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Research of technology on geosynthetics applied to flood control and bank-protection engineering in Liaoning Province

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ABSTRACT: This paper briefly introduces conditions concerning geosynthetics application on flood control and bank-protection engineering in domestic and abroad. According to years of technology research and achievements popularization of geosynthetics applied to river works of more than 200 locations in Liaohe River and Yalujiang basin, the paper comprehensively deals with geosynthetics types, main characteristics and effects of geosynthetics application in Liaoning Province, and its structural form and construction technology. Furthermore, demonstrates the design and construction of softy mattress of geotexture, and the design of anti-seepage geomembrance for sandy foundation and dykes; in addition, analyzes and elaborates economic, social and ecological benefits.

1 BRIEF INTRODUCTION

One of the key means to control river works is always considered as the improvement of the dangerous river works and regulation of river stretch. It has been for many years to pursue and explore the new material and special pattern of river work control. Those sandy-bag made of synthetic fiber was applied to the river works in the Netherlands, Germany and Japan in 1957. Polyvinyl chloride (PVC) fabric was used as the supporting layer of rubble to protect the slope of the seacoast in Florida, USA, in 1958. A variety of geosynthetics, consisting of goetexture, geomembrance, geofabricform and grid, had been applied to the engineering of flood control and bank-protection as well as anti-seepage in worldwide nations such as the Netherlands, Japan, the USA, the UK, France, Germany, former Soviet Union and Span in 1980s. Starting to apply geosynthetics in China was in the mid -1960s in 20th century. At the beginning, it was plastic film used in terms of anti-seepage of canals, then popularizing the application to other anti-seepage works of sluice and water-storage pool as well as weak-foundation and sandy dike. Fabric made of narrow thread of polypropylene compounding with rope net made of polyethylene and concrete blocks, acting as mattress to increase the load in order to avoid scouring riverbank, had been initially used in Sima Bank Protection Engineering of Yangtze River in 1976, in Jiangsu Province of China. Then analogous mattress was successively used in controlling flood and protecting bank in Jiangsu Province, Yangtze River stretch in Hubei Province. In addition, in Liaohe River, Songhuajiang River and Nenjiang River of northeast of China.Unwove fabire, geofabricform, grid had been popularized in the late 1980s.

2 THE NUMBER OF RIVER WORKS APPLIED GEOSYNTHETICS, MATERIAL TYPES, CHARACTERISTICS AND EFFECT

2.1 *The quantity of geosythetics applied to flood control and bank protection works*

Tableau 1. Statistics of geosythetics to river works in Liaoning Province

Types	Num.	Quantity ($10^4 m^2$)					Function
		Wove fabric	Unwove fabric	Compound geotexture	Geo-membrance	Geo-fabricform	
Bank- protec-tion	200	280.57	26.48		15.6	0.98	Inverted filter, preventing Scour, ballast, isolation
Dam conso-lation	100km	28.28	95.69	1.50	32.01	40.00	Inverted filter, anti-scour, bank-protection,anti-seepage
Anti-seepage	30	1.38		1.20	53.03		Anti-seepage
Anti-scour	32	7.50	2.96		1.59		Inverted filter,preventing scour, ballast, isolation
River weir	16	1.06	1.00			0.80	Inverted filter, solation
Foundation treatment	8	15.00					Reinforcement
Coffer dam cutoff	20	2.45	1.95	2.70	1.04		Inverted filter, reinforcement ballast, isolation
Flood break-down		30.00			10.00		Inverted filter,preventing scour, ballast, anti-seepage
Total		366.24	128.08	5.40	113.27	41.78	654.77

Tableau 2. Main characteristics and effects of geosythetics

Types	Weight (g/m^2)	Thick-ness (mm)	Sample strength				Equivalent Diameter O_{90} (mm)	Seepage Coefficent kg(cm/s)
			Tensile strength (N/5cm)		Extensibility (%)			
			Longitudinal	Lat-eral	Longitu-dinal	Lat-eral		
Wove fab-ric	100	0.45	496	408	26.0	20.0	0.70	6.8×10^{-4}
	110	0.67	666	551	28.6	25.0	0.72	3.57×10^{-3}
Unwove fabric	400	4.10	380	647	127.0	94.0	0.022	2.04×10^{-2}
Geomem-brance	220	0.27	156	183	26.2	48.5		1. 5Mpa (Water-proof)
Geofab-ricform	600		>1800	>2000	<25	<25	0.084	5.0×10^{-4}
	800		>1800	>2000	<25	<25	0.084	5.0×10^{-4}

2.2 *Application locations and effects of geosythetics*

Geotexture, in terms of Liaoning's river works, is mainly used to protect the toe of slope of the straight bank, act as the filter layer of bank and protect the bank of the spur dike, treat the foundation of submerged dam, block the layer of closuring projects and control flood, etc. Geomenbrance generally is made of soil-bag, soil-pillow and soil-quilt to prevent permeability of sandy-dam. Geofabricform is applied to slope protection and toe protection of dam. Grid can be made of crib work filled with stones to increase the ballast, other materials of geosythetics like wove fabric have already been used to invert to filter and drain water in river works. Geosythetics applied to flood control and bank protection works has six types of effects such as inverted filter, separation, preventing scour, anti-seepage, integration and adoption.

3 THE STRUCTURAL PATTERN OF GEOSYTHETICS APPLYING TO FLOOD CONTROL AND BANK PROTECTION

The typical structural patterns of application of geosythetics in Liaoning's river works are shown in Fig.1.

Fig.1 Schematic drawings of application of geosythetics to Hunhe River works

(a) Lijiafagan River work

(b)Zhangzz anti-seepage work of sandy-dam

4 DESIGN AND MAKING OF GEOTEXTURE MATTRESS

4.1 *Types of mattress*

According to the material, geotexture mattress applied to Liaoing's river works can fall into two types: mattress made of polypropylene wove fabric and mattress made of polyester wove fabric. The former can be classified into two types of single layer and double-layer. Mattress with regard to ballast also can be divided into rabble mattress and concrete blocks mattress, strip mattress made of iron thread net and mattress of soil pillow, in addition, mattress made of branch and stalk.

4.2 *Material choice*

According to the effects of application of geosythetics, it can be seen that choice of geotexture to make mattress need to take two sides into account: demand for inverted filter and tensile strength. Meanwhile, the condition of material of geotexture should be considered. For example, aging speed is very fast if reclamation material is involved, besides, attention should be paid to uniform of the thickness.

4.2.1 *Requirement for inverted filter*

The criterion for application of wove fabric adopted currently in domestic and abroad is as follows:

$0_{90} \leq (1\text{-}2)\ d_{90}$, $kg \geq 5ks$;

According to criterion given by Liaoning Provincial Research Institute of Water Resources and Hydropower:

1. For ballast consisting of clay larger than 10% under the condition of cover protection, 0_{90} $10d_{90}$;
2. For sand-soil consisting of clay less than 10% under the condition of cover protection, $0_{90} \leq (2\sim5)\ d_{90}$, when sand content is large in the flow, big value should be selected, otherwise, small value should be chosed.
3. For seepage demand, kg (1～5) ks.

4.2.2 *Tensile strength demand*

Tensile strength needs to be determined by calculation, in general, it should satisfy construction or laying down the mattress.

4.3 *Dimension design*

4.3.1 *Length of mattress (vertical to flow direction)*

Mattress for straight bank protection, which can be classified into the steady mattress above water and submerged, and the dislocated mattress. Mattress above water belongs to the protecting layer under the slope, which can be determined easily according to the designed gradient. The length calculation of the submerged mattress has two ways, when the main flow is approaching to the bank, adopting thalweg to calculate, otherwise, adopting the maximum depth value to calculate.

4.3.2 *The length of mattress (parallel to the flow direction)*

In theatrical, the longer mattress is along flow direction, the better integration because of few joints. However, construction is relatively difficult. Especially, mattress making, transportation, construction and machine condition on the site as well as the approach to lay down the mattress should be taken into consideration. Construction generally adopts 20-50m not only on the ice but also under the ice, however, 10-20m should be adopted by boat, under most circumstances, adopting 20m.

4.4 *Making mattress*

At present, manufacturers are able to make mattress related to the designed dimension and reinforced structure.

4.5 *Ballast types of mattress and design for the load*

Ballast types and the load of submerged mattress are as follows:

1. Edge load of concrete pre-casted product. When mattress is laid down into water, then throw down rubble stones, the average load is 1.2Kpa. The edge load should be enhanced up to 1.6Kpa. The edge facing the flow should be increased up to 2.0Kpa. The condition is the same as the construction by boat.
2. Double-layer mattress of polypropylene fabric made by branch-net with 1.0m×1.0m, has a load of 0.2~0.3m^3/m^2(approximate 3.7~5.6KPa). Construction of mattress on the ice was applied more widely in Xinmin, Liaozhong counties of Liaoning Province.
3. Soil-pillow load, adopting a piece of watertight wove-fabric coating polypropylene, 2.0m wide, and tensile strength is 838N/5cm and 517N/5cm respectively in longitude and latitude direction. Then make 2 types of bags with 5-10m long, which remains a mouth to fill soil later on, finally, binding 8 pieces of polypropylene ropes with 2.5m long, §4~§6,on the 10m long soil-pillow between a distance of 1.0m. The soil-pillow loads can be adopted.
4. Crib work filled with stones, is used for edge load with rubble, diameter of 0.3-0.6m, the load in the middle; also uses cribwork with the diameter of 0.3-0.5m.This has been more widely used in Tieling zone of Liaoning.
5. Compound load with gabion, rubble and soil-pillow. In general, the load is 1.0-2.0kpa.

5 ANTI-SEEPAGE DESIGN OF GEOMEMBRANCE

As for Zhangzz anti-seepage engineering, the following introduction is given.

5.1 *Determination to top height for anti-seepage*

Mechanical check measurement after dam construction shows that seepage coefficient of dam body is 10^{-4}cm/s, taking the short flood duration into account, thus the designed top height of flood is 23.32m, plus 1.03m freeboard, the height is determined to be 24.35m.

5.2 *Depth between anti-seepage curtain*

In general, the depth of the curtain can be selected as S=1~1.5H, as for Zhangzz anti-seepage engineering, S can be selected 1.5, thus S=1.5×3.72m=5.58(m),taking into consideration of other unfavorable factors, S=7.0m.

5.3 *Stability verification of seepage*

Adopting formula in documentary, transfer the vertical depth into the horizontal length to calculate (see Fig. 2)

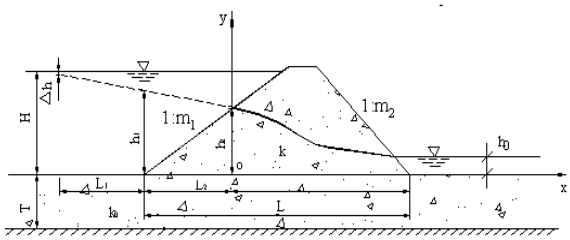

Fig.2 seepage calculation of blanket of geomembrance

$q=k_0T(H-h_1)/(L_1+0.44T)$

$q=k_0T(h_1-h_2)/(m_1h_2)$

$q=k(h_2^2-h_0^2)/2(L-m_1h_2)+k_0T(h_2-h_0)/(L-m_1h_2)$

All the symbols are shown in the Fig.3 above, by calculating, $q=7.39\times10^{-5}m^3/s/m$: $h_1=2.55m$: $h_2=2.41m$. Substituting these values into the following formula of seepage gradient can be obtained, $J=(h_1-h_2)/(m_1h_2)=0.023<[J]=0.18$.The depth of curtain can satisfy the stability need for seepage.

5.4 *Thickness of geomembrance*

By using the formula carried out by former Soviet Union in 1987, T=0.135E1/2pd/[σ]3/2,Where T is the thickness of geomembrance(mm),[σ] is the permission tensile strength of geomembrance(kg/cm2),E is the modulus of elasticity under the designed temperature (kg/cm2),P is the water pressure on the geomembrancep(t/ m2),d is the maximum diameter of particles in the layer under the geomembrance(mm). As for Zhangzz anti-seepage engineering,

$E=513.0kg/cm^2$: $p=10.72t/m^2$: $d=0.25mm$: $[\sigma]=22.77kg/cm^2$;

therefore T=0.075mm. Because Zhangzz anti-seepage engineering is the model engineering of geosythetics application performed by Water Department of China, so selecting the value of T=0.50mm related to Technical Specification of Application of Geosythetics for Hydropower Engineering (SL/T225-98).

6 CONSTRUCTION TECHNOLOGY

6.1 *Construction of geotexture mattress on bank protection*

6.1.1 *Construction technology on the ice*

1. Method for laying down mattress on the ice
   - Set sample,
   - make trench,
   - laying mattress,
   - place loads,
   - lay down mattress from ice surface

2. Lay down mattress in a natural way

This method should have a good command of the ice thawing period, otherwise, not only security problems will arise but also it is difficult to reach the expected results. The main steps are

- Set the designed sample,
- place loads,
- fasten mattress,
- lay down mattress when the ice thawing

6.1.2 *Construction technology under the ice layer*

- make trench,
- lay down mattress under the ice layer,
- place loads

6.1.3 *Construction technology above water*

1. By boat. By practicing, the best method has been found in Liaoning, the main steps are as follows:
   - Set sample
   - lay down mattress,
   - place loads
2. By floating bridge
   - make floating bridge and set sample,
   - lay down mattress,
   - determine the distance of floating mattress,
   - place loads

According to the method above, arrange the mattress from upstream to downstream step by step. Then fasten the one edge of mattress, in the end, place loads till reaching the designed loads.

The technologies above, characterized by cold zones and seasonal river, have their own advantages and disadvantages, which is better should be chosen related to the actual condition on the spot. Year's practice and experiments on engineerings show that the best technology is laying down mattress on the ice.

6.1.4 *Anti-seepage construction technology of geomembrance* (see Fig.3)

7 BENEFITS ANALYSIS

7.1 *Analysis of economic benefit*

Bank protection applying mattress of geotexture can save the investment of ¥12.83-51.44 per square meter than that of rubble stones. The cost of geomembrance preventing seepage is ¥600-100/m^2, which can save the investment of ¥40-70/ m^2 than that of traditional ways. In Liaoning, the area of application of geotexture is approximate 4 million m^2, saving direct investment of ¥83 million and that of geomembrance is about ¥1.0 million, saving ¥40 million. The total is up to ¥123.07 million.

7.2 *Analysis of benefit of the works duration*

Analysis of aging experiments show that applying geotexture to bank protection at least has a period of 15-20 years under condition of protection, which is 3-7 times of the duration life of 3-5 years of other mattress. In general, at least ¥222.49 million could be saved using geotexture unstead of traditional mattrass in more than 200 river works in Liaoning.

7.3 *Analysis of ecologic and social benefit*

The traditional way of bank protection need to chop a large area of trees, which will result in washing away soil heavily. That also can accumulate the development and formation of dangerous river. Thus a cycle of deterioration forms. However, geotexture mattress can solve the problems entirely.

Liaohe River has applied the geotexture with transportion only 400-900 tons in more than 200 locations. 0.2-0.35 million tons should be used if traditional mattress is applied. The benefit is significant. Also geotexture mattress can simplify all levels of construction orders. The efficiency can be increased 30-50% than that of traditional mattress. The construction period can be shorten, and could make the works bring up benefit early. Applying geosythetics in Liaoning Province is a revolution of technology in harnessing river works. The traditional mattress now has been replaced by geotexture mattress. This not only promotes the development of technology in harnessing river works but also has an active role on the development of chemical fabric industy.

Make platform – Make guide trench – Install machines – Start machines – Trench(Add clay liquid) – connect geomembrance – Lay down geomembrance – Refill – Form continuous curt

Fig.3 Flow diagram of construction technology