XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

RESEARCH ON GEOMEMBRANE-PAVING MACHINE FOR U-SHAPE CANAL

JUNFA WANG[1], XU MA[2], GUILIAN WANG[3]

[1] College of Mechanical Engineering, Jiamusi University, Jiamusi 154007, China, wangjunf2934@sina.com
[2] College of Engineering, South China Agricultural University, Guangzhou 510642, China, maxu1959@scau.edu.cn
[3] College of Mechanical Engineering, Jiamusi University, Jiamusi 154007, China, wangguilian@gmail.com

CSBE101680– Presented at Section 1: Land and Water Engineering including EnviroWater 2010

ABSTRACT: It is necessary and meaningful to realize the mechanization of paving geomembrane. A prototype of a geomembrane-paving machine for U-shape canal is researched and tested. The method of "specialist's assessment" is used for evaluating the effect of paving geomembrane on canals and is put forward by quantifying the effect into four sub-indexes, and this measuring method is presented. The machine forward velocity, the brush slope angle and the geomembrane thickness are considered main factors that have great impact on the effect of paving geomembrane. By uniformity design test, the mathematic model is established to evaluate and predict the effect of paving geomembrane lining, and the influence rules of three factors on paving geomembrane are analyzed. The test results show that the geomembrane-paving machine can reliably work for U-shape canal.

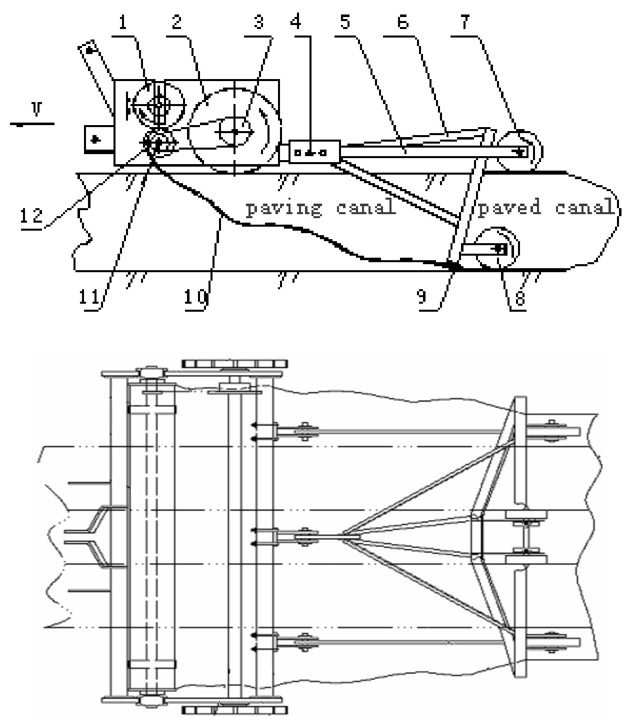
Keywords: Geomembrane; saving water; canal; seepage-proofing; mechanization

1 INTRODUCTION

China is relatively lack country in water resource and also a big agricultural nation. In China, the amount of water used in the agriculture is $3445\times10^9 m^3$ each year, and it accounts for 73% of the total amount. It was reported that 50% of the water (i.e. $1730\times10^9 m^3$) was run off in the transportation through canal in China, however, the loss was only 22% in America, 39% in Japan, 30%~40% in former Soviet Union (Xi and Li, 1997; Li, 2000; Wang and Ma, 2004). Transporting water through canal is and will be still the main way in agriculture. Therefore, solving the problem of canal seeping is an effective way to mitigate water deficiency.

For geomembrane-lining anti-seeping canals, it is regarded as one of the future developments of anti-seeping canal because there are many advantages such as low expense, high anti-bulge and anti-frozen performance and so on, especially after they are combined with stiff protective layer. At present, the engineering of geomembrane anti-seeping canal is still finished by hand or partly by machine in China. Its application and popularization is limited because this kind of engineering is very complex. It is necessary and meaningful to realize the mechanization of paving geomembrane, which will promote the popularization of the canal anti-seep technique in China and reduce the waste of water resource.

The principle diagram of the pave geomembrane machine is shown in Fig. 1(Wang and Ma, 2005; Wang, 2006). The axis of geomembrane roller 1 is mounted in the sliding bearing base, owing to the gravity, the roller 1 and the rubber rotator 12 may be stayed close together, which can ensure that the spreading geomembrane process is well-distributed and steady. According to the sliding rate between driving wheel 3 and the ground, as well as the sliding rate between the rubber rotator 12 and the geomembrane, the speed of spreading geomembrane and the machine's velocity was keep the uniform by means of adjusting the ratio of the transmission chain. When the machine moves forward, the driving wheel 2 drives the rubber rotator 12 through transmission chain, then the rubber rotator 12 drives the geomembrane roller 1. The spreading geomembrane is gone along with rolling of geomembrane roller 1. After passing the rubber rotator 12, the geomembrane is spread with proper flabbiness on the bottom, slope, and the canal edges. Subsequently, the U brush 9 spreads the geomembrane on canal bottom, side slopes and canal edges. The function of pressing wheel 7 fixes the geomembrane paved on the canal edges in order to prevent it from being taken canal bottom in the process of putting soil back. In addition, the height of the brush rack 6 may be adjusted by brush support wheel 8 to fit various states of canals and keep good lining effect.



1. geomembrane roller 2. driving wheel 3. chain wheel 4.connecting mechanism 5. presser rod 6. brush rack 7. pressing wheel 8. brush support wheel 9. brush 10. geomembrane 11. chain 12. rubber rotator

Fig. 1. Working principle of the machine of paving geomembrane lining for U-shape canal

2 EVALUATING METHOD FOR THE EFFECT OF PAVING LINING

2.1 Evaluating index

There is not uniform standard on the method of evaluating the effect of paving lining on the canal now. The method of specialists' assessment is adopted by quantizing the effect into four sub-indexes. They are following:

Sub-index A: the state of the geomembrane roller 1 laying down geomembrane.
Sub-index B: the smooth level of spreading geomembrane.
Sub-index C: the state of geomembrane tension.
Sub-index D: the changing amount of the geomembrane on the canal edge.

The standards of quantification of each sub-index are also put forward. The total index consists of four sub-indexes in the form of hundred-mark system. When total marks exceed 80, the effect of paving lining is thought to be satisfactory. Every sub-index has different weights for the different canal shapes, for example trapezoid, U or ladder.

2.2 Quantification standard of sub-index

(1) The sub-index A (%). At first, an ideal state of the geomembrane roller 1 laying down geomembrane is the prerequisite of paving lining on canal. The speed of the geomembrane roller 1 laying down geomembrane is fluctuant with changes of geomembrane weight and forward speed (Wang, 2006). The fluctuation is in a limited range. In this research, the fluctuant average value is supposed to be α % and the quantification standard is shown in Table 1. (2) Sub-index B (%). After geomembrane is laid down, part of the geomembrane can't be ensured close contact with the canal base owing to some air left under the lining, which may affect the stability of the canal slopes. Sub-index B (β %) is defined as the percentage that non-contact area occupies in a square meter. The quantification standard of sub-index B is shown in Table 2. (3) Sub-index C. The tensioning state of the geomembrane has the direct effect to its intensity, endurance and seeping. Sub-index C is the tensioning state of the geomembrane, i.e. the stretching rate of the geomembrane (η %). The quantification standard of sub-index C is shown in Table 3. (4) Sub-index D. According to Ministry of Water Resources' standard, the width of the geomembrane lining upper edges should be $300mm$, its function is to prevent rain from seeping under the lining so as not to decrease the safety index of slope stability. In this paper, sub-index D is the absolute value of the difference between the measuring value and design value divides the design value. The quantification standard of sub-index D is shown in Table 4.

Table 1. Sub-index A

$0<\alpha \le 0.5$	$0.5<\alpha \le 1.0$	$1.0<\alpha \le 1.5$	$1.5<\alpha \le 2.0$	$2.0<\alpha$
100>A≥95	95>A≥90	90>A≥85	85>A≥80	80>A

Table 2. Sub-index B

$0<\beta \le 2.5$	$2.5<\beta \le 5.0$	$5.0<\beta \le 7.5$	$7.5<\beta \le 1.0$	$10<\beta$
100>B≥95	95>B≥90	90>B≥85	85>B≥80	80>B

Table 3. Sub-index C

$0<\eta \le 0.2$	$0.2<\eta \le 0.4$	$0.4<\eta \le 0.6$	$0.6<\eta \le 0.8$	$0.8<\eta$
100>C≥95	95>C≥90	90>C≥85	85>C≥80	80>C

Table 4. Sub-index D

$0<\zeta \le 5.0$	$5.0<\zeta \le 10$	$10<\zeta \le 15$	$15<\zeta \le 20$	$20<\zeta$
100>D≥90	90>D≥80	80>D≥70	70>D≥60	60>D

2.3 Measuring method of the indexes

(1) Measuring method of the sub-index A. The fluctuant value of geomembrane is defined as the difference between theoretic length of the geomembrane laid and practical distance that machine go forward in specific distance. The measuring method is to take the average value of the three times results. (2) Measuring method of the sub-index B. In the process of spreading geomembrane, the geomembrane may make bulge due to the action of the brush. The sub-index B depends on the percentage that the bulge area occupies in specific area. (3) Measuring method of the sub-index C. According to the state of tension, the geomembrane is marked with nets before spread. The test geomembrane length is 3 meter. The size of the net is $10cm \times 5cm$. Then measure the increment percent of geomembrane length in each net and work out the average. Ten nets are considered as a unit, as shown in Fig. 2. (4) Measuring method of the sub-index D. The measuring method about the width change of the geomembrane lining upper edges is shown in Fig. 3. l is the design width of the geomembrane on the upper edges, and $\Delta l_1, \Delta l_2 \cdots$ are the differences between the design width and the practical width. The sub-index D is calculated Eq. (1).

$$D = (\Delta l_1 + \Delta l_2 + \Delta l_3 + \cdots \Delta l_n)/(n \times l) \tag{1}$$

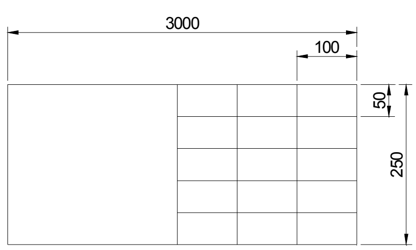


Fig. 2. Calibrated geomembrane net

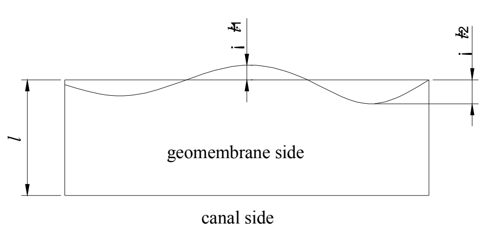


Fig. 3. Geomembrane width changes on upper edge

3 THE METHOD AND PROCESS OF THE TEST

3.1 Preparation and conditions

The test geomembrane material is low density ethylene. Its width is $2.0m$, the thicknesses are $0.06mm$, $0.11mm$ and $0.16mm$, respectively. The longitudinal and transverse intensity are $10MPa$. The extensible rate is 300% when the geomembrane is torn in width direction. The length of indoor soil box is $30m$, the width is $2m$. The soil is black earth. The soil is watered before a week in order to make it soft. The moisture content in soil is 20~22%. Then the canal is dug and shaped by hand. The average hardness is $0.6MPa$ on the upper edge, $0.5MPa$ on the slope, and $0.7MPa$ on the bottom. The machine speed is controlled by means of frequency converter. The structure of U brush used is shown in Fig. 4.

Fig. 4 The structure of U brush

3.2 Test design

On the base of theory analysis and experience of paving lining, The main factors which affect the effect of paving geomembrane lining are forward speed V, the brush slope angle α, the brush height h (distance between the brush handle and the canal base), brush hardness, geomembrane sorts, and geomembrane thickness, and the shape of the canal etc..

The forward speed V (factor X_1) and the brush slope angle α (factor X_1) are the main factors that affect the result for the U-shape canal, which are chosen as test factors. By testing, it is found that the brush height nearly has the same influence rules as the trapezoid canal, so this factor is ignored but the geomembrane thickness δ (factor X_3) is considered as an effect factor. The length of the brush is $10cm$, the average diameter of the brush mane is $0.22mm$. The size of the canal base is shown in Fig. 5. The uniformity design method is used for arranging the experiment (Fang and Ma, 2001; Ren, 2001). The forward speed V is selected 12 levels. The brush slope angle α is selected 6 levels. The geomembrane thickness δ is selected 3 levels. The test scheme is U_{10} (12×6×3), as shown in Table 5.

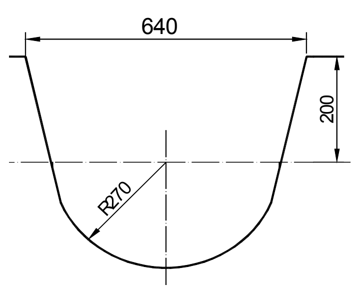


Fig. 5. The size of the canal base

Table 5. Factors and levels

Levels	$V(km/h)$	$\alpha(°)$	$\delta(mm)$
1	0.2	5	0.06
2	0.4	10	0.11
3	0.6	15	0.16
4	0.8	20	
5	1.0	25	
6	1.2	30	
7	1.4		
8	1.6		
9	1.8		
10	2.0		
11	2.2		
12	2.4		

4 TEST RESULTS AND ANALYSIS

4.1 Test results

In terms of above arranged experiment, the experiments are carried out with different forward speeds, brush slope angles and geomembrane thickness. The process of paving geomembrane can be seen in Fig. 6. The results are recorded, as shown in Table 6.

Fig. 6. The process of paving geomembrane on the U-shape canal

Table 6. Test results of paving geomembrane for the U section canal

No.	X_1 V	X_2 α	X_3 δ	Sub-index A (25%)	Sub-index B (25%)	Sub-index C (25%)	Sub-index D (25%)	Test results (100%)
1	1.4	25	0.16	21	21	20	20	82
2	0.2	15	0.11	23	23	23	22	89
3	1.6	5	0.06	21	19	19	20	79
4	0.4	25	0.06	22	20	22	22	86
5	1.8	15	0.16	19	22	22	19	82
6	0.6	5	0.11	22	19	21	20	82
7	2.0	30	0.11	19	18	18	18	73
8	0.8	20	0.06	20	21	21	21	83
9	2.2	10	0.16	18	20	17	19	76
10	1.0	30	0.16	20	19	20	21	80
11	2.4	20	0.11	17	18	16	17	68
12	1.2	10	0.06	19	19	16	17	71

Using uniformity design software UST1.0, the mathematic model is established to evaluate and predict the effect of paving geomembrane lining, as follows:

$$Y = 0.86 - 0.077X_1 - 0.0000164X_2^2 + 2.365X_3^2 \quad (2)$$

where X_1, X_2, X_3 are three factors mentioned as above respectively, Y is the effect of paving geomembrane lining.

4.2 Analysis of the test results

The interactions of pairwise factors between forward speed V, brush slope angle α and the geomembrane thickness δ are shown in Figs. 7~9, respectively. The effect of single factors is shown in Figs. 10~12, respectively. Table 7 shows examination results of regress significance.

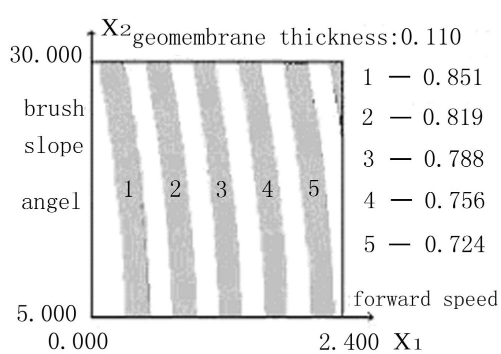


Fig. 7. Interaction of forward speed and brush slope angle

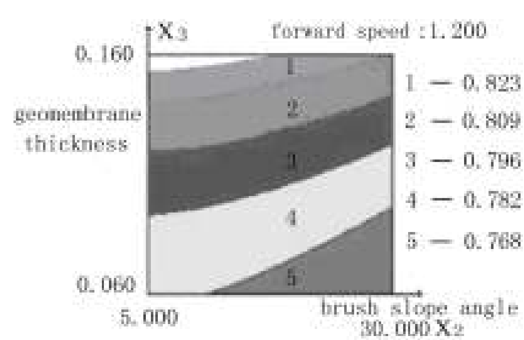


Fig. 8. Interaction of geomembrane thickness and brush slope

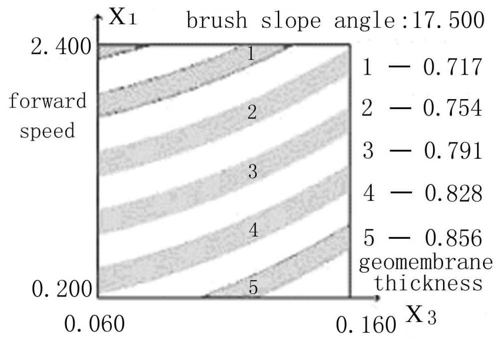


Fig. 9. Interaction of geomembrane thickness and forward speed

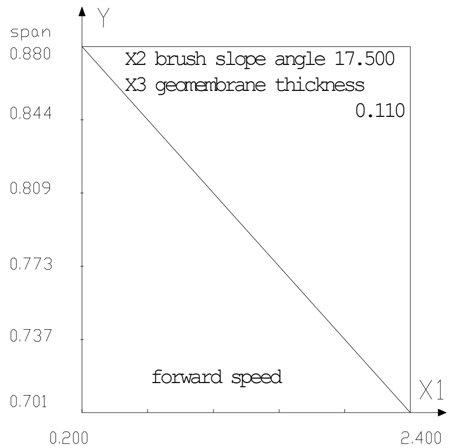


Fig. 10. Influence of forward speed on paving effect

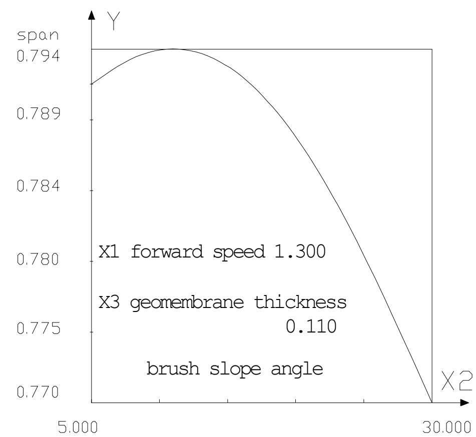


Fig. 11. Influence of the brush slope angle on the effect of paving

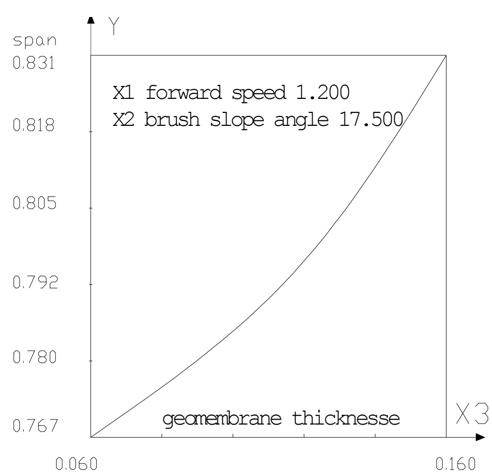


Fig. 12. Effect of the geomembrane thickness on the effect of paving

Table 7. Examination results of regress significance

Variance source	Square sum	Freedom	Mean square sum	Significance
Regression	0.4107	3	0.1369	$F_{0.01}(3,8)=5.9014$
Residual	0.1607	8	0.0739	F=6.8128
Total	0.5714	11		

Note: the correlative index R=0.847755, the remainder of the standard difference S=0.52148.

(1) The influence affection of forward speed V on effect of paving geomembrane lining

According to Fig. 7, the quality of paving geomembrane gradually declines as forward speed increases. The left area 1 is the best effect, and its value is 0.851. It can be seen from the Fig. 9 that the effect of paving geomembrane is sensitive to the forward speed when the bush slope angle keep the same because every equivalent zone is relative narrow. The best effect zone is at the bottom, namely zone 5. In addition, it is shown from Fig. 10 that the effect of paving geomembrane is nearly liner relation with forward speed and the slope is negative value. The effect value goes down to 0.701 from 0.88 when speed changes from $0.2km/h$ to $2.4km/h$.

(2) The influence of brush slope angle on effect of paving geomembrane lining

It's shown in Fig. 8 that the effect of paving geomembrane slightly declines when brush slope angle increases in the condition of the forward speed keeping the same, in other words, the equivalent zone have a little slope toward left. It can be seen from Fig. 11 that the effect of paving geomembrane is curve relation with brush slope angle. At first the quality of paving geomembrane goes up with the increase of the brush slope angle, then begins decline. The best value of the brush slope angle is about 10°.

(3) The influence of the geomembrane thickness on effect of paving geomembrane lining

It can be seen from Fig. 9 that when forward speed keeps the same the effect becomes better as thickness increases, and the equivalent zone is relatively wider, which implies that the geomembrane thickness has less influence on the effect of paving geomembrane lining. Fig. 12 reflects clearly that the effect of paving geomembrane lining become better as thickness increases, but the value of the effect goes merely up 0.064 when the thickness increases three times.

5 CONCLUSION

The machine of paving geomembrane lining for U shape canals is developed. The evaluation standard and measure method about the effect of mechanically paving lining for canal are presented. They are the fluctuant value of geomembrane, the percentage of non-contact area, the tensioning state of the geomembrane and the width change of the geomembrane lining upper edges respectively.

The test results show that the forward speed is the most important factor of influencing the effect of paving among the three factors, next is the brush slope angle, the third is the geomembrane thickness. The effect becomes bad as forward speed goes up. The effect of paving becomes better as slope angle increases at first, after reaching the extreme value, the effect becomes gradually bad. The thicker the geomembrane is, the effect is better, but not remarkable.

The test results show that the geomembrane-paving machine can reliably work for U-shape canal. If this geomembrane-paving machine is used in practice, it will can not only decrease labour intensity, but also promote the popularization of the canal anti-seep technique in China and reduce the waste of water resource.

Acknowledgements. This work was supported by the Natural Science Foundation of Heilongjiang province of China under Grant No. E2006-29.

REFERENCES

Fang, K. T., and Ma, C. X., 2001. The perpendicular and uniformity test design, first ed. Science and Technique Publisher, Beijing.

Li, A., 2000. Summary on the canal anti-seeping engineering technique in China. Journal of the anti-seeping technique, 6 (1): 1-4.

Ren, L. Q., 2001. Test design optimization and analysis, first ed. Science and Technique Publisher, Changchun.

Wang, J. F., and Ma, X., 2004. The present anti-seeping canal engineering technique and the mechanization technique to pave geomembrane lining on the canal. Jilin University Journal, 34 (2): 320-324.

Wang, J.F., and Ma, X, 2005. Research on the machine to pave the geomembrane lining. Journal of agriculture and mechanism Journal, 36 (4): 150-152.

Wang, J. F., 2006. Research on the theory of the anti-seeping canal and the mechanization technique to pave geomembrane lining, Jilin University, changchun.

Xi, G. Z., and Li, A. G., 1997. The developing trend of the anti-seeping technique in China. Journal of northwest water resource and engineering, 8 (4): 52-56.