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Erosion Resistance and Aggregate Distribution Characteristics of Vegetation Concrete

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ABSTRACT

Soil aggregate property, as a widely accepted soil quality indicator, is closely related to the erosion resistance of soil. In order to quantitatively assess the erosion resistance of vegetation concrete, a typical artificial composite soil, the distribution characteristics of aggregate particle size and eleven evaluation indexes were determined and calculated in laboratory by contrast with natural soil under the same site conditions. The research conclusions could be presented as follows: Compared with the natural soil, mechanical stability macroaggregate, water-stable macroaggregate, mean weight diameter, geometric mean diameter and organic matter content increased by 9.1% , 97.0%, 123.6%, 158.6% and 65.2% respectively. In contrast, erodibility factor, structural failure rate, fractal dimension and dispersion rate decreased by 75.8%, 38.1%, 24.4% and 27.2% respectively. Besides, aggregation status and aggregation degree improved by 63.9% and 38.5%, and the comprehensive principal component value of erosion resistance also increased by 252.6%. Due to the addition of natural organic material and cement, the erosion resistance of vegetation concrete was greatly superior to that of natural soil. Therefore, vegetation concrete was a suitable composite soil to create vegetation habitat on the surface of bare rock slope.

INTRODUCTION

China has been impacted by soil erosion for millennia, which is particularly evident on the slope. Numerous researchers commit to improving soil erosion resistance and reducing soil loss. In addition to climatic conditions, vegetation types and tillage patterns, the soil erosion resistance is closely related to its inherent physical and chemical properties, e.g. organic matter, texture, porosity, infiltration, etc. (Angers & Caron 1998, Barthes & Roose 2002). Soil aggregate can be defined as the basic structural unit formed by the primary fine particles through cementation, coagulation, etc. Aggregate distribution characteristics, which are effective indicators to evaluate the erosion resistance and stability of soil, seriously affected the process of soil erosion (Bronick & Lal 2005). Attention has been drawn to soil aggregates and erosion resistance, thus a series of research achievements have been obtained. An et al. (2008) studied the aggregate characteristics and main influence factors of the typical grassland soil on Loess Plateau during the natural revegetation through field investigations and laboratory analysis. Soil aggregate stability has been shown to provide a good index of soil erodibility, and the abundance of water-stable aggregates at the soil surface determines the potential for sheet erosion and crust formation (Kay 2000, Li & Fan 2014). Excessive tillage causes changes in soil aggregate size distribution, which leads to the degradation of soil erosion resistance (Parr et al. 1983, Yin et al. 2016). More significantly, soil erosion is substantially controlled by aggregate breakdown process (Selen et al. 2011), and many researchers have demonstrated that surface erosion processes are linked to aggregate stability (Morin & Van 1996, Ramos et al. 2003). Previous studies have provided valuable achievements for the enrichment of soil aggregates theory and the improvement of erosion resistance, while their research subjects were mostly confined to different types of natural soil, limited information has focused on the artificial composite soil aggregate or the quantitative analysis of its erosion resistance.

Vegetation concrete is equably mixed of four solid raw materials, including planting soil, cement, natural organic material and green additive with a definite ratio, and then a right amount of water is added. As a typical artificial composite soil, vegetation concrete has been widely used throughout the country for it could create suitable vegetation habitat on the surface of bare rock slope, so as to implement ecological restoration and shallow protection for the slope (Xu et al. 2012). Field application indicated that the erosion resistance of vegetation concrete was obviously higher than that of natural soil, but the exact degree and essence of the improvement are yet deficient in specific data and theoretical basis. Therefore, building on the base of comparing with natural soil which is added as the planting soil, this study focused on vegetation concrete and analysed the aggregate distribution characteristics and erosion resistance indexes. Meanwhile, it explored the reason and mechanism of the enhancement of erosion resistance, thereby providing experience reference for the research of artificial composite soil aggregate and offering scientific basis for the soil stabilization in slope ecological restoration

MATERIALS AND METHODS

Study site: Yichang is located in southwest China and has mid-subtropic climate. The average annual rainfall is approximately 1213.6 mm (1998-2010), mainly occurring in June and July with heat and rain in corresponding period. The annual accumulated temperature is high and frost season is short. The average annual temperature is about 16.7°C, varying from 14°C to 19°C.

The slope on the side of Xiazhou Road in Yichang was selected as the study slope. The bedrock of the slope is shallow red mudstone, which has been covered with 15-centimetre-thick vegetation concrete artificially since the late summer of 2005. The vegetation concrete base spraying technique (VCBS) restores the vegetation on slopes by spreading a mix of concrete, greening additives and plant seeds on slope surfaces (Chen et al. 2013). The planting soil was taken from a natural soil slope near the above mudstone slope, and it was classified as a sandy loam with a pH of 6.6. Meanwhile, the natural soil slope for planting soil was taken as the controlled slope, and its site conditions were closer to the study slope, consisting of 58° inclination, 2.6 m height, about 90% vegetation coverage and 30-200 cm plant height.

Sampling: In June 2015, six plots with good vegetative growth were selected for the soil aggregate analysis on the study slope and controlled slope respectively. The size of each plot was set at 1.5 m × 1.5 m and five locations were randomly selected by following S curve at the depth of 0-15 cm to form a composite sample. After being air-dried, all samples were stripped into small blocks along the natural structure plane, while removing plant roots and small stone tablets. All analyses were repeated thrice for each sample.

Index analysis: There are lots of indexes to characterize the soil aggregate and soil erosion resistance, and many factors should be focused on, e.g. the research object, research conditions, etc. The single index only can reflect the relative sensitivity of soil to the erosion force, while the combination of indexes could be a more comprehensive response to the actual soil erosion resistance. In this paper, the following eleven evaluation indexes were selected from the four aspects.

According to the procedure described by Hofman (1973), the soil was dry-sieved through a set of sieves with openings of 7, 5, 3, 2, 1, 0.5 and 0.25 mm. For aggregates >0.25 mm resistant to external forces, mechanical stability macroaggregate (MSA $_{>0.25}$, %) was chosen and calculated as the cumulative mass percentage of aggregates > 0.25 mm under dry sieving (Choudhury et al. 2014).

According to the procedure described by Elliott (1986), the soil was wet-sieved through a set of sieves with openings of 5, 3, 2, 1, 0.5 and 0.25 mm. For aggregates > 0.25 mm resistant to hydraulic dispersion, six indexes were selected and calculated, including water-stable macroaggregate (WSA$_{>0.25}$, %), mean weight diameter (MWD, mm), geometric mean diameter (GMD, mm), destruction rate (PAD, %), fractal dimension (D) and erodibility factor (K).

WSA$_{mac}$(%) refers to the cumulative mass percentage of aggregates > 0.25 mm under wet sieving (Young 1984). MWD and GMD are calculated following Nimmo & Perkins (2002):

$$\mathrm{MWD} = \sum_{i=1}^{n} x_i \ \omega_i \qquad ...(1)$$

$$\mathrm{GMD} = \exp\left(\sum_{i=1}^{n} \omega_i \log_{10} x_i\right) \qquad ...(2)$$

Where, n is the number of aggregate fractions under wet sieving (n=7, with the fractions being < 0.25, 0.25-0.5, 0.5-1.0, 1.0-2.0, 2.0-3.0, 3.0-5.0 and > 5.0 mm); x_i is the mean diameter (mm) of aggregate fraction i under wet sieving, equalling to 0.25, 0.375, 0.75, 1.5, 2.5, 4.0 and 5.0 mm, respectively; and ω_i (%) is the mass proportion of aggregate fraction i under wet sieving.

PAD is calculated as equation (3) (Xu et al. 2013, Su et al. 2004):

$$\mathrm{PAD} = \frac{\mathrm{MSA}_{>0.25} - \mathrm{WSA}_{>0.25}}{\mathrm{MSA}_{>0.25}} \times 100\% \qquad ..(3)$$

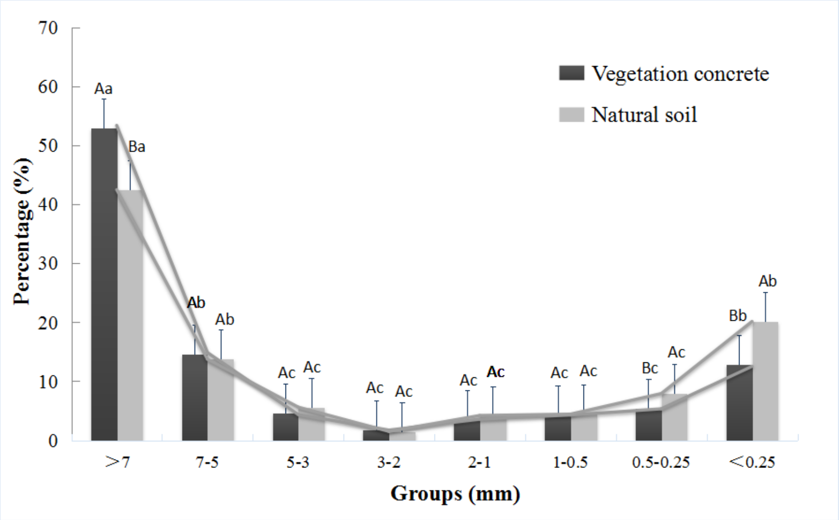

Fig. 1: PSD of mechanical stability aggregates.
*Bars with the same capital letter(s) within each group are not significantly different between vegetation concrete and natural soil at P<0.05, and bars with the same lowercase letter(s) among different groups are not significantly different for the same soil (vegetation concrete or natural soil) at P<0.05.

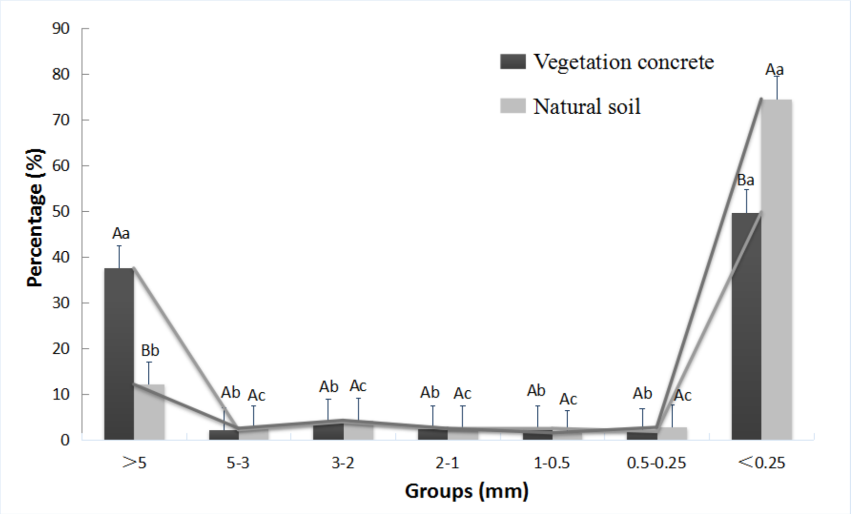

Fig. 2: PSD of water-stable aggregates.
*Bars with the same capital letter(s) within each group are not significantly different between vegetation concrete and natural soil at P<0.05, and bars with the same lowercase letter(s) among different groups are not significantly different for the same soil (vegetation concrete or natural soil) at P<0.05.

D is used to express mass and size information about aggregates and calculated as equation (4) (Chen et al. 2016, Xia et al. 2015):

$$\frac{M(r < R)}{M_T} = \left(\frac{R}{R_L}\right)^{(3-D)} \qquad ...(4)$$

where M(r < R) is the cumulative mass of aggregates with size r smaller than a comparative size R under wet sieving, i.e., as R is 1.0 mm, M(r < R) refers to the mass of aggregates < 0.25 and 0.25-0.5mm under wet sieving; M_T is the total mass of aggregates under wet sieving; R is the sieve size opening, equalling to 0.25, 0.5, 1.0, 2.0, 3.0 and 5.0 mm, respectively; R_L is the maximum aggregate size deûned by the largest sieve size opening, equalling to 5.0 mm.

K is a complex concept and reflects the soil resistance to erosion (Buttafuoco et al. 2012), which can be calculated in accordance with equation (5) (Wischmeier et al. 1971, Foster et al. 1981, Rosewell 1993):

$$K = 2.77 \times 10^{-7}(12 - OMC)[(100 - C)(L + Armf)]^{1.14} + 4.28 \times 10^{-3}(s - 2) + 3.27 \times 10^{-3}(p - 3) \quad ...(5)$$

Where OMC is the organic matter content (%), C is the mass proportion (%) of clay (< 0.002 mm), L is the mass proportion (%) of silt (0.002-0.05mm), Armf is the mass proportion (%) of very fine sand (0.05-0.1mm) , s is the soil structure code used in soil classification, and p is the profile permeability (SSS, 2006).

For aggregates <0.25mm, which are defined as microaggregates and indicate the structure and dispersion of soil under the condition of immersion, aggregation status (AS, %), aggregation degree (AD, %) and dispersion rate (DR, %) were chosen as follows:

$$AS = \omega_{(0.05-0.25)} - \omega_{mc\,(0.05-0.25)} \quad ...(6)$$

$$AD = \frac{AS}{\omega_{(0.05-0.25)}} \times 100\% \quad ...(7)$$

$$DR = \frac{\omega_{<0.05}}{\omega_{mc\,(<0.05)}} \times 100\% \quad ...(8)$$

Where $\omega_{(0.05-0.25)}$ is the mass proportion (%) of microaggregate (0.05-0.25mm), $\omega_{mc(0.05-0.25)}$ is the mass proportion (%) of soil mechanical composition (0.05-0.25mm), $\omega_{<0.05}$ is the mass proportion (%) of microaggregate (<0.05mm), $\omega_{mc(<0.05)}$ is the mass proportion (%) of soil mechanical composition (<0.05mm), and all of them were measured through the pipette method described by Xu (2013).

For the organic colloid, organic matter content (OMC, %) was chosen and determined by potassium dichromate-external heating method (Liu et al. 1996).

Statistical analysis: Statistical analysis of all data was conducted by SPSS 16.0, and the results were expressed as mean values. Independent sample T test was used to compare the differences within the same parameter between vegetation concrete and natural soil, one-way ANOVA was performed to test the differences among different parameters of the same soil, correlation analysis was performed to determine the relationships and interactions among different indexes of vegetation concrete, and PC analysis was used to assess the principal components of the two soils.

RESULTS

Distribution characteristics of aggregate particle size: Dry sieving has less damage to the soil particle structure, reflecting soil particle size distribution (PSD) in the natural state (Gee & Bauder 1986). The PSD of mechanical stability aggregates for vegetation concrete and natural soil are presented in Fig. 1. For vegetation concrete, it exhibited an inverse J shape. The group >7 mm predominated, constituting about 53% of the total mass, which was significantly higher than any other groups ($P<0.05$). The groups 7-5 and <0.25 mm were about 15% and 13% respectively, significantly higher than groups 5-3, 3-2, 2-1, 1-0.5 and 0.5-0.25 mm ($P<0.05$). The least of the group was 3-2 mm in particle size, which was less than 2%. The others, including groups 5-3, 2-1, 1-0.5 and 0.5-0.25 mm, were all about 5% and slightly higher than group 3-2 mm, while there were no significant differences among groups 5-3, 3-2, 2-1, 1-0.5 and 0.5-0.25 mm ($P<0.05$).

For natural soil, the PSD of mechanical stability aggregates also presented an inverse J shape, which was similar to vegetation concrete. While group >7 mm was 11% less than that in vegetation concrete or so ($P<0.05$). At the same time, the groups <0.25 and 0.5-0.25 mm were higher than those in vegetation concrete by about 8% and 3% respectively, both of which revealed significant differences, too ($P<0.05$). However, there were no significant differences between vegetation concrete and natural soil in terms of groups 7-5, 5-3, 3-2, 2-1 and 1-0.5 mm and 0.5-0.25 mm ($P<0.05$).

The PSD of water-stable aggregates mainly reflects the soil resistance to hydraulic erosion (Kosugi 1996). As shown in Fig. 2, for vegetation concrete, the PSD of water-stable aggregates exhibited a U shape after wet sieving. The groups >5 and <0.25 mm, which accounted for about 37% and 50% of the total mass respectively, were markedly higher than the others ($P<0.05$). There were no significant differences among groups 5-3, 3-2, 2-1, 1-0.5 and 0.5-0.25 mm with a range of 1-4% ($P<0.05$).

For natural soil, the PSD of water-stable aggregates presented a J shape and was obviously different from that of vegetation concrete. The group <0.25 mm was the highest, reaching about 74%, which was significantly higher than that in vegetation concrete ($P<0.05$). However, the group >5 mm was only about 12%, which was significantly lower than that in vegetation concrete ($P<0.05$). No significant differences were observed in groups 5-3, 3-2, 2-1, 1-0.5 and 0.5-0.25 mm between vegetation concrete and natural soil ($P<0.05$).

Characteristics of erosion resistance: After determination, eleven evaluation indexes above are presented in Table 1, indicating the significant differences between vegetation concrete and natural soil ($P<0.05$). On the PSD, $MSD_{>0.25}$ and $WSA_{>0.25}$ in vegetation concrete were 87.01% and 50.25% respectively, which were higher than those in natural soil (79.86% and 25.51%). Under wet sieving, MWD and GMD of vegetation concrete were 2.84 mm and 0.75 mm respectively, significantly higher than those of natural soil (1.27 mm and 0.29 mm), while PAD and K were 42.40% and 0.08 respectively, significantly lower than those of natural soil (68.49% and 0.33). D of vegetation concrete was 2.11, which was significantly lower than those of natural soil (2.79). On the microaggregates, AS and AD of vegetation concrete were 11.18% and 28.23%, remarkably better than those of natural soil (6.82% and 20.39%), while DR of the former was 53.36%, significantly smaller than that in the latter (73.32 %). Additionally, OMC of vegetation concrete was 2.49%, which was also significantly higher than that of natural soil (1.51%).

Correlation analysis of erosion resistance indexes: Correlation analysis was conducted and among $\text{MSA}_{>0.25}$ (X1), $\text{WSA}_{>0.25}$ (X2), MWD (X3), GWD (X4), K(X5), D (X6), PAD (X7), AS (X8), AD (X9), DR (X10) and OMC (X11), displaying in Table 2. As a result, the $\text{WSA}_{>0.25}$ (X2) of vegetation concrete was closely related to other erosion resistance indexes and had highly significant positive correlations with MWD (X3) (r =0.985**), GWD (X4) (r=0.966**) and OMC (X11) (r=0.968**) at P<0.01. However, it correlated highly negatively with K (X5) (r=-0.983**) and D (X6) (r=-0.950**) at P<0.01. Furthermore, a significant negative correlation was found between $\text{WSA}_{>0.25}$ (X2) and PAD (X7) (r =-0.923*) at P<0.05.

Table 2 shows that OMC (X11) was a key index affecting the erosion resistance of vegetation concrete, too. Specifically, OMC (X11) had highly significant positive correlations with MWD (X3) (r = 0.982**) and GWD (X4) (r = 0.974**) (P<0.01) and a significant positive correlation with $\text{MSA}_{>0.25}$ (X1) (r=0.914*) (P<0.05). However, it revealed a highly significant negative correlation with K (X5) (r=-0.950**) (P<0.01) and significant negative correlations with D (X6) (r=-0.915*) and PAD (X7) (r=-0.906*) (P<0.05). Furthermore, there were different degrees of correlations among other indexes.

PC analysis of erosion resistance indexes: The indexes of soil erosion resistance are various and complex, and there is some mutual information to a certain extent as shown in Table 2. In order to further reveal the contribution of each index to the soil erosion resistance, PC analysis was conducted and results are summarized in Table 3. According to the principle of PC extraction, three principal components (Y1, Y2 and Y3) were extracted from the eleven erosion resistance indexes above, and their characteristic values were 6.305, 2.276 and 1.942 with the contribution rates of 57.32%, 20.69% and 17.66%, respectively. The cumulative contribution rate was 95.67%, meeting the requirement of information loss for PC analysis.

From the load of each index in Table 3, the results of PC analysis suggested that the major contribution indexes to the principal component Y1 were $\text{MSA}_{>0.25}$ (X1), $\text{WSA}_{>0.25}$ (X2), MWD (X3) and GWD (X4). Accordingly, the major contribution indexes to the principal component Y2 were AS (X8), AD (X9) and DR (X10), and OMC (X11) was the most important index in determining the principal component Y3.

Among them, only DR(X10) was a negative contribution, and others were the positive contribution, including $\text{MSA}_{>0.25}$ (X1), $\text{WSA}_{>0.25}$ (X2), MWD (X3), GWD (X4), AS(X8), AD(X9) and OMC (X11). PC analysis indicated that stronger erosion resistance of soil was achieved with the higher $\text{MSA}_{>0.25}$, $\text{WSA}_{>0.25}$, MWD ,GWD, AS, AD and OMC as well as the lower DR.

On the basis of index loads and characteristic values in Table 3, the expressions of Y1, Y2 and Y3 could be derived respectively as follows:

$$Y_1 = 0.148X_1 + 0.152X_2 + 0.150X_3 + 0.151X_4 - 0.136X_5 - 0.138X_6 - 0.130X_7 + 0.037X_8 + 0.067X_9 - 0.086X_{10} + 0.022X_{11}$$

$$Y_2 = -0.017X_1 - 0.006X_2 + 0.011X_3 + 0.011X_4 + 0.073X_5 + 0.007X_6 + 0.116X_7 + 0.384X_8 + 0.374X_9 - 0.364X_{10} - 0.007X_{11}$$

$$Y_3 = -0.110X_1 + 0.131X_2 + 0.149X_3 + 0.128X_4 - 0.222X_5 + 0.195X_6 - 0.242X_7 - 0.195X_8 - 0.073X_9 + 0.044X_{10} + 0.506X_{11}$$

According to the expressions, the principal component values of the erosion resistance for vegetation concrete and natural soil were calculated as shown in Table 4.

The comprehensive principal component model $Y = 0.599Y_1 + 0.216Y_2 + 0.185Y_3$ was obtained by taking the proportion of the characteristic value corresponding to each principal component as the total characteristic value, and then comprehensive principal component values of the erosion resistance for vegetation concrete and natural soil were calculated as 0.617 and 0.175, respectively.

DISCUSSION

The research methods of soil erosion resistance could be grossly classified into two main types. One is described in ISSCAS (1981) to study some physical and chemical indexes of soil directly, e.g., the aggregate characteristic and OMC. The other is to study the changes of soil under various external forces, which is controlled by the former (Amezketa et al. 1996). This paper used the former to carry out the changes of erosion resistance indexes for vegetation concrete based on natural soil.

It is generally considered that the soil erosion resistance is proportional to $\text{MSA}_{>0.25}$, $\text{WSA}_{>0.25}$, MWD, GMD, AS, AD

Table 1: Characteristics of erosion resistance indexes of vegetation concrete and natural soil.

Soil type	$MSA_{>0.25}$ (%)	$WSA_{>0.25}$ (%)	MWD (mm)	GMD (mm)	*K*	*D*	PAD (%)	AS (%)	AD (%)	DR (%)	OMC (%)
Vegetation concrete	87.01A	50.25A	2.84A	0.75A	0.08 B	2.11B	42.40B	11.18A	28.23A	53.36B	2.49A
Natural soil	79.86B	25.51B	1.27B	0.29B	0.14A	2.79A	68.49A	6.82B	20.39B	73.32A	1.51B

*The same capital letter(s) within each index are not significantly different between vegetation concrete and natural soil at $P<0.05$.

Table 2: Correlation analysis of erosion resistance indexes for vegetation concrete.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
X_1	1.000										
X_2	0.954^{**}	1.000									
X_3	0.961^{**}	0.985^{**}	1.000								
X_4	0.957^{**}	0.966^{**}	0.974^{**}	1.000							
X_5	-0.853	-0.983^{**}	-0.864	-0.868	1.000						
X_6	-0.912^{*}	-0.950^{**}	-0.915^{*}	-0.907^{*}	0.879	1.000					
X_7	-0.907^{*}	-0.923^{*}	-0.921^{*}	-0.913^{*}	0.910^{*}	0.864	1.000				
X_8	0.773	0.875	0.768	0.774	-0.562	-0.798	-0.865	1.000			
X_9	0.832	0.845	0.821	0.830	-0.764	-0.690	-0.675	0.903^{*}	1.000		
X_{10}	-0.814	-0.891	-0.879	-0.871	0.745	0.619	0.902^{*}	-0.921^{*}	-0.911^{*}	1.000	
X_{11}	0.914^{*}	0.968^{**}	0.982^{**}	0.974^{**}	-0.950^{**}	-0.915^{*}	-0.906^{*}	0.865	0.871	-0.821	1.000

** indicated that it is significant at $P<0.01$, * indicated that it is significant at $P<0.05$.

Table 3: PC analysis of erosion resistance indexes.

Principal component	Index load											Characteristic value	Cumulative contribution rate %
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}		
Y_1	0.932	0.961	0.943	0.952	-0.858	-0.870	-0.822	0.231	0.425	-0.543	0.141	6.305	57.32
Y_2	-0.038	-0.013	0.024	0.026	0.167	0.015	0.264	0.874	0.852	-0.828	-0.015	2.276	78.01
Y_3	-0.213	0.254	0.289	0.249	-0.431	0.379	-0.469	-0.379	-0.142	0.086	0.983	1.942	95.67

Table 4: Principal component values of erosion resistance for vegetation concrete and natural soil.

Soil type	Y_1	Y_2	Y_3	Y
Vegetation concrete	0.249	0.006	0.361	0.617
Natural soil	-0.072	0.040	0.207	0.175

and OMC, while it is inversely proportional to PAD, K, D and DR (Staricka & Beniot 1995, Cotler & Ortega-Larrocea 2006, Liu et al. 2012), which was consistent with the PC analysis in this paper. Compared with natural soil, all the erosion resistance indexes of vegetation concrete had improved. On the distribution characteristic of aggregate particle size, $MSA_{>0.25}$ and $WSA_{>0.25}$ of vegetation concrete increased by 9.1% and 97.0% respectively, and the variation was particularly noticeable in $WSA_{>0.25}$. On the indexes resistant to hydraulic dispersion, MWD and GWD of vegetation concrete increased by 123.6% and 158.6%, while K, PAD and D decreased by 75.8%, 38.1% and 24.4%. On the indexes of microaggregate, AS and AD of vegetation concrete improved by 63.9% and 38.5%, while DR decreased by 27.2%. On the organic colloid indexes, OMC of vegetation concrete increased by 65.2%. Especially, the comprehensive principal component value (Y) of erosion resistance for vegetation concrete also increased by 252.6%. Therefore, the connection capability between particles had been improved and the anti-dispersion ability had been strengthened for vegetation concrete, and its erosion resistance was obviously better than that of natural soil.

The erosion resistance of vegetation concrete was obviously better than that of natural soil because of the addition of a large amount of natural organic material and cement in the latter when mixing vegetation concrete. On the one hand, as a kind of natural organic material, the fir sawdust added into natural soil would be decomposed into organic matter after a long time of decay, which made the OMC in vegetation concrete much higher than that of natural soil. Data in this article displayed that OMC had highly significant positive correlations with $WSA_{>0.25}$, MWD and GWD and the very significant negative correlation with K. At the same time, PC analysis above also presented that OMC made a greater contribution to the erosion resistance of vegetation concrete. To a great extent, the erosion resistance of soil depended on the ability of organic and inorganic cementing materials to connect soil particles (Tisdall et al. 1982, Bandyopadhyay et al. 2010, Yin et al. 2016). Blazejewski et al. (2005) have pointed out that macroaggregates and organic matter were the basis of stable soil structure. Studies by Yao (2009) also showed that higher OMC would facilitate the formation of soil aggregates and the increase of erosion resistance. Further, organic colloids in organic matter have cementation and hocculation, which could promote the formation of macroaggregates in soil, enhance the cohesive force between soil particles and improve the soil erosion resistance (Barral et al. 1998). In addition, organic matter would decompose under the action of microorganisms and organic acids would be produced to prevent agglomerates from dissipating, which also enhance the stability and erosion resistance of soil (Wu et al. 1997).

On the other hand, the cement added into natural soil would react with water and directly convert into hydrated calcium silicate, hydrated calcium aluminate, $Ca(OH)_2$ crystal and other compounds. These crystalline compounds would make microaggregates agglomerate together to form crystalline networks and solid compact structures under the action of strong chemical bonds, so as to improve the content of macroaggregates ($MSA_{>0.25}$, $WSA_{>0.25}$) in vegetation concrete and enhance its erosion resistance. This view was similar to the result of of Su (2011) that the addition of EN-1 curing agent could improve the erosion resistance of slope soil. After adding cement into natural soil, complex substance has essentially become a kind of cement soil. The effect of cement and curing agent were the similar, which could improve the erosion resistance of vegetation concrete.

It is a prerequisite to create the vegetation habitat with the strong erosion resistance as carrying out ecological restoration work on the surface of bare rock slope. The erosion resistance of vegetation concrete is much higher than that of natural soil, and its damage degree is lower under the hydraulic force as well as the better stability. Thus, vegetation concrete has a broad prospect in the future of engineering applications.

In the distribution characteristics of aggregates particle size, mechanical stability aggregates of vegetation concrete and natural soil, both presented an inverse J shape, while water-stable aggregates of vegetation concrete and natural soil exhibited a U shape and a J shape respectively. As a whole, the group <0.25 mm in natural soil was significantly higher than that in vegetation concrete ($P<0.05$).

Compared with natural soil, all the erosion resistance indexes of vegetation concrete were significantly improved ($P<0.05$). $MSA_{>0.25}$, $WSA_{>0.25}$, MWD, GWD, AS, AD and OMC increased by 9.1% , 97.0%, 123.6%, 158.6%, 63.9%, 38.5% and 65.2% respectively, while K, PAD, D and DR decreased by 75.8%, 38.1%, 24.4% and 27.2% respectively. Meanwhile, the comprehensive principal component value (Y) of erosion resistance for vegetation concrete also enhanced by 252.6%.

Correlation analysis showed that there were highly significant correlations among erosion resistance indexes of vegetation concrete ($P<0.01$), e.g. $WSA_{>0.25}$, OMC, MWD, GWD, K, etc.

The natural organic material and cement added in the preparation of vegetation concrete were the main reasons for its erosion resistance obviously better than that of natural soil. Therefore, vegetation concrete was a suitable compound to create vegetation habitat with the strong erosion resistance on the surface of bare rock slope.

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