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Slope Protection Effect Contrastive Studies on Soil Bioengineering Measures for Natural Stream Bank and Artificial Slope

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Abstract. Soil bioengineering is a kind of slope ecological restoration technology which is very vigorous. It is the use of living plant materials just like root, stem and branch or even the whole to perform specific engineering functions in the process of plant growth and phytocommunity construction for the purpose of slope stabilization, water and soil conservation and river ecosystem improvement. Researches based on the experiments settled in natural stream bank of Liuli River and artificial slope of Changping by using *Salix alba* var. *tristis* and *Salix matsudana* materials have been compared in the respect of soil bioengineering restoration application in this paper. The result indicates that: repairing effects in artificial slope is better than in natural stream bank. The figure of infant root growth vigor shows: After 5-month project implementation, significant effectiveness was obtained on slope stability, the new biomass of *Salix alba* var. *tristis* applied in artificial slope is 28.7% bigger than that in natural stream bank; The new biomass of *Salix matsudana* applied in artificial slope is 36.4% bigger than that in natural stream bank. The figure of root maximum tensile test also shows: *Salix alba* var. *tristis* applied in artificial slope is 1.4 times bigger than that in natural stream bank; *Salix matsudana* applied in artificial slope is 1.3 times bigger than that in natural river bank.

Keywords: Soil bioengineering, *Salix alba* var. *tristis*, *Salix matsudana*, slope protection

1. Introduction

Soil bioengineering is a kind of biological technology based on reliable soil engineering. It is a kind of integrated engineering technology which can stabilize the steep slope, reduce water and soil erosion and improve the environment by constructing variety side slopes (Mountain slope, river bank and coast slope) which is under the use of plants and other auxiliary materials [1~4]. The use of natural materials such as plants and soil in slope protection can date back to the ancient time of China. Soil bioengineering has been brought to Europe since the 16th century. In the latest 30 years, a lot of research has been done and great progress has been made on this sphere. It has been widely used to stabilize the slope surface in Europe. Recently, scholars in China come to do some research on soil bioengineering. Experimental area such as a 4-km-long river way located on shanghai Pudong international aerodrome, has been put to use to prove the superiority of soil bioengineering. This project aims to find the development potential of soil bioengineering in China. Jiarong Gao[5~8] has been making use of bio-engineering measures to repair the river ecology in Beijing, which can offer technical guidance and theory basement to river ecological restoration in Beijing even the nation as a whole. Salix alba var. tristis and Salix matsudana have been selected to do this research. To conduct an ecological restoration experiment in Liuli River, it needs to investigate and monitor the growth condition of plants, and evaluate the suitability. This paper is based on contrastive studies about the soil shear, habitat condition and biodiversity between natural stream bank and artificial slope before and after the soil bioengineering implement. Studies and demonstrate projects indicate that using the soil bioengineering measures can stabilize the slope bank, improve the habitat suitability and restore the

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environment. Soil bioengineering [9 ~ 13] could be widely applied in ecological restoration of all kinds of slopes in China.

1.1. Research area profiles

Application of soil biological engineering is studied in Changping and Huairou District, including artificial slope in Changping District and ecological remediation at Liuli River in Huairou. Changping is located at northwest Beijing, which has longitude scope E115°50′17″ ~116°29′49″ , N40°2′18″ ~40°23′13 " , and belongs to Semihumid Temperate District. This is profoundly manifested in the following ways: high-cool rich-wind arid climate in the spring, hot and rainy in the summer, cool autumn and cold and dry in winter. Average of annual sunshine hours, temperature and annual rainfall is respectively about 2684h, 11.8℃ and 550.3 mm. Annual sunshine hours is between 2748h and 2873h.The frost-free period is about 150-200d.Average temperature is from6℃ to 12℃. Annual rainfall is about 470 - 850mm. The average of annual sunshine hours, temperature and annual rainfall in huairou district is respectively about 2748h， 10.5℃ and 645.0mm.

A 40m long and 45° gradient soil slope was artificially built in White floating village in Changping in April, 2010. Five measures (including live stake, live pole drains, brush layering, live silt fences, live gully breaks) have been governed to artificial slope with experimental material such as *Salix matsudana*, *Salix Alba* var. *tristis*, Amorpha *fruticosa* L. and so on. In addition, a soil biological engineering construction was carried in 150 meters long river reach of Liuli River in May in 2009. The demonstration figure in experimental area is as follows:

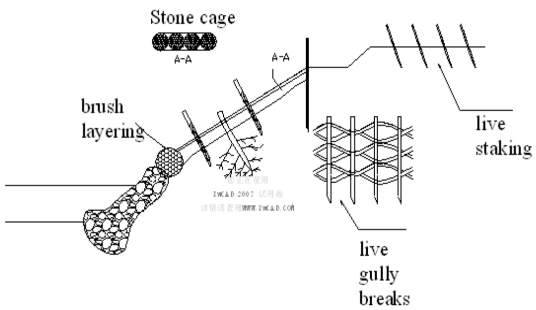

Fig.1 Experiment site of measures allocation in Liuli River

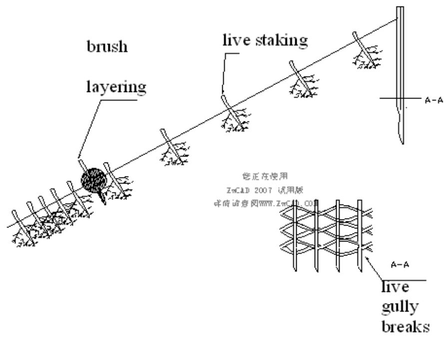

Fig.2 Experiment site of measures allocation in Changping

1.2. Construction methods

1.2.1. Live Stake

Live stake is one of the soil bioengineering measures. After certain processed, plants live branches which are likely to survive, according to certain angle, are directly inserted into the soil. In this study, we choose *Salix alba* var. *tristis* and *Salix matsudana* branches with diameter for 1-3cm around, length for about 30-50cm. The best right size of diameter is 3cm, and the best right size of length is 40cm. These branches are inserted into the soil according to a certain angle of 45 degrees, with scissors repair after inserting. Distance between branch and branch is about 1m or so. The first column and second column branches are interlaced. These branches can also be inserted into the rocks and the cage made with lead wire. After plants live, the roots, soil and rock will fix together. What’s more, the lead wire on the cage will fall off over for a long period of time, Then the roots of the plants can be able to replace the fixed function of the cage. Clearance between the roots can provide shelter space for marine life. Live staking is a simple, economic and fast measure. The only fly in the ointment is that plants could not play a role to protect the slope immediately after the completion.

1.2.2. *Brush layering*

Brush layering is used to restore slopes by constructing a fill-slope consisting of alternating layers of live branches and soil, creating a series of reinforced benches. In some cases, fill materials must be placed on steep (1.5:1 or greater) angles due to the geometry of the site. In these cases (2 to 5m long) can be inserted into the fills as they are constructed. The branches provide immediate protection against surface erosion. It involves the cutting and placement of live branch cuttings on slopes. The live cuttings eventually root and provide permanent reinforcement. When local overstepping of the fill is required, for example where gullies cross slopes that are being deactivated, development of brush layers in fills may be particularly useful. This will provide stability to the fill and will eventually result in the development of shrubby vegetation along the gully. Scheduling requirements for the use of cuttings may dictate that machine work be organized for these sites during seasons when cuttings can be used.

1.3. Investigation and monitoring

One month after the completion, monitor and survey is very important. Various indicators such as plant survival rate, coverage, the base diameter and new branch height should be valued. In order to make a better assessment, slope reinforcement effect of plants in ecological improvement action should be investigated five months later (in the first plant growth season). Then make comparisons adaptability of plants between artificial slope and natural stream banks.

2. Analysis of Results

2.1. The growth characteristics of slope-protecting plants

2.1.1. Under the measure of live stake

From Table 1, under the use of live staking measure on artificial slope, the average base diameter of *Salix alba* var. *tristis*'s fresh branches reaches 8.0mm; average height is 115.6cm. The average base diameter of *Salix matsudana*'s fresh branches reaches 6.4mm, average height up to 102.0 cm. On natural stream bank, the average base diameter of *Salix Alba* var. *tristis*'s fresh branches reaches 6.4mm, average height is 57.2cm. The average base diameter of *Salix matsudana*'s fresh branches reaches 6.2mm, average height up to 99.5mm. The survival *Salix Alba* var. *tristis* and *Salix matsudana* have achieved a high level of growth condition under the implement of different soil bioengineering technologies

2.1.2. Under the measure of brush layering

Under the use of brush layering measure on artificial slope, the average base diameter of *Salix Alba* var. *tristis*'s fresh branches reaches 5.4 mm; average height is 92.0 cm. The average base diameter of *Salix matsudana* 's fresh branches reaches 6.4 mm , average height up to 102.0 cm. On natural stream bank, the average base diameter of *Salix Alba* var. *tristis*'s fresh branches reaches 3.6mm, average height is 52.3cm. The average base diameter of *Salix matsudana* 's fresh branches reaches 4.9mm, average height up to 76.8mm.

Table 1 Growth of plants under different soil bioengineering measures on different types

Type	Cuttings (Single)	Planting technique	Completed five months	
			New diameter (mm)	New length (cm)
artificial slope	*Salix alba* var. *tristis*	Live strakes	8.0±0.5a	115.6±6.9a
		Brush layering	5.4±0.3	92.0±5.5
	Salix matsudana	Live strakes	6.2±0.4c	99.5±8.4d
		Brush layering	6.4±0.4	102.0±5.8
natural stream bank	*Salix alba* var. *tristis*	Live strakes	6.4±0.3b	57.2±43.0b
		Brush layering	3.6±0.2	52.3±44.3
	Salix matsudana	Live strakes	5.0±0.2bc	71.7±20.3d
		Brush layering	4.9±0.3	76.8±6.7

① （$p < 0.01$）

The results show that the germination rate and the survival rate of *Salix alba* var. *tristis* and *Salix matsudana* is all more than 90% since several of soil biological engineering measures have been constructed for five months. It shows that *Salix alba* var. *tristis* and *Salix matsudana* are adaptability to the northern part of China. From Table 1 we can get the following conclusion: the application of living staking measure leads to result that the average basal diameter and height of *Salix alba* var. *tristis* of natural slope are respectively 20.0% and 50.5% smaller than that of artificial slope.The same goes for *Salix matsudana*, which figure is separately19.4% and 27.9%.

While under the measure of brush layering, the average basal diameter and height of *Salix alba* var. *tristis* in natural slope is respectively 33.3% and 43.2% smaller than that of Salix alba var. tristis in artificial slope. And the data goes to 16.7% and 22.1% for *Salix matsudana* by the same measure. Analysis of variance shows that there is significant difference ($p < 0.01$) between *Salix alba* var. *tristis* grown on natural stream bank and *Salix alba* var. *tristis* planted on artificial slope.

2.2. Soil biological engineering in slope protection effect

Slope protection effect of soil bioengineering plant roots is essential to slope stability. The shear or bond strength is always proportionate to the roots biomass. The biomass of neonatal roots and branches of the two kinds of plants which are planted on artificial and natural stream banks is shown in Table 2. After five-month's growth, the underground root depth of *Salix alba* var. *tristis* and *Salix matsudana* can reach 1m. The biomass of neonatal roots of the two plants planted on artificial slope is 4.02g/4.78g respectively, while the biomass of neonatal branches is 22.86g/36.55g and the average of max root tensile force is 765.23N/802.92N. For the situation of these two plants planted on natural stream bank, the corresponding data are 2.87g/3.04g, 16.57g/22.45g, and 542.53N/663.93N.

Table 2 Comparison of New root biomass and root maximum tensile strength on different types

Type	Species of cuttings	New root biomass (g)	New biomass（g)	root maximum tensile strength (N)	Number of cutting
artificial slope	*Salix alba* var. *tristis*	4.02	22.86	765.23±79.35	17
	Salix matsudana	4.78	36.55	802.92±64.86	17
natural stream bank	*Salix alba* var. *tristis*	2.87	16.57	542.53±36.78	19
	Salix matsudana	3.04	22.45	633.93±52.66	19

From Table 2, for the plant of *Salix alba* var. *tristis*, the root biomass of natural stream bank is 28.7% smaller than that of artificial slope; the maximum root tensile strength of artificial slope is 1.4 times bigger than that of natural stream bank. For the plant of *Salix matsudana*, the root biomass of natural stream bank is 36.4% smaller than that of artificial slope; the maximum root tensile strength of artificial slope is 1.3 times bigger than that of natural stream bank.

3. Conclusion and Discussion

The experiment about soil bio-engineering on natural stream bank of Liuli River and Changping artificial slope shows that this technology is very viable in the use of ecological restoration. By using viable plant roots, stems (branches), or the overall structure, soil bio-engineering technology can stabilize the bank slope and prevent water loss and soil erosion by means of plant construction. The above discussion indicates that soil bio-engineering applied to artificial slope is better than the natural stream bank. All this can be manifested in the following:

- After 5-month project implementation, significant effectiveness has been obtained on slope stability, habitat improvement and ecological restoration. It was concluded that the approach could be widely applied in slope ecological restoration in China.
- Under the measure of living staking, the average DBH and diameter of *Salix alba* var. *tristis* on natural slope is separately 50.5% and 20.0% smaller compared with that planted on artificial slope; the average DBH and diameter of *Salix matsudana* on natural stream bank is separately 27.9% and 19.4% smaller compared with that planted on artificial slope. Similarly, under the measure of brush layer, the average DBH and diameter of *Salix alba* var. *tristis* on natural slope is separately 33.3% and 43.2% smaller compared with that planted on artificial slope; the average DBH and diameter of

Salix matsudana on natural stream bank is separately 16.7% and 22.1% smaller compared with Salix matsudana planted on artificial slope.

- In artificial slope, the newly born biomass allocation of *Salix alba* var. *tristis* root is 28.7 %bigger than that in natural stream bank. The same, *Salix matsudana* applied in artificial slope is 36.4 % bigger than that in natural stream bank. The figure of root maximum tensile test also shows: *Salix alba* var. *tristis* applied in artificial slope is 1.4 times bigger than that in natural stream bank; *Salix matsudana* applied in artificial slope is 1.3 times bigger than that in natural stream bank.

Further research is required on other factors which are related to the ecological restoration effect of soil bio-engineering such as construction time, cover hickness and the choice of plant species. The adaptation of plants in practical application is the core and foundation technique of Soil bio-engineering. The research we have done can be served as reference in the future ecological restoration in Beijing district. More research about shear and tensile strength, characteristics of plant growth is the main development trend.

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