Review on The Progress of Expansive Soil Improvement in Ten Years

Yaosen Pan¹, Mingdong Li¹,²* and Renhui Dai¹

¹ School of Civil and Architectural Engineering, East China University of Technology, Nanchang 330013, China
² State Key Laboratory of Nuclear Resources and Environment, East China University of Technology, Nanchang 330013, China
Email: ytpanys@163.com

Abstract. In the past ten years, due to the property of expansive soil foundation is worse than the general foundation, a series of new problems have been encountered in the improvement treatment, and the research and solution of these new problems have promoted the sustainable development of technology. The characteristics of various methods and their effects on the improvement effect were summarized. Soil displacement is suitable for projects with high engineering requirements and thin expansive soil layer. For projects with weak expansive soil improvement and high environmental protection requirements, fiber improvement and wind-blown sand improvement can be adopted. The longer the curing period, the better the lime improvement effect. The solid waste improvement should be adopted according to the local waste situation. When the effect of single improvement is not good, compound method can be adopted.

1. Introduction

1.1. A Large Amount of Expanded Land Foundation Needs to be Treated
Expansive clay is a kind of unsaturated clay that expands with water absorption and shrinks with water loss [1], expansive clay is widely distributed in more than 40 countries and regions on six continents [2]. China is one of the countries with the widest distribution of expansive soil [3]. Expansive soil is distributed in 26 provinces and regions of China. A sino-canadian cooperative study shows that the economic losses caused by expansive soil in China amount to 90 billion yuan every year. In order to improve the properties of expansive soil, it is necessary to treat the foundation because expansive soil tends to cause uneven settlement, grouting, landslide and structural damage. In the last ten years, a great deal of research has been carried out on expansive soils, and new and improved methods and techniques have been developed. This paper summarizes the progress of expansive soil improvement in recent ten years, points out the characteristics of various technologies, has guiding significance to the selection of new expansive soil improvement treatment scheme, analyzes the possible research and development direction, for the reference of engineers.

2. Physical improvement

2.1. Improvement of Soil Displacement Method
Soil displacement is an effective method to deal with the non-uniform settlement caused by expansive soil, and the non-uniform settlement is strictly required by engineering such as road bed foundation. It is treated from the source, dredge all or part of the expansive soil and replace it with non-expansive cohesive soil, sand soil, sand and gravel soil or ash soil to reduce foundation deformation [4]. The method is reliable in the case of thin expansive soil, but it is not economical for the large area of expansive soil distribution.

2.2. Improvement of Fiber Reinforcement Method
The fiber has the properties of tensile and crack resistance. When the expansive soil absorbs water and expands, there will be shear stress between the soil and the fiber, and the network structure formed by the interlaced fibers will limit the expansion of the expansive soil. When the expansive soil was treated with polypropylene fiber, the fiber content increased from 0.2% to 0.6%, the shrinkage coefficient decreased from 0.16 to 0.09 [5], and the unconfined compressive strength peaked from 125KPa to 195KPa when the polypropylene fiber content was 0.3% [6]. When the content of basalt fiber was 0.4%, the compressive strength increased from 0.6MPa to 0.72 MPa [5]. When the content of basalt fiber increased from 0 to 0.6%, the linear shrinkage of the sample decreased from 4.43% to 3.35%, the linear shrinkage decreased by 24%, the bulk shrinkage decreased from 13.35% to 5.88% [7], and the coefficient of shrinkage decreased from 0.38 to 0.26 [8]. This was because the fibers in the sample were interlinked with each other to form a network structure, which constrained the soil mass [7]. In terms of shear strength, can be found that the shear strength of fiber reinforced expansive soil were greater than not reinforced expansive soil shear strength, shear strength increased with the increase of curing age increases, when the curing age is 14 d, the shear strength of fiber reinforced expansive soil tends to the maximum, shear strength by 72KPa, up to 119KPa [9], basalt fiber content was 0.4%, maximum expansive soil cohesive force, by the 70KPa. Increased to 84KPa [10]. The addition of fiber can also improve the long-term strength of expansive soil [11]. The addition of 0.4% basalt fiber into expansive soil can show that the long-term strength is 26.7% higher than that of plain soil under the same conditions [12].

2.3. Improvement of Wind-Blown Sand
Wind-blown sand can be used to improve the grading of soil particles, reduce the liquid limit index, improve the shear strength, increase the initial moisture content, so as to reduce the expansion performance of expansive soil. It was found that the uncharged expansion rate decreased from 14.15% to 7.51% when 40% sand was added to the expansive soil [13]. When the sand content ratio reaches 10%, the total expansion and contraction rate decreases from 1.12 to 0.67, a decrease of 40% [14]. This is because the surface of sand particles is rough and angular. Friction resistance is generated when sand particles are mixed with soil particles, which inhibits the expansion of soil. At the same time, ion exchange occurred between sand and expansive soil, and the expansive trend decreased [13].

2.4. Other Physical Methods Improved
Other physical improvements are ramming method, pile foundation method, geotextile method and so on. Compaction method, also known as compaction method, through compaction to increase the dry density of soil and reduce the soil moisture content, so as to improve the bearing capacity of foundation. Because the dilatancy of expansive soils is not inhibited, this method is only suitable for weakly expansive soils [4]. Pile foundation method is to use pile to reinforce expansive soil foundation to make it meet the requirements [15]. The geotextile method can improve the bearing capacity of the foundation, and at the same time, it can quickly remove the surface water and prevent the swelling soil from softening [16].

3. Chemical Modification

3.1. Lime Improvement
Lime is a kind of inorganic cementing material, which can be hardened in both air and water. It can undergo ion exchange [17], pozzolanic reaction, carbonation and crystallization with expansive soil, which improves the strength and water stability of expansive soil. After 6% calcareous soil was added, the static triaxial test showed that the strength increased by 72.7%. It is worth noting that the cohesion of the improved soil increased by 40% after 28d curing compared with that without curing [18]. With the addition of 4% calcareous soil, the free expansion rate decreased from 58% to 18% [19]. After adding 3% lime soil and 9% fly ash, the expansion force decreased from 240KPa to 93KPa [20]. At present, lime improved expansive soil effect is good, easy to draw materials, age and improved effect has a major relationship, still need to spend time curing, has reached the best effect.

3.2. Solid Waste Improvement
The unconfined compressive strength increased from 178.22 KPa to 305.39 KPa, and the free expansion rate decreased from 61% to 28% [21]. Mixing coal gangue powder can also improve expansive soil. The linear shrinkage, volume shrinkage and coefficient of shrinkage decreased by 33.3%, 27.5% and 46.6% when the coal gangue powder content increased from 0 to 9% [22]. When the sand content is 30%, the free expansion rate decreases to the maximum, and the free expansion rate of the improved soil changes from 53% to 32%. The unconfined compressive strength reaches the maximum value of 1171KPa, an increase of about 56.8% compared with the unconfined compressive strength of plain soil of 747 KPa [23]. After the addition of 7.5% phosphorus tailings, the load-free expansion rate changed from 16% to 10%, and the unconfined compressive strength increased by 129.7 kpa compared with plain soil [24].

3.3. Improvement of Soil Curing Agent
Soil stabilizer has excellent permeability, diffusion, emulsification, biodegradability, antistatic and sterilization, such as performance, mixed with soil to cementing soil particles or with clay minerals in hydration reaction, ion in accordance with the process, biological function, and can to a certain extent, improve soil compactness, strength, elasticity and water resistance properties of the material. By adding 0.33% bioenzyme, the compressibility decreased from 1.13 MPa$^{-1}$ to 0.01MPa$^{-1}$[25],the free expansion rate decreased from 61.5% to 8% [26]. The free expansion rate decreased from 66.1% to 21.6%, and the unconfined compressive strength changed from 1.04MPa to 1.89MPa [27]. Pylase is an enzymatic substance obtained by natural fermentation and extraction. When adding pylase curing agent, the unconfined strength is 19.8% higher than that of plain soil. Study found that ion exchange [28] biological enzymes [29] and organic soil curing agent because curing mechanism is novel, application technology is not mature enough, if separate use one kind of curing agent, the properties of solidified soil and cannot reach the engineering demand, if with the right amount of cement or lime in order to get the performance and cost of stabilized soil were superior to the traditional curing materials, huge potential for development [30].

4. Compound Method Improvement
The improvement effect of using a certain material to treat the expansive soil foundation may not meet the engineering requirements or cost a lot of money, so the composite method will be used to improve the expansive soil, the improvement effect and cost will be better than the single material improvement. When adding phosphorus tailings 7.5% and 20% EPS plastic particles, the unloaded expansion rate changed from 16% to 8.5%, and after adding 0.4% basalt fiber, the unloaded expansion rate changed from 8.5% to 6.6% [24]. With the addition of 20% slag powder and 20% fly ash, it can be found that the unconfined compressive strength increased from 188KPa to 440 KPa. After the addition of Na$_2$SiO$_3$ [31], it was found that the unconfined compressive strength increased from 440 KPa to 911 KPa [32].

5. Conclusion
The progress in the improvement of expansive land foundation in recent ten years is summarized, and
the main conclusions are as follows:

1. The soil displacement method can be used under the condition that the non-uniform settlement of the project is strictly required and the expansive soil layer of the foundation is relatively thin.

2. Select materials that can be used to improve weak expansive soils in the immediate vicinity of the project, depending on local conditions, such as fibers, solid waste, and wind-blown sand.

3. Lime is selected to improve expansive soil, which needs to be preserved to achieve the best improvement effect, and the curing agent suitable for improving expansive soil in different places and the corresponding optimal amount of addition are sought to form a technical guide and guide engineering practice.

4. When the improvement effect of expansive soil foundation is high, the combination of suitable improvement methods can be selected to promote the realization of the goal.

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References
[1] Wang M, Li J, Ge S, Qin S, & Xu P. (2015) An experimental study of vaporous water migration in unsaturated lime-treated expansive clay. Environmental Earth Sciences, 73(4), 1679-1686.
[2] Liu Y, Zhu W, & Yang E. (2016) Alkali-activated ground granulated blast-furnace slag incorporating incinerator fly ash as a potential binder. Construction and Building Materials, 1005-1012.
[3] Yuan G, Tian L. (1999) Expansive soil on the structure of the harm and prevention and control [J]. Design of coal mine, (4), 30-32.
[4] Yan, J. (2010). Study on Expansive Soil Foundation Treatment Methods [J]. Journal of Hebei Institute of Architecture and Civil Engineering, 28(2), 1-4.
[5] Zhang, P, Shi, B. (2008) Experimental Study on Reinforced Fiber Expansive Soil [J]. Experimental Study on Reinforced Fiber Expansive Soil, 25(4), 60-62.
[6] Deng, Y, Wu, P, Zhao, M. (2017). Strength of expansive soil reinforced by polypropylene fiber under optimal water content [J]. Rock and Soil Mechanics, 38(2): 349-353.
[7] Xu, H, Peng, Y, Zhao, Z. (2012) Experimental Study on Short Basalt Fiber Reinforced Expansive Soil [J]. Building Science, 28(9): 44-47.
[8] Zhang, D, Xu, Q, Guo, Y. (2012). Experiments on strength and shrinkage of expansive soil with basalt fiber reinforcement [J]. Journal Of Southeast University ( Natural Science Edition), 42(5): 975-980.
[9] Zhuang, X, Yu, X, You, P. (2015). The Application of Cascade Inverter into the Direct Drive Wind Power Generation System [J]. Journal of Hubei University of Technology, 30(2): 102-104, 120.
[10] You P, Xu H, Dong J. (2015) Triaxial Tests of Expansive Soil Reinforced with Basalt Fibe [J]. Journal of Disaster Prevention and Mitigation Engineering, 35(4): 503-507, 514.
[11] Ramasubbarao, G. V. (2014). Strength behaviour of kerosene coated coir fibre-reinforced expansive soil [J]. Series: Architecture and Civil Engineering, 12(2), 113-120.
[12] Cheng X, Du S, Zhang D. (2017) Triaxial Creep Properties of Fiber Reinforced Expansive Soil [J]. Journal of Engineering Geology, 25(1): 80-87.
[13] Zhuang X, Wang Z. (2018). Experimental Study on Non-load Swelling Rate and Strength Characteristics of Expansive Soil Modified by Weathered Sand [J]. Highway, (9): 248-252.
[14] Li X. (2014). Experimental Study on the Characteristics of Expansion Soil Weathering Sand Modified [D]. China Three Gorges University.
[15] He S. (2015). Treating Method of Expansive Soil Foundation [J]. Research & Application of Building Materials, (5): 26-28.
[16] Xiong Y. (2013). Research on the Treatment Technology of Expansive Soil Subgrade [J]. Urbanism and Architecture (16): 250.

[17] Sahu V, Srivastava A, Misra A K, et al.(2017) Stabilization of fly ash and lime sludge composites: Assessment of its performance as base course material[J].( Archives of Civil and Mechanical Engineering), 17(3): 475-485.

[18] Hui H, Hu T, Wang X. (2006). Improved Mechanism of Expansive Soils by Lime and Fly-ash [J]. Journal of Chang an University (Natural Science Edition), 26 (2): 34-37.

[19] Song Y. (2009). Experimental study on the lime-stabilized expansive soils of Hefei [D]. Hefei University of Technology.

[20] Zha P, Liao B, Cui K. (2010). Experimental Study on Fly ash -Lime Additives on Swell-Shrinkage Properties of Expansive soil [C]// Shanghai Geology, 2010: 83-86.

[21] Zhang L, Sun S, Zhang Y, Chu H. (2019). Experimental Study on Physical and Mechanical Properties of Modified Expansive Soil with Magnesium Slag [J]. Journal of Hebei University of Engineering (Natural Science Edition),36 (3): 79-83.

[22] Li T, Zhang Y, Feng X, et al. (2018). Research on shrinkage of expansive soil modified by coal gangue powder [J]. China Science paper ,13(12): 1434-1439.

[23] Zhao H, Chu C, Guo K, et al. (2017). Experimental analysis of the basic engineering properties of expansive soils improved by iron tailings sand [J]. Journal of Chongqing Jianzhu University, (6): 98-104.

[24] Zhuang X, Wang K, Li K.(2019). Experimental Study on Modified Expansive Soil of Phosphorous Tailings-EPS Basalt Fiber [J]. Highway Engineering, 44(1): 38-43.

[25] Zeng J, Wen C, Liu Z.(2018). Characteristics of compressibility of bio-enzyme expansive soil modified [J]. Journal of Civil, Architectural & Environmental Engineering,40(3): 133-138.

[26] Zeng J.(2017). Experimental Research on the Physical and Mechanical Property of Bio-Enzyme-Treated Expansive Soil [D]. Central South University of Forestry& Technology.

[27] Shang Y, Geng B. (2010). Experimental study of the performance of expansive soils improved w with HTAB [J]. China Civil Engineering Journal,43(9): 138-143.

[28] Zhang B. (2018). Applied Research of Improved Backfill Soil [D]. Journal of Guangxi University.

[29] Tang B, Jiang Y. (2011). Application of Biological Enzyme in Low-Grade Highway [J]. Highway Engineering, 12(23): 55-58.

[30] Li P, Yang W, Deng Y. (2014). Status Quo and Trend of Soil Stabilizer Development [J]. Subgrade Engineering , (3): 1-8.

[31] Sharma, A. K., & Sivapullaiah, P. V. (2016). Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer. Soils and Foundations, 56(2), 205-212.

[32] Li G, Xu H, Sun Y, et al. (2019). Experiments on mechanical properties of fiber reinforced geopolymer for expansive soil improvement [J]. Journal of nanjing tech university ( Natural Science Edition) ,41(4): 456-462.