yin
Central South Forestry University: Central South University of Forestry and Technology
Guojie Lai
Guangdong Zhongye Shanhe Construction Engineering Co.Ltd

Original Paper

Keywords: Live stump, Bamboo anchor, Deep landslide, Force characteristics, Slope stability

Posted Date: February 1st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-162641/v1

Abstract

Five slope states were selected to research deep protection effect of the living tree stump-bamboo anchor supporting structure. These five states were the natural slope state,the bamboo anchor slope protection state, and the living tree stump-bamboo anchor initial supporting state,living tree stumps-bamboo bolt mid-term support status,living tree stump slope protection status. Three-dimensional numerical models are established by Midas GTS/NX finite element software, and the force characteristics and stability of the living tree stump-bamboo anchor support structure were studied. The results show that: (1) Compared with natural slopes, the relative stability and safety factors of bamboo anchor slope protection, live tree stumps-bamboo anchor initial slope protection, live tree stumps-bamboo anchor mid-term slope protection, and live tree stump slope protection have increased by 18.6%, 19.7%, and 44.0 %, 44.1%, it can be found that the living tree stump-bamboo bolt supporting structure has obvious deep protection effect. (2) In the initial supporting state of live tree stumps and bamboo anchors, the bamboo anchors have the largest stress value at the position where the bamboo anchors are buried at a depth of 5m on the slope; The bamboo anchors in the fourth row and the fifth row are below the buried depth of 6m on the slope, and the stress value of the bamboo anchors increases linearly. (3) The closer to the toe of the slope, the greater the tensile stress generated by the root system on the left side of the living tree stump, and the greater the compressive stress generated by the root system on the right side of the living tree stump. The research results can be used as an important basis for the new living tree stump-bamboo bolt support structure to effectively prevent and control deep-seated slope protection, and it is of great significance to expand the green technology for preventing and controlling deep-seated landslides.

1. Introduction

Ecological construction and environmental protection are hot topics of common concern for mankind in the 21st century. With the development of the national economy, large-scale resource development and infrastructure construction have produced a large number of artificial slopes, causing serious soil erosion and land desertification, forming a large number of exposed slopes. Traditional engineering slope protection technology mostly uses gray protection such as masonry and concrete. For example, anti-slide piles[Deng YS ect.(2016); Zhao FC.(2009)], soil nail walls[Geng XZ etc.(2015)], lattice anchoring structures[Yang B etc.(2014)], reinforced retaining walls[Yang ZW etc.(2013)],etc.These structures destroyed the original vegetation and caused permanent damage to the ecology. Ecological protection technology[Peng C etc.(2010)] is an engineering technology that has emerged with the construction of highways worldwide. Unlike traditional engineering technology, ecological protection technology makes full use of the characteristics of plants, combined with necessary engineering protection, to achieve the purpose of both engineering construction and environmental protection. With more and more attention to environmental protection and quality of life today, plant protection technology has become a trend in slope protection, and represents the development direction of slope protection[Wang B etc.(2020)].

Vegetation slope protection[Katrin B etc.(2009)] is a green protection measure, and its effect is based on the stability of the slope itself. At the same time, the rationality of the vegetation slope protection design

is directly related to the slope reinforcement effect. The slope protection effect of herb plants[Hao ZF.(2014)] is mainly to enhance the anti-scouring ability of the slope and reduce soil erosion. The slope protection effect of woody plants[Ding W etc.(2017)] is even more significant. Due to its well-developed root system, it can not only prevent shallow landslides[Peng AQ etc.(2012);Tien H etc.(2014)], but also has a good slope protection effect on deep landslides[Xu ZM etc.(2005); Lon D etc.(1998)]. In recent years, many scholars at home and abroad have done a lot of research on woody plant root system slope protection. For example: using mechanical model analysis and calculation[Wu P etc.(2014);Zhu XH etc.(2009);Donn S etc.(2014)], numerical simulation[Li XE etc.(2018);Fu HF etc,(2007);Wang HX.(2018)], similar material simulation experiments, and field tests, etc. A large amount of information and data have been obtained, which is of great significance for studying the theory and technology of woody plant root system slope protection.Huang Shaoping[Huang SP etc.(2018)] analyzed the influence of different parts of woody plants on the stability of soil slopes. It is believed that the interception and transpiration of plant stems and leaves are beneficial to the stability of slopes, but they are greatly affected by wind; The acidic substances produced by the decomposition products of litter and vegetation derivatives will erode the slope soil; The reinforcement of plant roots improves the stability of the slope by increasing the shear strength of the soil, and the pore formation increases the porosity of the soil and reduces the stability of the slope. Han Liliang et al.[Han LL etc.(2015)] studied the mechanical properties of the roots of 4 woody plants (elm, amorpha, black locust, and lespedeza). It is concluded that the root tensile strength increases as the root diameter increases, and the tensile strength decreases as the root diameter increases. Zhu Haili et al.[Zhu HL etc.(2008)] based on the mechanical properties of the root systems of four shrubs, Caragana korshinskii, Nitraria tangutorum, Bawang, and Atriplex in the loess area of the Qinghai-Tibet Plateau, combined with root morphological characteristics. Li Guorong et al. [Li GR etc.(2010)] established a shrub plant root-soil complex slope model using ANSYS finite element software. The slope displacement field, slope shear stress distribution and slope stability are analyzed. Xiao Shengxie et al.[Xiao SX etc.(2006)] conducted a systematic analysis from three aspects: the ability of woody plant roots to protect rock slopes with different structures, the tangential strengthening ability of plant roots to slopes, and the strengthening ability of matrix-root complexes.

Aiming at the research of plant prevention and control of deep landslides, this paper studies the mechanical characteristics and slope stability of the new supporting structure of living tree stump-bamboo bolt. A three-dimensional slope model was established using the finite element software Midas GTS/NX. Discuss the maximum shear stress distribution and stability analysis of natural slope, bamboo anchor slope protection, live tree stump-bamboo anchor initial support, live tree stump-bamboo anchor mid-term support, and live tree stump slope protection. The stress distribution law of bamboo anchors[Li YB etc.(2000);Sun ML etc.(2011)] and live tree stumps[Xu ZH etc.(2004);Yue JS etc.(2009);A.E.Hunolt etc.(2013)]. The research has filled the gap of plant prevention and control of deep landslides and is of great significance.

2. Slope Protection Form

The whole life cycle of living tree stump-bamboo bolt joint slope protection technology includes three stages:

Stage 1: The frame beam at the slope surface and the bamboo anchor rod group in the slope body constitute the anchor system for the stable slope in the early stage to ensure the stability of the slope before the live tree stumps fully exert their effects.

Stage 2: As the roots of the living tree stumps gradually grow vigorously, the interaction between the living tree stumps and the soil is used to ensure the stability of the soil slope together with the bamboo anchor that has not completely lost its function.

Stage 3: When the root system of the living tree stump grows to a certain extent and the bamboo anchor completely loses its anchoring effect, the interaction between the living tree stump and the soil is used to play the role of deep stabilization of the slope.

3. Numerical Analysis

3.1Establishment of calculation model

Aiming at the bamboo anchor-living tree stump slope protection technology, a three-dimensional finite element model of the slope is established: The length L is 40m, the width B is 12m, the slope height Hs is 8m, and the slope foot α is 45°. The frame beam adopts bamboo plywood rectangular beam with a width of 0.15m and a height of 0.4m; the diameter of the bamboo anchor is 0.05m. In the modeling process, the influence of the branches and leaves above the slope on the slope is ignored. Assuming that the burial depth of the living tree stump slope is 2m and the diameter is 0.05m; When the buried depth of the main root slope surface of the living tree stump reaches 3m, the diameter is 0.075m, and the diameter of the side root is 0.015m～0.0375m; When the buried depth of the main root slope surface of the living tree stump reaches 4m, the diameter is 0.1m, and the diameter of the lateral root is 0.02m～0.05m. The specific model material parameters are shown in Table 1.

Table 1 Model material parameters

Material	Elastic Modulus /MPa	Bulk density /(kN·m-3)	Poisson's ratio μ	Cohesion c/kPa	Internal friction angle/°	Thickness/m
Soil	12	15.2	0.33	16	24	6.3
Frame beam	14900	9	0.34	—	—	—
Bamboo anchor	40000	15	0.28	—	—	—
Bamboo anchor (partial loss)	20000	15	0.28	—	—	—
Live stump	200	10.5	0.394	—	—	—

This paper uses Midas GTS to perform three-dimensional numerical simulation of the slope. The model is shown in Figure 2 and Figure 3.

According to the bamboo anchor-living tree stump combined slope protection technology, the model is divided into five working conditions for slope stability analysis. The simulated working conditions are shown in Table 2.

Table 2 Simulation conditions

Working condition	Slope protection	Buried depth of live stump/m	Stress state of bamboo anchor
1	Natural slope	-	-
2	Slope protection with bamboo bolt	-	No loss
3	Living tree stump-bamboo bolt initial slope protection	2	No loss
4	Living tree stump-bamboo bolt mid-term slope protection	3	Partial loss
5	Slope protection with live stumps	4	Total loss

3.2 Analysis of simulation results

3.2.1 The maximum shear stress distribution and stability analysis of soil slopes

Calculated by Midas GTS/NX finite element software, the maximum shear stress distribution of natural slope is shown in Figure 4. In the state of a natural slope, the soil is subjected to the greatest stress at the 3m depth of the slope angle, and its stress range presents an elliptical shape. There is a large shear stress at the 4.5m depth of the top of the slope, which extends to the lower right to form a shallow sliding surface. When the slope encounters rainwater seepage, the damage of the slope further develops, and the

position of the potential maximum shear stress on the slope will form a slender slip zone, causing the slip damage of the slope.

Calculated by Midas GTS/NX finite element software,the maximum shear stress distribution of bamboo anchor slope is shown in Figure 5.In the state of bamboo anchor protection, there is a small range of stress concentration at the position of the bamboo anchor on the slope. There is a large shear stress at the buried depth of 2.5m at the foot of the slope, showing a circular shape. Compared with the natural slope state, the potential maximum stress area of the slope is shallower, the stress concentration range is smaller, and the slope stability safety factor has increased by 18.6%, indicating that the bamboo anchor can significantly enhance the slope stability. It can be seen from the stress cloud diagram that the contact area between the bamboo anchor and the frame beam should be appropriately increased to reduce the stress concentration.

Calculated by Midas GTS/NX finite element software,figure 6 shows the distribution of maximum shear stress of live tree stumps and bamboo anchors with a buried depth of 2 meters.According to the comparison between Fig. 6 and Fig. 5, the stress cloud diagram of the combined slope protection state of live tree stumps with a buried depth of 2m and bamboo anchors is consistent with that of bamboo anchors. Compared with the natural slope state, the safety factor of slope stability has increased by 19.7%. It can be seen that the live tree stumps with a buried depth of 2m have little effect on the stability of the slope, and the slope protection effect is not obvious.

Calculated by Midas GTS/NX finite element software, the maximum shear stress distribution of the slope with a buried depth of 3 meters and live tree stumps and bamboo anchors (partial loss) is shown in Figure 7. The maximum shear stress cloud map of the combined slope protection of live tree stumps with a buried depth of 3m and bamboo anchors (partial loss) has two areas with the highest stress, respectively at the 3m buried depth and 7.5m buried depth of the slope. Comparing with Figure 7, it can be seen that the living tree stump with more developed root system interacts with the soil, which makes the potential maximum stress area of the slope change from shallow to deep, and the maximum shear stress value decreases. Compared with the natural slope state, the safety factor of slope stability has increased by 44%. It can be seen that live tree stumps with a buried depth of 3m can significantly improve slope stability.

Calculated by Midas GTS/NX finite element software, the maximum shear stress distribution of the live tree stump slope with a buried depth of 4 meters is shown in Figure 8. According to the comparison between Fig. 8 and Fig. 7, the stress concentration range of the live tree stump slope protection state with a buried depth of 4m is reduced, and the maximum shear stress value is also reduced. Compared with the natural slope state, the safety factor of slope stability has increased by 44.1%. It can be seen that the stability of the slope in the state of the slope protection of the live tree stumps with a buried depth of 4m is much smaller than that of the combined slope protection of the live tree stumps with a buried length of 3m and bamboo anchors (partial loss).

In summary, during the combined slope protection of living tree stumps and bamboo anchors, the maximum stress area in the slope body changes from shallow to deep, the range of stress concentration gradually decreases, and the maximum shear stress value decreases. Compared with natural slopes, bamboo anchor slope protection, living tree stumps with a buried depth of 2m and bamboo anchors combined slope protection, 3m living tree stumps with a buried depth of 3m and bamboo anchors (partial loss) combined slope protection, and a buried depth of 4m live tree stumps The stability safety factor was increased by 18.6%, 19.7%, 44.0%, 44.1% in turn, the slope stability safety factor increased significantly, and the slope protection effect was obvious.

3.2.2 Stress analysis of bamboo anchor

Calculated by Midas GTS/NX finite element software, the stress distribution of the bamboo anchor in the bamboo anchor slope is shown in Figure 9. Under the condition of working condition 2, the stress value of bamboo anchor first increases and then decreases along the length direction. At the position of 5m in length of the bamboo anchor, the stress value basically reaches the maximum. When the length of the bamboo bolt is between 0m and 4m, the stress value of the bamboo bolt increases linearly. When the length of the bamboo anchor rod is between 4m and 5m, the stress value of the anchor rod in the middle position of the first row increases slowly, and the stress value of the anchor rod in the middle position of the second row to the fifth row increases rapidly. When the length of the bamboo anchor rod is between 5m and 8m, the stress value of the anchor rod in the middle of the first row gradually decreases until it stabilizes; The stress value of the anchor rod in the middle position of the second row decreases rapidly in a straight line, and the length of the bamboo anchor rod gradually decreases at the position of 7m; The stress value of the anchor rod in the middle of the third row gradually decreases; The stress value of the anchor rod in the middle of the fourth row increases slowly, and the length of the bamboo anchor rod gradually decreases at the position of 6m; The stress value of the anchor rod in the middle of the fifth row gradually decreases first, and the length of the bamboo anchor rod begins to stabilize at the position of 7m.

Calculated by Midas GTS/NX finite element software, figure 10 shows the stress distribution of bamboo anchors in the slope of 2m live tree stumps and bamboo anchors. Under the condition of working condition 3, when the length of the bamboo anchor rod is between 0m and 4m, the stress value of the bamboo anchor rod in the middle position increases gradually; Among them, the stress value of the bamboo anchor in the middle of the third row is the largest. When the length of the bamboo bolt is between 4m and 8m, the stress value of the bamboo bolt in the middle of the first row basically rises slowly; The stress value of the bamboo anchor in the middle of the second row increases first and then gradually decreases; The stress value of the bamboo anchor in the middle of the third row increases first, then decreases, and then gradually increases; The stress value of the bamboo anchor in the middle of the fourth row shows a gradually rising trend; The stress value of the bamboo anchor in the middle of the fifth row increases firstly, then slowly increases, and then increases rapidly. Among them, the length of the bamboo anchor in the middle of the fifth row has the maximum stress value at 8m, which is 300MPa.

To sum up: when only bamboo anchor rods are used to reinforce the soil slope, it can be judged from the change law of the stress value of the bamboo anchor rod along the length direction that the deep sliding zone of the soil slope is at 5m of the bamboo anchor rod length. At the foot of the slope, the stress value of the bamboo anchor is larger, and it can be concluded that the slope reinforcement at the middle and lower positions of the slope is more critical. When the bamboo anchor rod has not completely lost its function, the living tree stump grows to 3m, and the root system is relatively developed, the stress value of the bamboo anchor rod □ and □ basically does not change. The stress value of the bamboo bolt(□,□,□) increases linearly between the length of the bamboo bolt from 6m to 8m.

3.2.3 Stress analysis of live tree stumps

Calculated by Midas GTS/NX finite element software, the stress distribution of live stumps in the 2m live stump slope is shown in Figure 11. when the buried depth of the live tree stump slope is 2m, without roots, the live tree stumps in the first, second, third and fourth rows all have compressive stress; The fifth and sixth rows of live tree stumps produce tensile stress, and the deeper the live tree stump, the greater the tensile stress.

Calculated by Midas GTS/NX finite element software, the stress distribution of the 3m live tree stump is shown in Figure 12. when the buried depth of the live tree stump slope is 3m and the root system is relatively developed, the first and second rows of live tree stumps and their root systems all have tensile stress; The third, fourth, fifth and sixth rows of live tree stumps generate tensile stress. The closer the root system of the live tree stump is to the toe of the slope, the greater the tensile stress generated by the root system on the left side of the live tree stump; The greater the compressive stress generated by the root system on the right side of the live stump.

Calculated by Midas GTS/NX finite element software, the stress distribution of live stumps in the 4m live stump slope is shown in Figure 13. when the depth of the slope surface of the live tree stump is 4m and the root system is very developed, the stress law of the live tree stump and its root system is consistent with the condition of working condition 3.

In summary, the closer the live stump is to the toe of the slope, the greater the tensile stress generated by the root system on the left side of the live stump; The greater the compressive stress generated by the root system on the right side of the live stump. According to the stress distribution law of the living tree stump and its root system in the soil slope, sufficient nutrients and water can be injected into the left root system of the living tree stump to promote the directional growth of the root system, thereby improving the stability of the soil slope.

4. Conclusion

This paper introduces the structural form of the living tree stump-bamboo bolt slope protection, and the mechanical characteristics and stability of the living tree stump-bamboo bolt supporting structure are studied by means of numerical analysis.

1. During the slope protection process of living tree stump-bamboo anchor support structure, the maximum stress area in the slope body changes from shallow to deep, the range of stress concentration gradually decreases, and the maximum shear stress value decreases. The safety factor of slope stability has been significantly increased, and the slope protection effect is obvious.

2. The stress value of the bamboo anchor at the foot of the slope is relatively large. As time goes by, when the bamboo anchor has not completely lost its function, the tensile stress value of the bamboo anchor at the slope toe will increase rapidly.

3. The closer the live stump is to the toe of the slope, the greater the tensile stress generated by the root system on the left lower side of the live stump; The greater the compressive stress generated by the root system on the lower right side of the live stump.

4.The living tree stump-bamboo anchor joint structure slope protection plays a role of reinforcement and soil consolidation on the slope, which effectively improves the anti-sliding force of the slope. As the living tree stump continues to grow, its root system is more and more developed, which will greatly improve the safety factor of the slope soil.

The above conclusions have reference value for the design of ecological slope protection in the future. The combined structure of living tree stump and bamboo anchor rod can not only effectively achieve the purpose of stabilizing the slope, but also conform to the current development trend of protecting the ecological environment. However, it is worth noting that in the process of continuous growth of living tree stumps, the longer and taller the tree stumps may be, adversely affecting the slope soil. Therefore, live tree stumps must be properly cut in a certain period of time. The method used in this article is a qualitative analysis of ecological slope protection, which can only serve as a starting point for inducing jade. In some places, further research is needed.

Declarations

Author contribution

Ying bo Zhu and Yong Liu contributed to the conception of the study;

Xueliang Jiang performed the experiment;
Riwen Deng contributed significantly to analysis and manuscript preparation;
Li Huang and Peng Yin performed the data analyses and wrote the manuscript;

Guojie Lai helped perform the analysis with constructive discussions.

Data Availability Statement

The relevant data, models and conclusions of this article are analyzed and compiled by the author.

Conflict of interest

The authors declared that they have no conflicts of interest to this work.

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted

Acknowledgements

This work was supported by the National Natural Science Foundation of China[Grant nos.31971727]and the Hunan Provincial Natural Science Foundation of China[Grant Number.2018JJ3882,2020JJ4944]and the project of Hunan Education department[Grant Number.18A162]and the Hunan Province Work Safety Prevention and Emergency Special Fund Project in 2019.

References

A.E.Hunolt,E.F. Brantley,J.A.Howe,A.N. Wright,and C.W. Wood.(2013)Comparison of native woody species for use as live stakes in streambank stabilization in the southeastern United States[J]. Journal of Soil and Water Conservation.68(5):384-391.http://doi:10.2489/jswc.68.5.384.

Donn S,Wheatley RE,McKenzie BM etc.(2014)Improved soil fertility from compost amendment increases root growth and reinforcement of surface soil on slopes[J].Ecological Engineering 71:458-465.http://dx.doi.org/10.1016/j.ecoleng.2014.07066.

Deng YS, Xu WT,Liu HF,Yao ZG.(2016)The influence of rainfall on soil slope and vegetation system and anti-slide piles[J]. Highway Engineering,41(02): 6-9+18.

Ding W, Sun SL, Chen YY, Chu H, Zhang L.(2017)Analysis of the influence of woody plant roots on slope stability [J]Journal of Hebei University of Engineering (Natural Science Edition), 34(03): 27-31 .

Fu HF,Jiang ZQ, Zhang SF. (2007)Simulation of slope consolidation effect and numerical analysis of stability of plant roots[J]. Bulletin of Soil and Water Conservation,(01): 92-94+98.

Geng XZ, Luo FJ, Li P, Yan YT, Chen Z, Shao YS, Zeng J. (2015)Application of composite supporting technology of soil-nailed wall and anchored slope protection piles[J].Construction Technology,44(S1): 21-twenty four.

Huang SP, Yan EC.(2018)The influence of different parts of woody plants on the stability of soil slope[J]. Safety and Environmental Engineering,25(03): 21-26.

Han LL, Song GL.(2015)The mechanical properties of slope protection woody plant roots and their relationship with cell wall components[J].Journal of Beijing Forestry University,37(11):120-127.

Hao ZF. (2014) Study on the soil-fixing ability of herbaceous plant roots on the cut side slope of expressway[D]. Sichuan Agricultural University.

Katrin B,Frank G and Albert B.(2009)Revegetation measures improve soil aggregate stability: a case study of a landslide area in Central Switzerland[J].Snow Landsc. Res 82(1):45–60.

Lon D,Rick L.(1998)Deep-Planting Willow Cuttings Via Water Jetting[C].Wetlands Engineering and River Restoration Conference,Denver,US,1046-1051.

Li GR,Hu XS,Mao XQ, etc.(2010)Numerical simulation of slope protection effect of shrub plant roots in the loess area of the northeastern Qinghai-Tibet Plateau[J]. Chinese Journal of Rock Mechanics and Engineering,29(09): 1877-1884.

Li XE,Xie CY,Li Y, etc.(2018)Finite element numerical analysis of plant root system slope protection[J].Journal of Southwest China Normal University(Natural Science Edition),43(02): 76-82.

Li YB, Su XG, Zhang ZQ.(2000)Experimental research on new anchored bamboo bolts[J].Well Construction Technology, (01): 30-32.

Peng C,Xu ZP. (2010)The application of ecological bag retaining wall and slope protectiontechnology in the canal channel regulation project[J]. Water Resources Planning and Design, (05): 100-102.

Peng AQ,Wu JH,Jin S.(2012)Research on the technology of shallow landslide control plant slope protection[J].Roadbed Engineering,(02): 124-127.

Sun ML,Wang XD,Li ZX,Zhang JK.(2011)Research on the bonding force of Nanzhu anchor rods to strengthen soil sites[J].Dunhuang Studies,(06): 81-84.

Tien H etc.(2014)Use of Live Poles for Stabilization of a Shallow Slope Failure[J].Geotech.Geoenviron.Eng.140(10).https://doi.org/10.1061/(ASCE)GT.1943-5606.0001161.

Wu P,Xie PC,Song WL, etc. (2014)Root system mechanics based on root morphology and mechanism of soil stabilization and slope protection[J].Journal of Northeast Forestry University, 42(05): 139-142.

Wang B,Wang W,Xie WJ.(2020)Application of ecological blocks in highway slope protection construction[J].Highway, 65(06): 249-251.

Wang HX. (2018)Numerical analysis of the influence of plant root system on the stability of roadbed slope[D]. Northeast Forestry University.

Xiao SX, Zhou H, Ling TQ.(2006)Reinforcement mechanism and ability analysis of plant roots in slope protection engineering[J]. Chinese Journal of Rock Mechanics and Engineering,(S1): 2670-2674.

Xu ZH, Xiao FG, Chen JJ, Wang JH, Feng JC.(2004)Numerical analysis of the influence of living tree stumps on slope stability[J]. Rock and Soil Mechanics,(S2): 275-279.

Xu ZM, Huang RQ, Tang ZG, Wang SD. (2005)Limitations of vegetation slope protection and its contribution to deep landslides[J]. Chinese Journal of Rock Mechanics and Engineering, (03):438-450.

Yue JS, Li H,Chen KQ, Shen YP.(2009)The application of living wood pile soil-fixing andgrass-planting technology in highway soil slope protection[J]. Highway and Transportation Science and Technology (Applied Technology Edition),5(10): 174- 176.

Yang B, Shi ZD.(2014)The application of lattice anchoring structure in slope engineering[J].Science and Technology Information,12(36): 26+28.

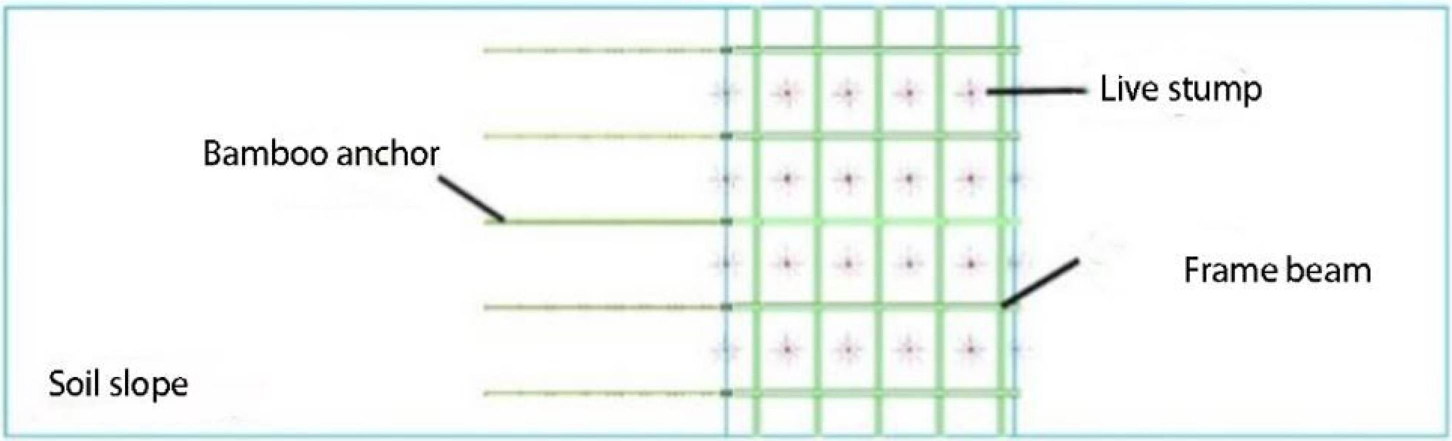
Yang ZW,Li T,Zhu YJ.(2013) Study on the reinforced retaining wall structure of ecological bag slope protection[J]. Shanxi Architecture,39(19): 126-128.

Zhu HL,Hu XS, Mao XQ, et al.(2008)Study on mechanical properties of shrub plant roots for slope protection in loess areas of the Qinghai-Tibet Plateau[J]. Chinese Journal of Rock Mechanics and Engineering,(S2): 3445-3452.

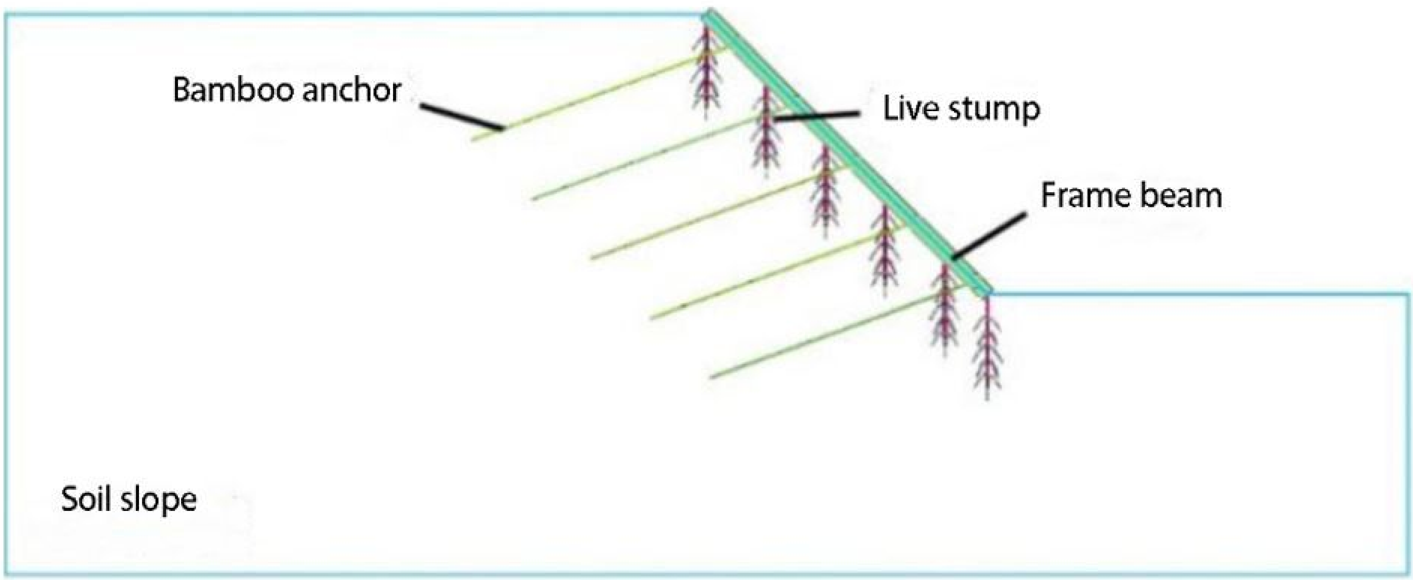
Zhu XH,Zhang LJ,Guo ZY, etc.(2009)Mechanical mechanism and simulation of plant slope protection for high-steep composite slopes[J]. Mining Research and Development,29(05):34-36.

Zhao FC.(2009)Application of anti-slide piles in the treatment of slope slippage at the UHV Jingmen Substation[J].Electric Power Construction,30(10): 26-29.

Figures



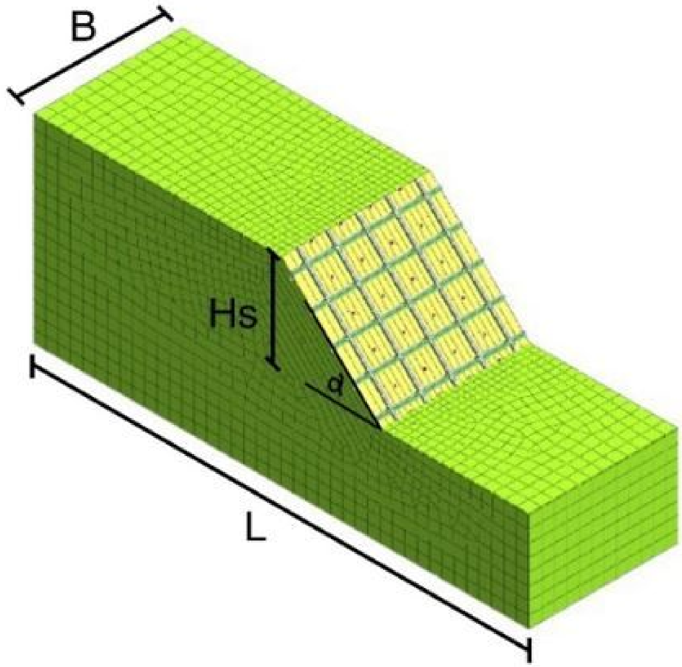
(a) Top view



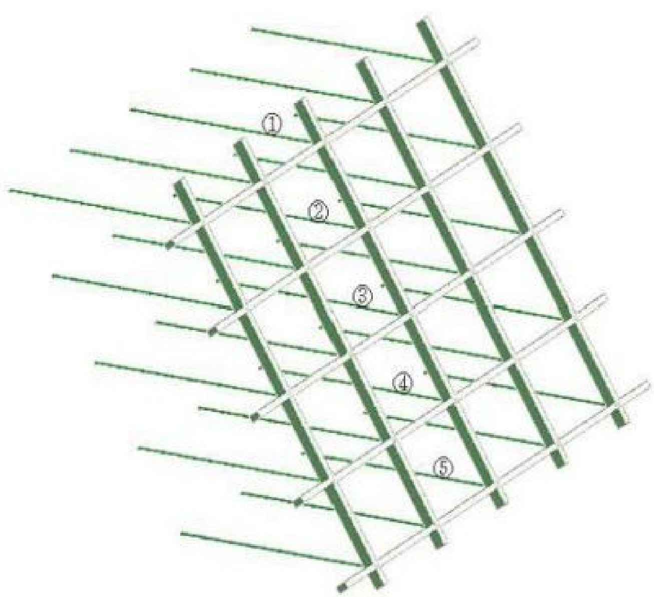
(b) Front view

Figure 1

Live stump-bamboo anchor supporting structure



(a) Global picture



(b) Partial picture

Figure 2

Three-dimensional finite element model of slope

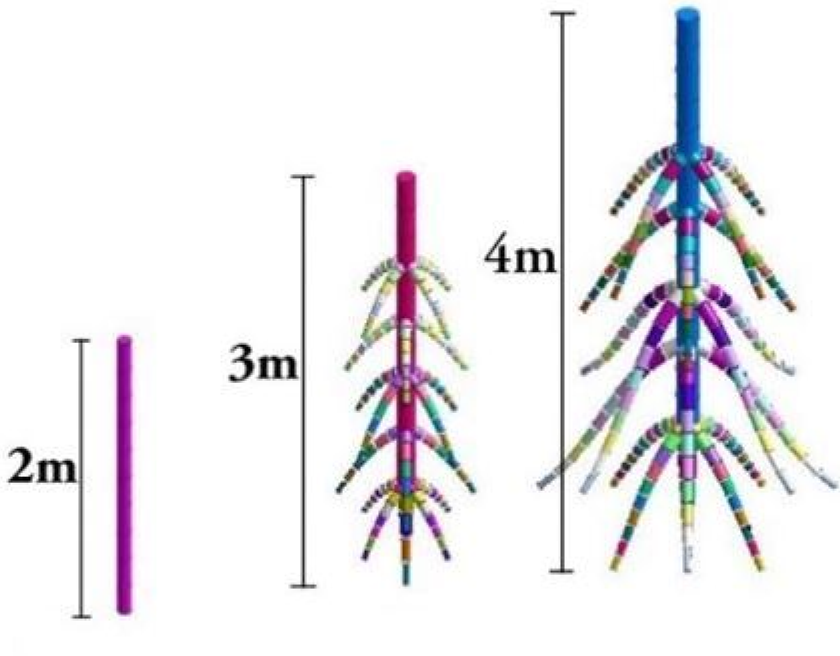


Figure 3

Three-dimensional finite element model of live stumps with different depths

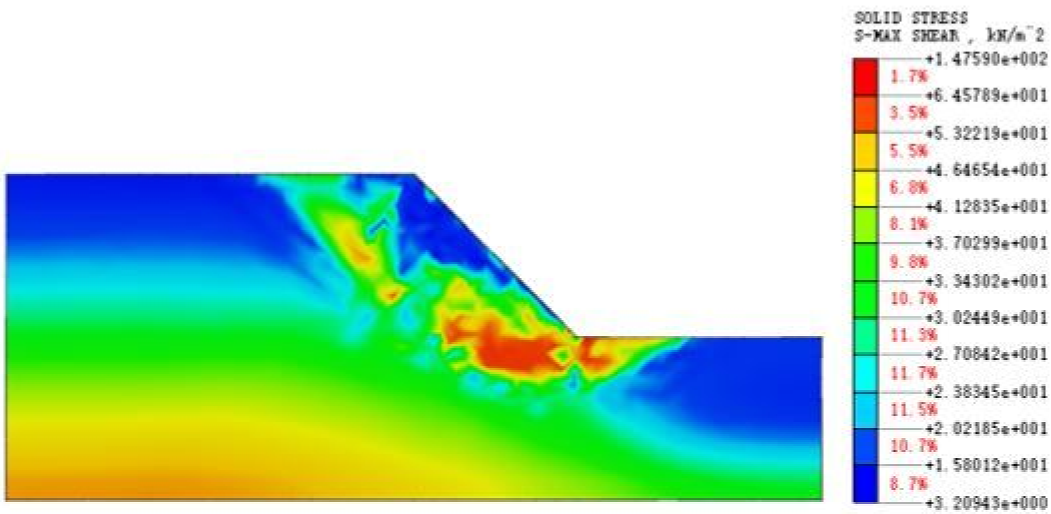


Figure 4

Cloud diagram of maximum shear stress of slope under condition 1

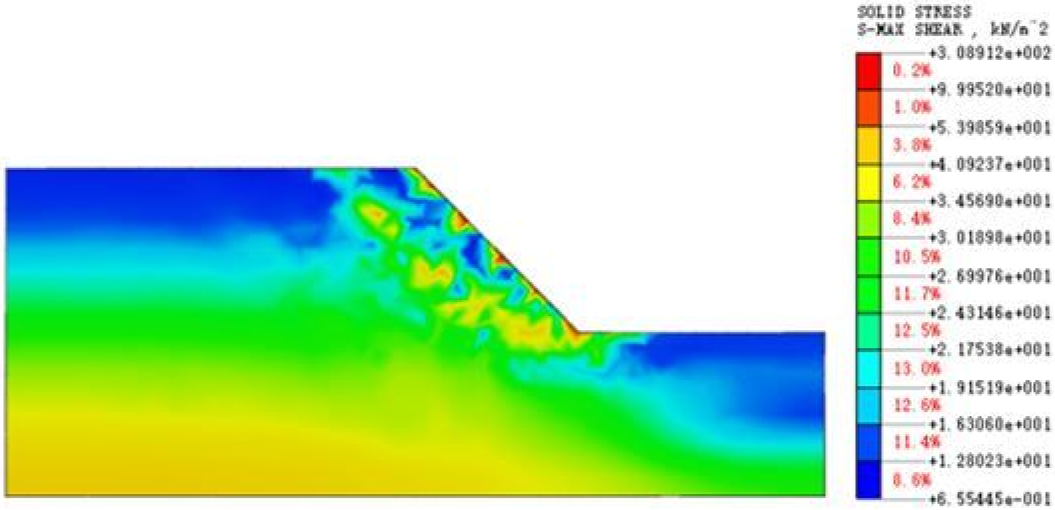


Figure 5

Cloud diagram of maximum shear stress of slope under condition 2

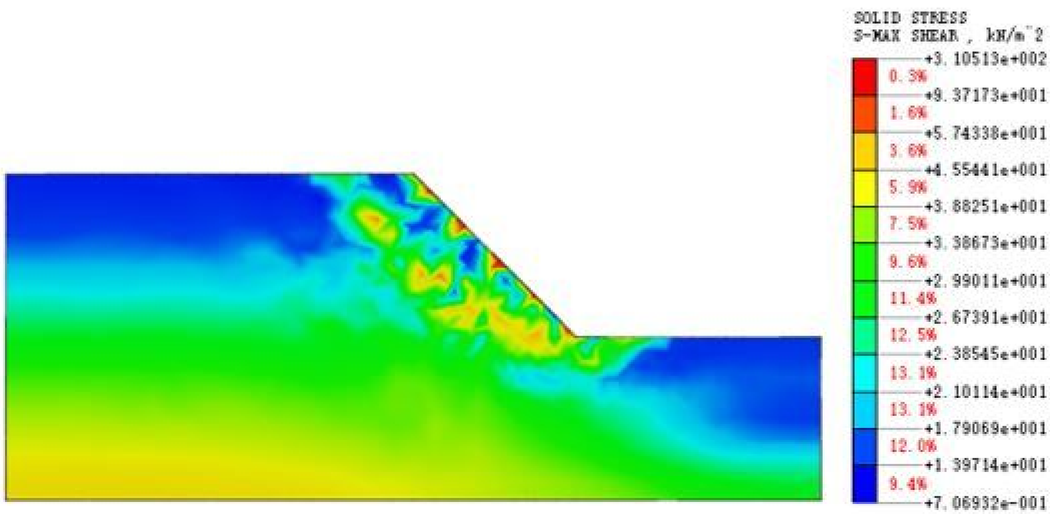


Figure 6

Cloud diagram of maximum shear stress of slope under condition 3

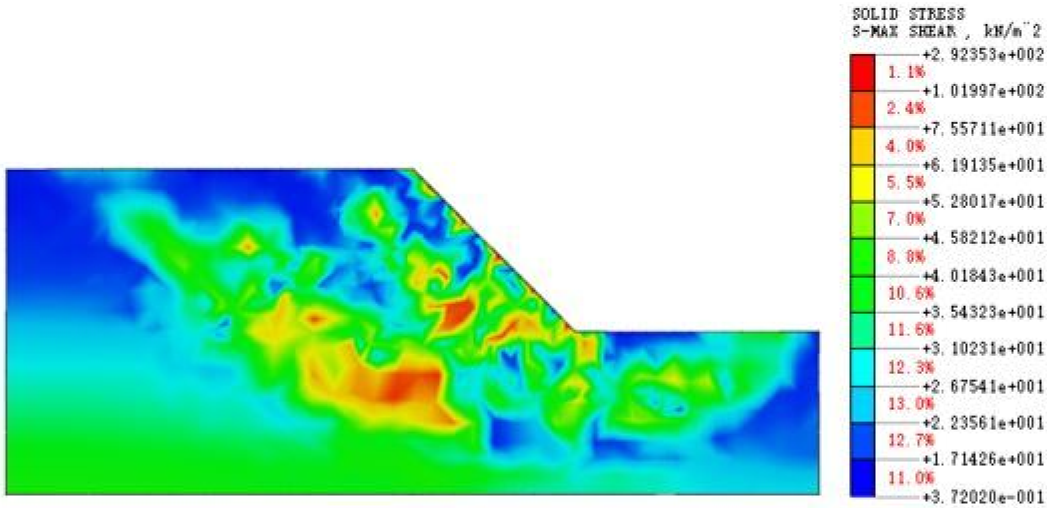


Figure 7

Cloud diagram of maximum shear stress of slope under condition 4

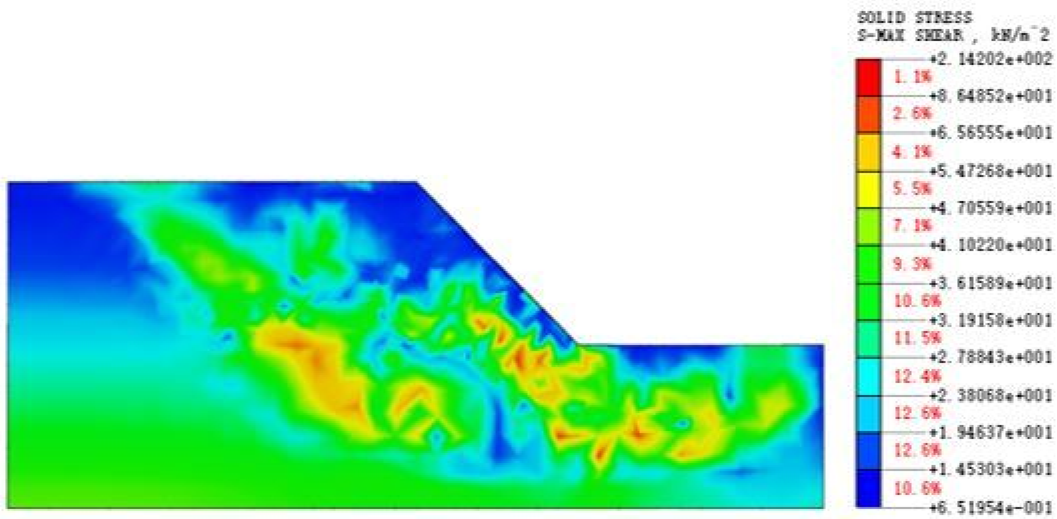


Figure 8

Cloud diagram of maximum shear stress of slope under condition 5

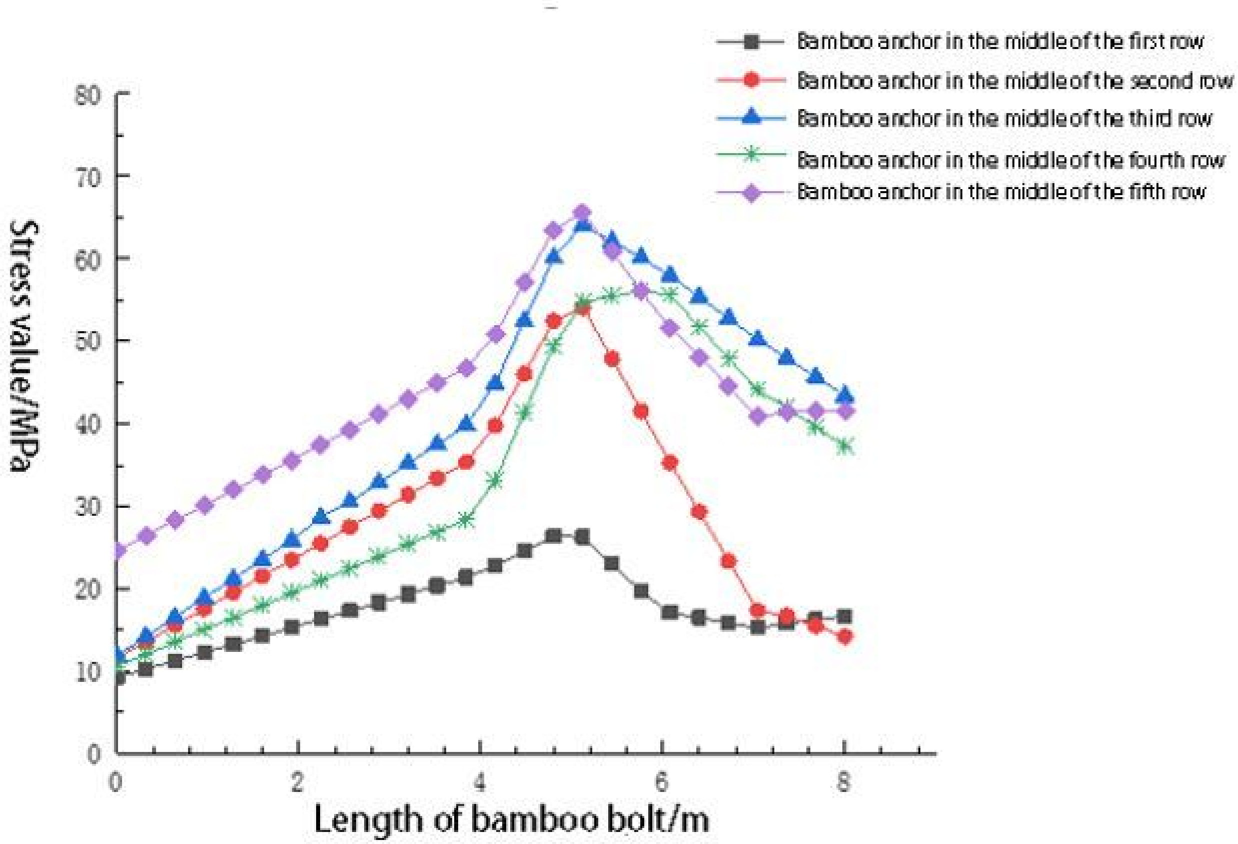


Figure 9

Stress of bamboo anchors under the condition 2

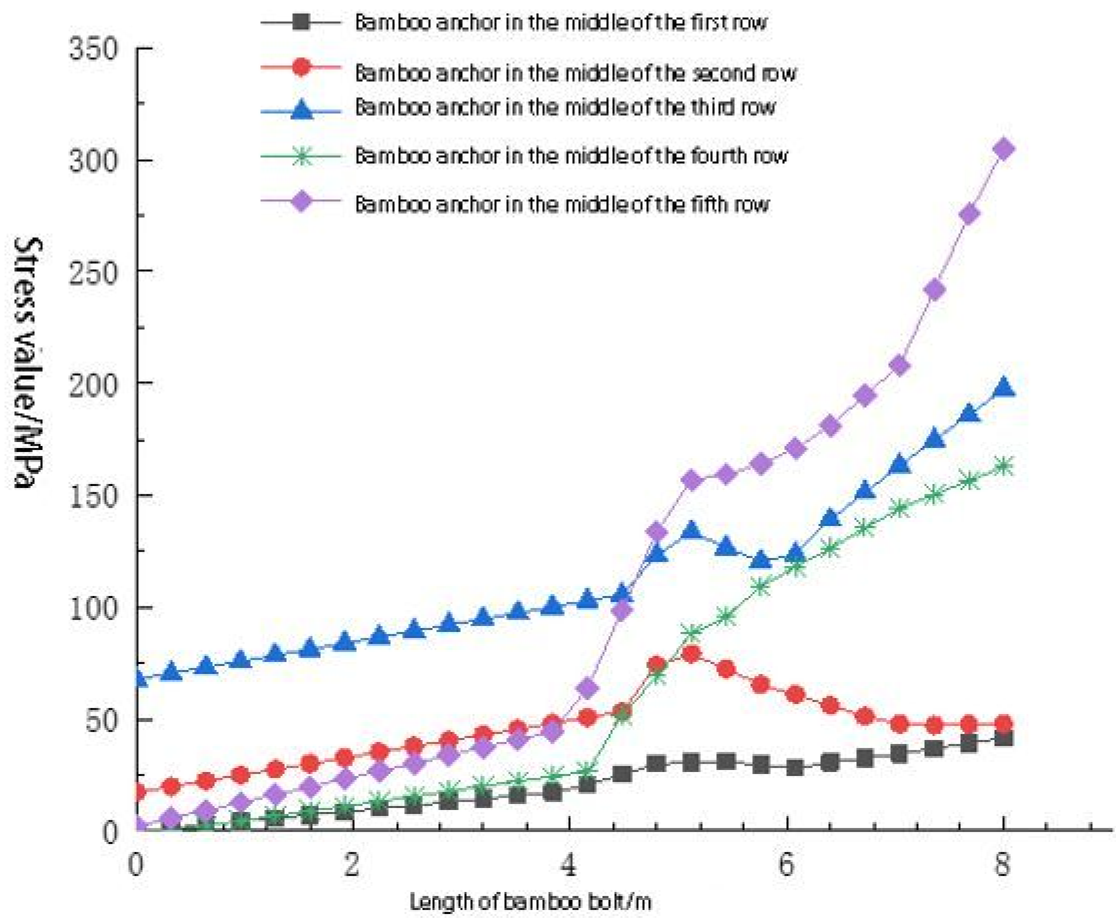


Figure 10

Stress of bamboo anchors under the condition 3

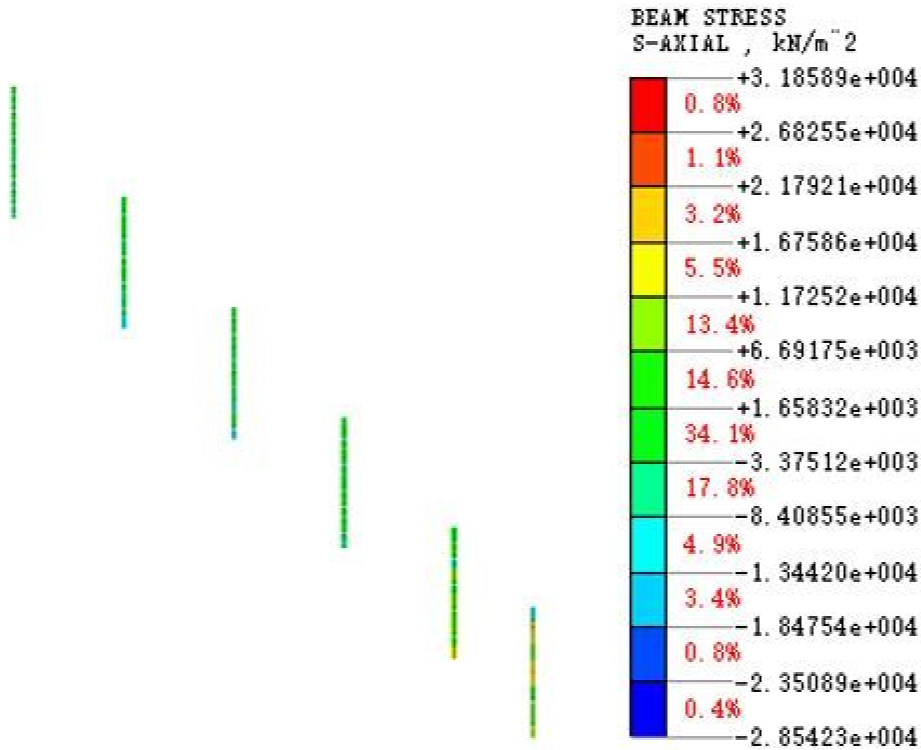


Figure 11

Stress cloud diagram of live stump under condition 2

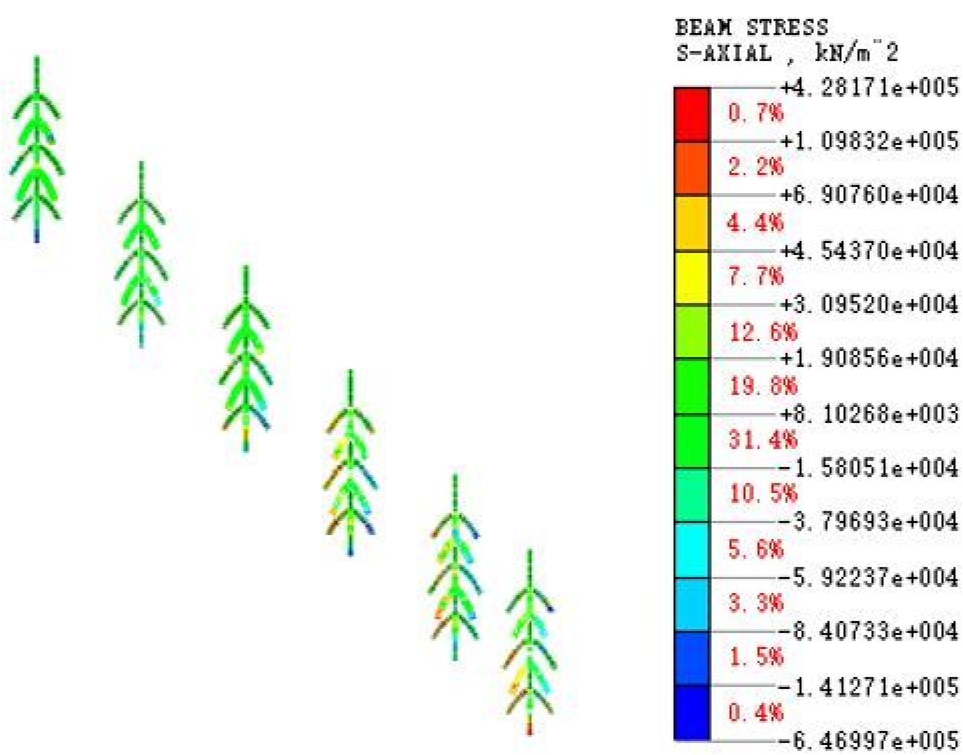


Figure 12

Stress cloud diagram of live stump under condition 3

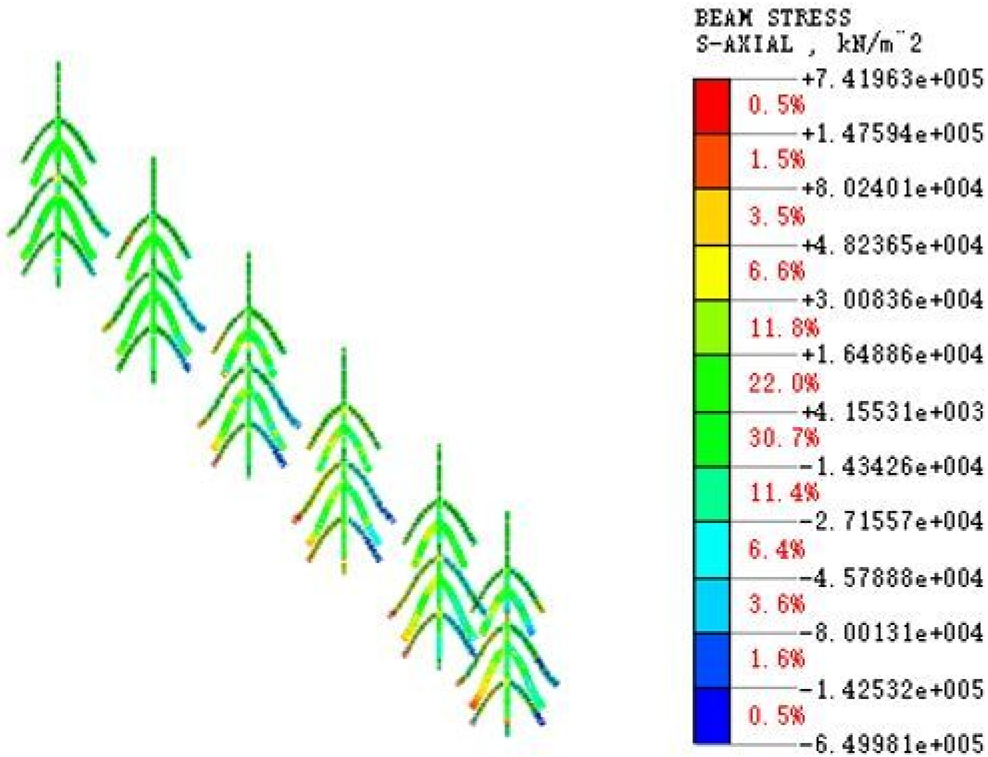


Figure 13

Stress cloud diagram of live stump under condition 4