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Special lecture: Historical review of geotextiles for reinforcement of earth works in Asia

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ABSTRACT : This paper reviews the historical background of the geotextile in its uses in the field of earth reinforcement in Asia. Ancient historical relics are explored to study where natural materials have been employed as earth reinforcements over a period of 4000 years in China and the Middle East countries, and the paper introduces the current state-of-the-art of earth reinforcement, especially its research and application, together with the consideration of the process of recent development from the natural materials to polymeric ones for earth reinforcement in almost every country of Asia.

1 INTRODUCTION

The present paper in this research deals with the review of historical developments of the geotextile and earth reinforcing materials which have been used in Asian countries from the ancient time to the present and it aims at extending the works undertaken by Kerisel (1985), Yamanouchi (1986), Giroud (1986) and Fukuoka (1988).

The technological trend of the Asian countries is that the people have always tried, since ancient time, to harmonize the construction materials with the nature, the climate and the land. Thus the present use of natural materials and the geotextile for reinforcement is a technology that is inherited from the past. In fact using the polymeric materials as geotextiles has started from around the year 1970 in the developed countries and after that the material has rapidly gained popularity and its advantages are recognized by the geotechnical engineers.

Since the second International Conference on Geotextile was held in the year 1982 the 'geotextile' has become an international industrial product as accompanied by the publication of the magazine 'Geotextiles and Geomembranes' and the founding of the International Geotextile Society. As Giroud (1986) has pointed out the Geotextile is considered to be a technical break-through in so far as the geotechnical engineering is concerned. Its technical development was led by France, U.K., USA and other countries. In fact the polymeric material has undergone a tremendous in-road in the past decades into the Asian countries and it is expected that the natural materials from Asia will, as in recent Japan, also be put to use along with the recycled synthetics which are increasingly in large demand as accompanied by the general trend of necessary environmental preservation and the joint-use of polymeric materials.

2 TRADITIONAL USES OF NATURAL MATERIALS IN EARTH WORKS

2.1 Embankments

The natural materials used in embankment construction in Asian countries are wood, timber, bamboo, twigs of tamarisuku (i.e. a family of willow) other various twigs, reeds, jute, hemp and palm fibers.

The oldest embankments of Mesopotamia (BC 3,000~) in the Middle East countries had been mostly constructed of adobe. Kerisel (1985) has introduced an example of embankment base construction such as the laying of plaited reeds that are treated with bitumen.

The embankment construction that have been origionally practised in China was the hanzhu in which compaction was carried out adding some water and using tampers on a soil with layer thickness of 10cm. This method of construction is the most suitable to the yellow earth and it dated back to BC 4,000 and the finding of these embankments over the last several hundred years is quite amazing. The technique of hanzhu construction is called 'tufa' (earth work by own means) in Chinese. This ancient technique is still actively in use in many of the present yanfa 'western means or method'. The real hanzhu is as illustrated in Fig.1. The reason why this hanzhu is not widely utilized in Japan lies with the properties of earth that is that unlike the yellow earth which is dry with a high content of lime the earth in Japan has a high moisture content and as a result the earth tends to lead to over-compaction.

The representative examples of the embankment remains in China which were constructed by means of hanzhu or adobe using natural materials as earth reinforcements are compiled as shown in Table 1. Such remains are mostly seen at the west end of the Great Wall that runs parallel to the silk road. Such examples of earth works with the combined use of adobe and natural materials in the Middle East countries can be easily realized as they have been made known by the British in the past. But it is presumed that such type of earth works of China was unknown to the western countries. The reason why this kind of embankment remains was found in China is considered to be due to the fact that they were built in the area which had remained isolated from the rest of the world for a long long time, and this area is certainly endowed with a dry weather hardly influenced by Asian monsoon. Out of these remains three types of construction method are assessed and they are as shown in Fig. 2 ~ Fig.4.

2.2 Flood control works

The use of gabions for the construction of dykes in the flood control structures had been a common practice in China since the time of Hsia dynasty. The bamboo has been

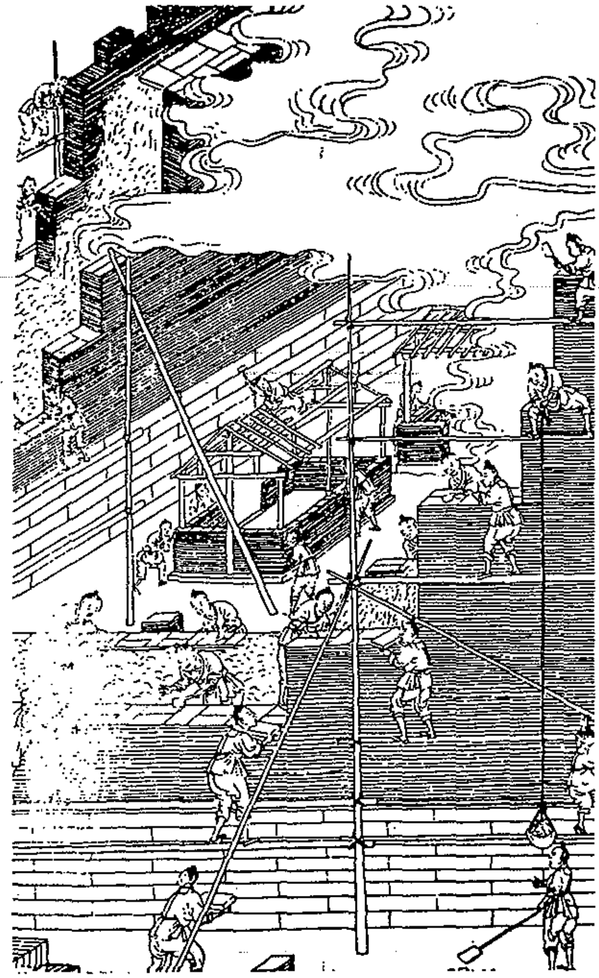


Fig.1 Chinese traditional soil compaction method "hanzhu" "The Great Wall near Beijing" (China Pictoria Pub. Co., Ltd. by He Shiyao, 1989, p.27)

traditionally used in earth works in India and Japan.

As convinced from the old Chinese proverb 'to control the river means to govern the country' the construction methods for flood control works were developed in China. For example the 'sao' (Fig.5) developed during the Song dynasty had been used for the repair of breached Yellow River dykes. The 'sao' is a bundle of stalks of gaoliang fastened by bamboo hoop with the fascines as core as shown in Fig.5 (Needham, 1970).

In Japan the chisan-chisui: the mountain-slope erosion control and river flood-control have been considered very important since the ancient time. The wide-spread of the bamboo related technology started around the year 1600 AD (Fig.6). The bamboo gabions were the most

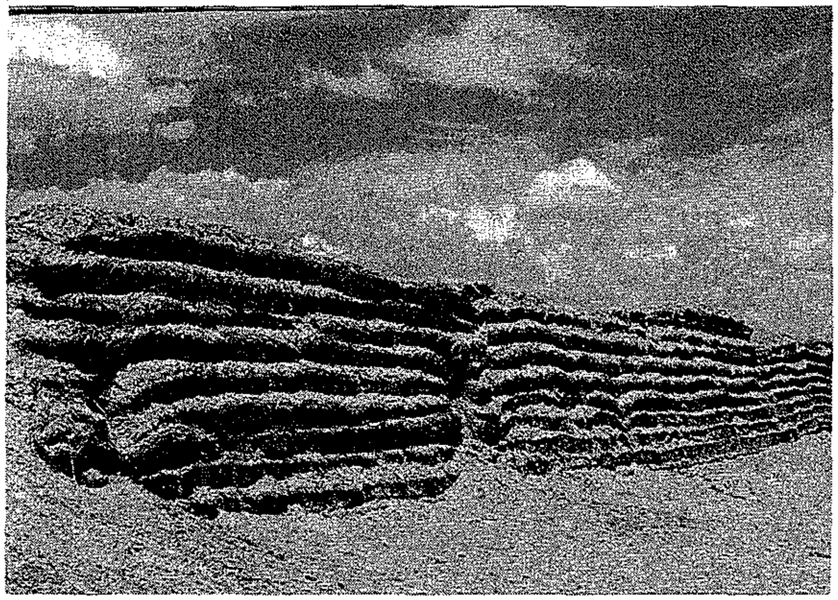


Fig.2 West end of the Great Wall built of soil, reeds, etc. ("The Great Wall", Sunday Mainichi Press Co., Spec. Vol., photographed by A. Yaguchi, 1991, p.120)

Table 1 Remains of embankments that had been built of natural materials in old China

Dynasty	Christian era	Construction method	Site of remain	Note
Qianhan (Early Han)	BC 202 - AD 8	Embankment Wall, "hanzhu" and reeds, twigs of "tamari-suku"	Near Dunhuang, Gansu Province	"Han Dynasty" Great Wall (Fig. 2)
		Castle gate, adobe and reeds	Ditto	"Yumenguan notable in a poem
		Office or palace	Ditto	Three room house
Houhan (Late Han)	AD 25 - 220	City castle wall, "hanzhu" and timber	Xian, Shaanxi province, etc.	(Fig. 3)
Tang	AD 618 - 907	Beacon tower, "hanzhu" and reeds, twigs	Near Dunhuang, Gansu Province	
		Stupa, adobe and timbers and twigs		(Fig. 4)

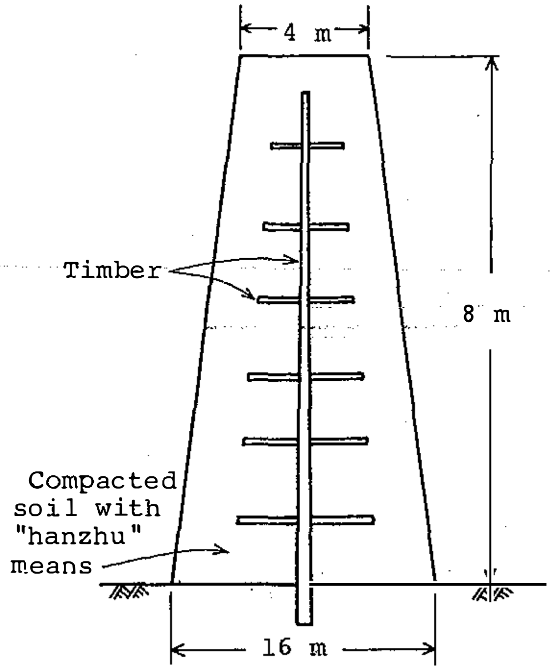


Fig.3 Conceptual profile of the typical city-castle wall built of soil and timber

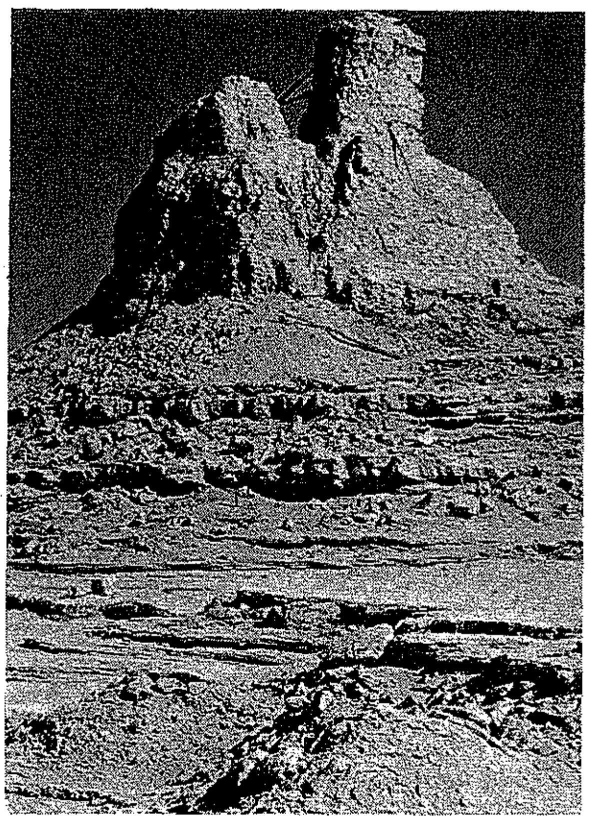


Fig.4 A stupa built of adobe, twigs, etc. near Dunhuang, Gansu Province ("Exploration of Longlang", Asahi Press Co., 1988, front piece No.3)

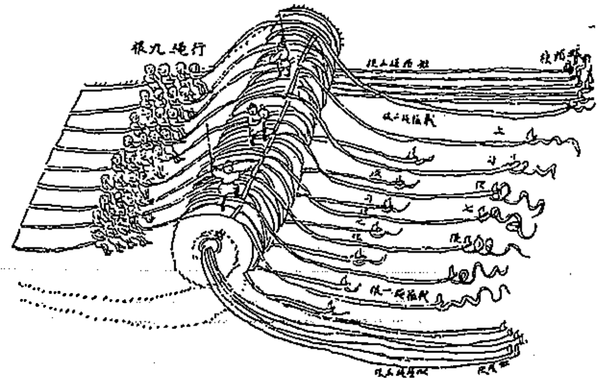


Fig.5 Great bundle core used for repairing breached dyke along the Yellow river, China (Needham, 1970) (Shisaku-Sha, 1979)

commonly used materials for flood control until the year 1911 when the steel wire mesh was first introduced and put into use. The urgent countermeasures against the breach of river dykes which are called 'suibo' are enacted as a law in Japan. The natural materials were used traditionally as countermeasures and recently being replaced by the polymeric materials since the latters are comparatively easy in handling and storage.

2.3 Soft ground

Kerisel (1985) has introduced fascines that were practised in Holland and Italy during the medieval era. That is the method of reinforcing by filling the area between the small wooden piles with straw, willow and twig for the case of dyke construction on soft ground. It was well known the fact that the natural fibers were used for the construction of polder dykes along the Zuider sea in Holland. What has ever attracted our attention is the fact that such natural fibers are used recently for the dyke construction in Belgium. Even in Japan the method of laying 'soda' the bundles of fascine for the dyke construction on soft ground was handed down from the Edo era until the 1960s. After the end of Meiji era the kind of soda mattress construction for flood control work of low land was called as Holland mattress since the former is very similar to the method recommended by a Dutch engineer. Fig.7 illustrates the old method of construction. Fig.8 depicts the application of that method during the years 1980s around Ariake sea, Kyushu.

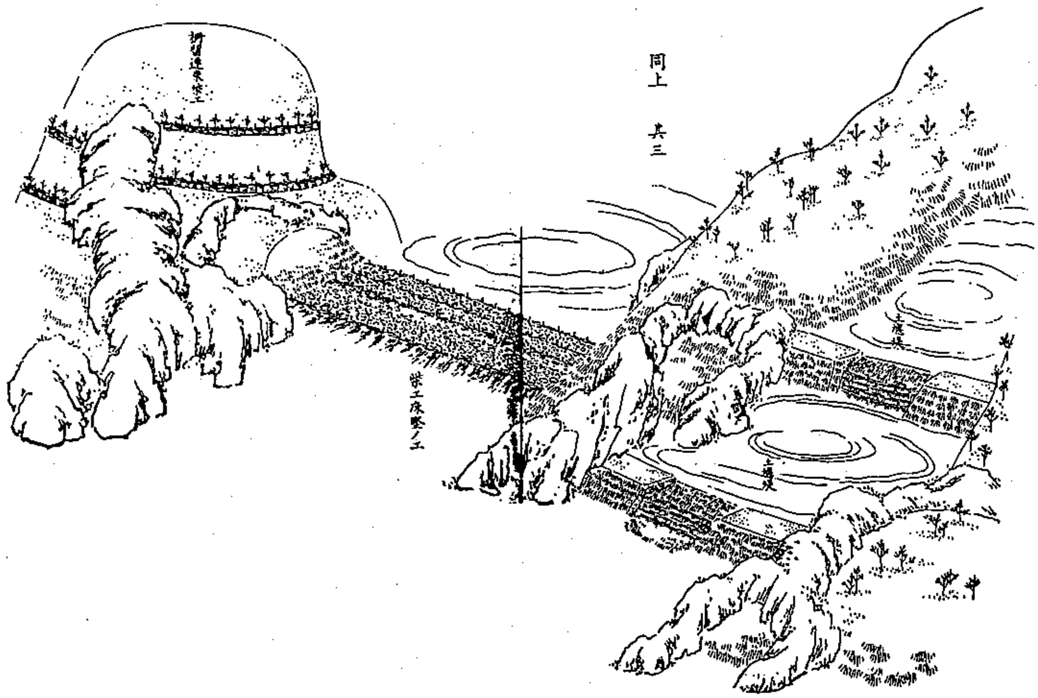


Fig.6 Typical Japanese technique for mountain-erosion control and river-flood control during Japan's feudal age (MIF, 1881) (Kowa-Shuppan, 1976)

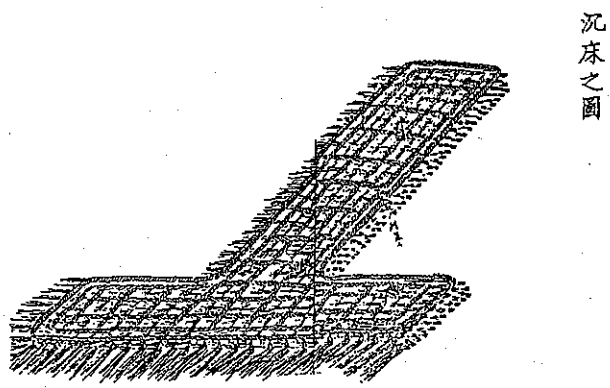


Fig.7 Mattress construction works on soft ground during Japan's feudal age (MIF, 1881) (Kowa-Shuppan, 1976)

Fig.8 The use of fascines for a sea-side dyke construction, Kyushu, Japan, 1987

Here the application of twigs to fascine is a rare case in Japan where the modern soft ground technology is flourishing.

3 JAPANESE CONSTRUCTION METHOD FOR SUPER-SOFT CLAY DEPOSIT

In Japan the reclamation of coastal land by filling the revetment enclosure with the dredged sea-bed silty clay was very popular during 1960s. The water content of the surface layer of such a super-soft deposited clay goes up to 300% and the sedimentation process is named by the New Design Group that organized a geotextile meeting in Ithaca, N.Y. in 1990 as a Japanese construction method. It is in fact a primary treatment method for ground improvement that has been developed by the author.

The HDPE net (plastic net) that was developed during the late 1970s for field use is employed in the case of such kind of clay deposits. The effect of the net is more of a restraint (restraining) than the reinforcement. The term 'restraint' is in fact an Asian concept that has been transmitted up to India.

The plastic net laying method has been employed in numerous construction sites around Japan, and JNR (Japan National Railways) (at present JR) has named this method as a 'shiki-amiko': the net laying method. The use of nonwoven fabrics contrived almost at the same time with the plastic net has terminated with the wide-spread use of the latter. What is to be stressed here is the fact that the structural pattern of the plastic net is more matching to the restraining function than the fabrics though the former's tensile strength is several kN/m less than that of the latter.

The use of plastic net has led to some additional contrivances. Here three examples will be stated. The first is the rope-netted method (the net is covered by a rope-net) that has been used since the year 1974 (Fig.9). The second is the method that has been developed by a company; it is the placing of pumped sand suspending to a certain thickness upon the plastic net laid on a soft clay deposit (Yamauchi & Kitamori, 1985). In this method the pump-up of lower-layer clay does not occur as a result of construction vehicles travelling on it.

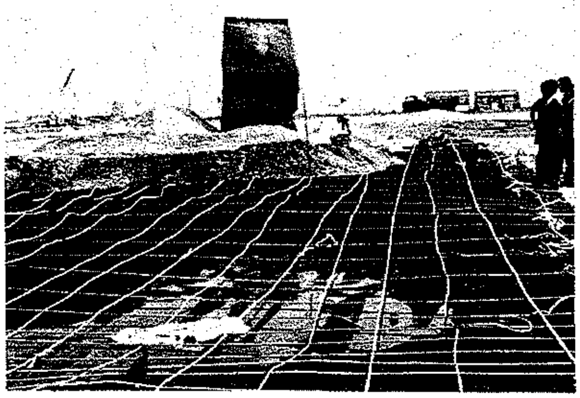
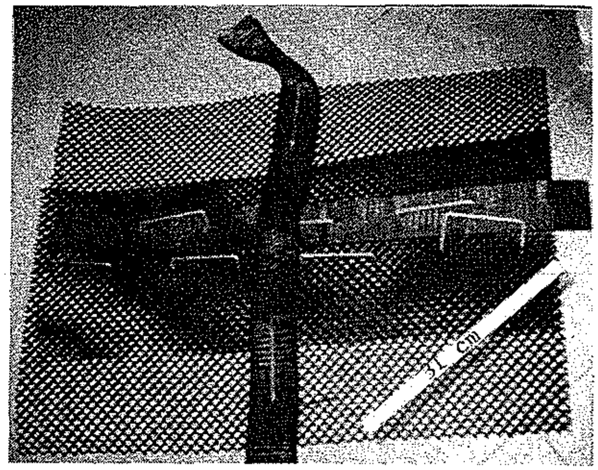
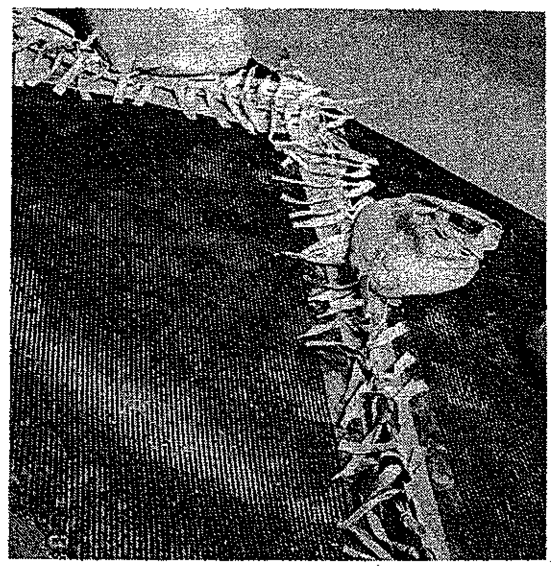


Fig.9 The rope-netted method of reclamation on super-soft clay deposit:- a Japanese construction method



(a) For plastic nets: metal staples and fabric belts



(b) For "fiber-grid" : fabric belts and ribons

Fig.10 Joint-contrivances used in Japanese construction method

The third is the method that is to be noted for its simple contrivance such as the making of joint between the plastic nets by the metal staple and the fabric belt (Fig.10 (a)) where the break-up is likely to occur due to the weak joining or the concentrated stresses due to over-tension.

Recently the so-called 'fiber-grids' with tensile strength of 70 or 80 kN/m are used as restraining materials in addition to the plain polymer geogrids in the Japanese construction methods (Fig.10(b)).

4 INTRODUCING POLYMER GRIDS TO JAPAN

4.1 The historical background

Terre Armee was introduced to Japan through the efforts of JNR in the year 1970 and after that in 1982 its Manual was published. On the other hand there was the Horimatsu's earth reinforcement idea in 1972, through the help of which JNR has standardized the plastic net reinforcing method.

The polymer grids invented by F.B. Mercer of U.K. along with plastic nets were enthusiastically introduced to Japan taking the opportunity of 1984 London Symposium as a starting point. The experiences on reinforcement stated above made it easier in accepting the material. Applying the materials to field use has begun with the practical construction of the steep reinforced embankment using pumice soil in 1984 (Yamanouchi et al.,1986). The doctorate thesis by N. Fukuda on the geogrid reinforcement was also a brilliant achievement in 1985.

The polymer-geogrid reinforced earth embankment was accepted with a warm welcome in Japan since it enables the engineers to conduct an easy slope vegetation gaining environmental preservation merit and flexibility. The method attracted the attention of geotechnical engineers as an innovative one. The cost per unit slope area of polymer-geogrid reinforced embankment was lower than that of the wall by Terre Armee method in the case of the wall height less than 8m. This was the limiting condition until 1990 that is the year when the supply of Japanese-made geogrids started with the production of the materials by the world's third largest factory in Japan. At present the limit of embankment height has gone up more than 11m (Fig.11). In Japan it is a necessity to protect the geogrid-reinforced walls with non-conbustable slope surface, especially in the area where the field burning method of cultivation is still in practice.

M. Fukuoka who always exerts great effort to community activities organized the Geotextile Action Committee affiliated with JSSMFE in the year 1984. The Geogrid Meeting was planned in Kyushu in 1983 and the organizing committee has taken over a part of the geotextile research activities to assist JSSMFE. This geogrid-meeting organizing committee has developed into a Geogrid Research Board in 1987 and the

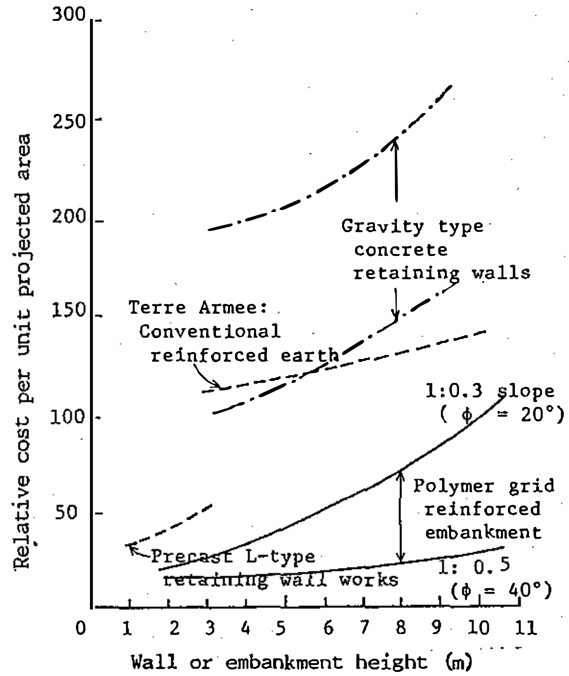


Fig.11 Relationship between wall height and unit cost per slope area in Japan

'Guidelines to Geogrid' was published and widely used by the geotechnical engineers in 1990. Moreover the JSSMFE has started to establish the Standardization Committee on Testing of Geotextiles in 1992.

In the year 1987 the continuous yarn reinforcing method, a French Method related to E. Leflaive and considered in Japan as a new method whose testing procedures are standardized, was introduced to Japan and it gradually gained popularity. But some problems as to uneasy excavation which is done whenever necessary after embankment completion and the erosion due to excessive rain in Southern Kyushu where pumice soils are widely distributed remain to be solved.

4.2 Related technical contrivances

Bartos (1979) has stated the possibility of one hundred and one methods of retaining wall construction other than the Terre Armee. In Japan also several methods of construction were developed and the concrete-block-faced polymer grid reinforced embankment and the coated-steel-mesh reinforced embankments have been practically constructed. Moreover in the case of metal reinforced embankment the metal is not strictly demanded to meet

Table 2 Comparison of tensile strengths for various geotextiles

Material	Range of tensile strength (kN/m)		Country	Application
Plastic nets (high density poly ethylene,HDPE)	5 8 11		Japan	Restraining
	7.68		India	Reinforcement
Fiber-grids (polymer filaments and PVC coated)	70 80		Japan	Restraining
Woven fabrics	4.26		Japan	Reinforcement
Nonwoven fabrics				
polypropylene	31		USA	
,, 2-layer	62			
,, 3-layer	92			
Multiwoven fabrics polyester	186			Reinforcement
Polymer grids	Longi.	Trans.	Japan	
	Uni-ext.			
	55	5		
	80	8		
	100	10		
	Bi-ext.			
	12	18		
	15	28		

the durability requirements as much as the polymer grids are.

4.3 Woven or nonwoven fabric reinforced structures

The woven or nonwoven fabrics reinforced embankments are vigorously developed in the USA. The first one is the retaining wall by R.M. Koerner in 1980, and the clayey-soil-filled wall, 12m in height, the highest in the world, and bearing surcharge load of an equivalent embankment of 5m height, was successfully constructed in Seattle in 1990. That is credited to the result of improved tensile strength of the fabrics i.e. 92 kN/m.

The reinforced steep-slope embankment, the first ever constructed in Japan for testing using nonwoven fabrics, is the one built by Kinki Regional Construction Bureau in 1989. In that the slope's expanding deformation is a big problem.

During 1980s Tatsuoka et al. (1986) undertook research studies on the reinforcing mechanism of the nonwoven fabrics having tensile strength of 30 kN/m or 50 kN/m. Applying the results of the studies JR has successfully constructed a reinforced-soil railroad retaining wall of 5m in height and 7.0 km in length in 1991 by using the woven fabric "fiber grid" of 4.26 kN/m with an elongation less than that of nonwoven fabrics.

4.4 Structure and strength of geotextile

Structure of geotextile, that has to be three-dimensional, is supposed to be an important factor that brings about useful functions at the field, and the factor often governs the range of tensile strength of the material. A comparison of the tensile strengths is made for some polymeric materials as in Table 2.

For example, unit tensile strengths of plastic net are much less than those of woven or nonwoven fabrics, but the nets can be of use not only to the Japanese construction methods but also to other methods adopted upto the present time. The author would like to emphasize the fact that the polymer grid is a unique invention as viewed from the aspect of its structure as well as its high tensile strength. The material greatly contributes to saving workmanship of an expert.

However there seems to be a trend toward increasing the wide range of tensile strength of woven or nonwoven fabrics, especially in the USA as shown in Table 2. For some time to come a kind of competition will continue in so far as both structural and tensile-strength improvement efforts are concerned for plastic nets on one hand and the polymer grids on the other.

5 DESIGN METHODS OF EMBANKMENT REINFORCEMENT IN JAPAN

Here some design methods of reinforced embankment usually practised in Japan will be explained.

5.1 Japanese Construction Methods

The methods are concerned with the restraint imposed by the construction of low embankments on soft alluvial deposit. The approach is as follows.

(a) A solid-plastic approach without consideration of deformation

(b) An approach with consideration of deformation

As stated in Table 3 the above approaches have developed into three methods and two methods respectively (Yamanouchi, 1990).

The British engineers have considered the structure on super-soft alluvial clay deposit as a special case of Japanese construction works, but recently they have started their own research on this subject with respect to the design approach.

5.2 Geogrid Reinforced Steep Embankments

In Japan the British design method proposed by Jewell et al. (1984) was used from time to time for the design of

Table 3 Summary of five theoretical studies of the use of geotextiles on soft ground (Geogrid Research Board, 1990, credited to Y. Tanabashi)

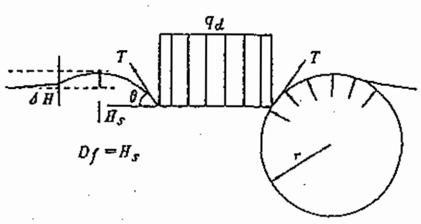
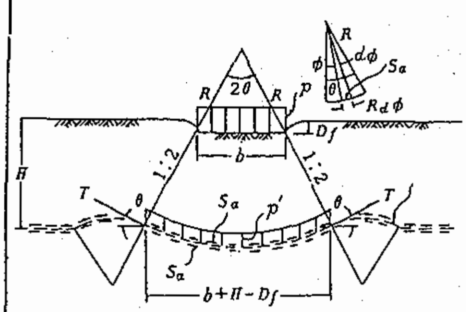
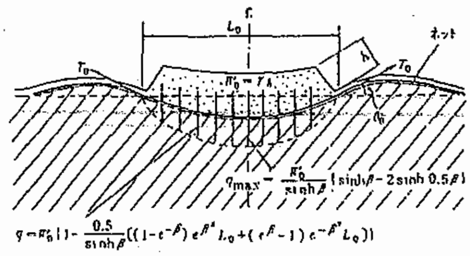
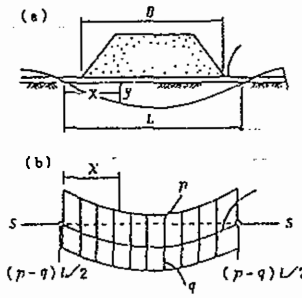
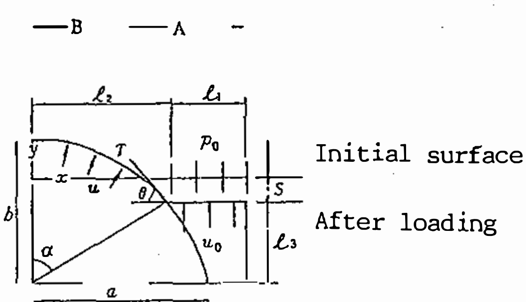
Reference	(1) Formula of bearing mechanism (Nishibayashi et al., 1966)	(2) Practical formula of practical bearing capacity (Yamanouchi et al., 1979)
Mechanism		
Formula	$q_d = q_1 + q_2 + q_3 + q_4$ $= c\ N_c + 2T \cdot \sin\theta / B + T/r + \gamma_t \cdot D_f$	$q_{a2} = (1 + \frac{H - D_f}{b})(\frac{1}{F_s}\{5.3c + T \times (\frac{0.9}{b} + \frac{1}{r}) + 0.5 S_a\} + \gamma_t D_f)$
Load intensity	$q = \gamma H + p_0$	$\sigma = \gamma H + \frac{p \cdot b}{b + H + D_f}$
Safety factor	$F_s = \frac{q_d}{q}$	$F_s = \frac{q_d}{\sigma}$

Table 3 (continued)

Reference	(3) Cable theory (Shimizu et al., 1977)	(4) Slab theory (Yamanouchi et al., 1979)
Mechanism		
Formula	$q = W'_0\{1-\frac{0.5}{\sinh\beta}((1-e^{-\beta})e^{\beta\frac{X}{L_0}}+(e^{\beta}-1)e^{-\beta\frac{X}{L_0}})\}$	$q=p(\frac{D}{S^2}\frac{1}{\cosh\sqrt{S/D}\cdot L/2}+\frac{L^2}{8S}-\frac{D}{S^2})$ $+(\frac{D}{S^2}\frac{1}{\cosh\sqrt{S/D}\cdot L/2}+\frac{L^2}{8S}-\frac{D}{S^2}-\frac{12h(1-\nu^2)I_K L/2}{\pi E})$
Load in-tensity	$W'_0 = C_z \cdot Z$, $C_z = f(\lambda, \frac{D_{60}}{D_{10}}, W', \gamma_s, C, \text{etc})$	
Safety factor	$F_s = \frac{q_d}{W'_0}$	

Reference	(5) Membrane theory (Hayashi et al., 1988)
Mechanism	$y(x) = b/a\sqrt{a^2-x^2} - b + y(\ell_2)$ 
Formula	◎ A part (along y) $P_0 \cdot \ell_1 = u_0 \cdot \ell_1 + T \cdot \sin\theta$ ◎ B part (along y) $T \cdot \sin\theta = \int_0^{\ell_2} u(x, y)dx$
Load in-tensity	p_0
Safety factor	$F_s = \frac{T_u}{T}$

polymer grid reinforced embankments. This method is also referred to and recommended for application in the Guidelines to Geogrids. Moreover in the Manual published in the year 1992 by the Research Institute of Public Works, Ministry of Construction (PWRI, 1992), there include, in addition to the internal and external stability computation, the checking of circular shear failure that involves the reinforced base section. Here the soil's cohesion is adopted to be 10 kN/m^2 as the upper limiting value. And as to the internal stability the clearance length of up to 1m is adopted taking into consideration the surcharge. The manual also instructs to adopt, due to consolidation effect, the increment of shear strength of filterable fabrics joint-used with polymer grids in embankments that are built using cohesive soil of high water content (PWRI 1992).

The seismic computation is a necessity to the country like Japan and the seismic coefficient method, an old classic approach to seismicity, first published in 1914 by R. Sano and arranged by Mononobe (1933), has been usually applied. The checking against seismic forces involves various problems; especially the basic problem is considered to be whether or not the safety factor under seismic condition should be taken lower than that of the normal condition. In the ordinary checking against seismic forces the horizontal seismic forces are taken into consideration but an appropriate approach was not yet decided as to the vertical seismic forces that are likely to occur especially within the area near the seismic epicenter.

Japan has not had any experience with respect to the damages of reinforced embankment due to the seismic forces. In the above mentioned Manual of the Research Institute of Public Works it is prescribed that the checking against seismic forces are to be done, but a specific computation method is not clearly defined.

6 HARDLY USED GEOTEXTILE METHODS IN JAPAN

At the beginning of 1980s the polymer grids made in UK were introduced to Japan. The application methods of this material were known to the Japanese engineers as the British ones. But out of these some methods were hardly ever used and they were namely:

(a) geocell mattress of polymer geogrids,

(b) the asphalt surface-layer reinforcement by using polymer geogrids and

(c) soil stabilization by integrated use of polymer mesh elements.

The method (a) involves the complicated labour works and high cost, and it has the problem of the speeded-up consolidation on soft ground due to the heavy weight of the mattress.

The method for (b) is not used since the process of work for lengthening the polymer grids on the tortuous (in both plane and level) Japan's road is difficult and requires a large working space, and the thermal shrinkage problem also prohibits the engineers from using the method. The nonwoven-fabrics reinforcing method, one of USA's methods that is used for preventing longitudinal cracking of asphalt surface, was tested by Kinki Regional Construction Bureau in 1989 and it gained popularity.

The method (c) is recognised as an effective one for easy integration of the polymer mesh with the decomposed granite or sandy soil like 'Masado', but for the volcanic-ash cohesive soil such as Kanto loam the CBR value is not gained when affected by over-compaction.

The practical experiences and usages gained from various field studies on geotextiles in Japan can be briefly compiled as shown in Table 4. The solid lines denote the effective utilization and the dotted lines mean the hardly used cases of geotextiles.

7 SOME REMARKS ON GEOTEXTILES IN ASIAN COUNTRIES

The people of all Asian countries show their earnest desire to use polymeric materials, and as pointed out in Section 2 they are, even now, using the traditional natural materials, e.g. bamboo that has a certain quantity of tensile strength, as earth reinforcing members.

7.1 China

In China the geotechnical engineers are getting more and more interested in geosynthetics. The first Chinese Geosynthetics Conference was held in 1981 and the second was in 1989. The details of

Table 4 Practical uses of various geotextiles in Japan

Material and uses	1960's	1970's	1980's	1990's
Woven or nonwoven fabrics				
Restraining	- - -	- ——→		
Reinforcement		- - -	- - - - - -	——→
Asphalt surface		- - -	- - - - - -	- -→
Plastic nets				
Restraining	- - -	- - - ——	——————	——→
Polymer grids				
Restraining			- - - ——	——→
Reinforcement			- - ———	——→
Geocell mattress			- - - - -	- -→
Steel mesh				
Retaining wall		- - -	- - - - - -	——→
Embankment reinforcement		———	——————	——→
Mesh element stabilization			- - -	- -→
Continuous yarn reinforcement			- - -	- ——→
Polymeric flood control works			——————	——→

Solid line: fully in practice Broken line: partially in practice

these conferences can be learnt from Liu Zong Yao (1988) and from the proceedings of the second conference.

At present the man who is behind the research and practical activities on geosynthetics in China is Liu Zong Yao. Moreover some Chinese railway engineers from the Department of Railways have made early contribution to the research. The special features of China's geosynthetics is that both woven and nonwoven fabrics of geosynthetics and polyvinyl alcohol are produced in large quantity and various kinds of geosynthetics are utilized. However the expensive polymeric materials are, in fact, hardly used at present. With the progress of chemical industry it is expected that the practical utilization of them will expand in China in the near future.

As to the research papers the topics range from plastic wick-drains to fabriform and polymer grids. The research paper of special interest to the author, such as Chinese construction method using natural materials, was hardly found among the papers.

The contents of the Second Chinese Geosynthetics Conference are:- the protection works: 14 papers, seepage cut and separation including geomembranes: 24 papers, reinforced earth structures: 20 papers, testing of physical properties: 19 papers, textile manufacturing: 7 papers. The study of polymer grid is included in the earth reinforcement chapter. The reference papers that were mostly referred to are those western papers published since the third Geotextile Conference, Vienna, 1986.

7.2 Southeast Asian countries

Both Hong Kong and Malaysia have, in a similar way with Japan, early introduced the British design and construction method of polymer grids. In Hong Kong gabion walls were built for the disaster prevention againt mountain-stream erosion

Fig.12 Polymer-grid gabion wall built in 1983, Hong Kong

in the year 1983 (Fig.12) and recently the polymer grids for reinforcement of backfill behind retaining wall have been specified under the geotextile standards (Geotech. Engg. Office, 1991). In Malaysia the reinforcement of asphalt surface by polymer grids has been successfully carried out led by S. F. Chan.

In the case of Thailand AIT has made some progress since 1980 so far as the research on geosynthetics itself is concerned, and considering the cost effectiveness the research on the application of steel grids other than bamboo to reinforcing the embankment was being conducted (Bergado et al., 1991).

Singapore was interested in the Japanese construction method for the sea-shore reclamation works already constructed in 1980s. Hong Kong seems to have completed recently the study on the method of reclamation for the new international airport.

7.3 India

In India the plastic net attracted the attention of engineers during 1970s. The device for the use of natural materials only and the use of polymeric materials as additional reinforcements is quite noteworthy in its development. And the First Indian geotextile Conference was held in the year 1988 and led by Mandal. From its proceedings the trend of India's research and practice can be fully realized.

The contents of the proceedings are properties and laboratory evaluation: 10 papers, ground restraint and stabilization: 6 papers, reinforced earth structures: 12 papers, slope protection and erosion control: 5 papers, drainage and filter: 5 papers, special application to problems: 13 papers and special session on geojute: 6 papers. Out of these papers the paper on jute has attracted the attention of the research engineers..

As a conclusion of the Conference Jha and Mandal (1988) have stated or concluded the following favourable conditions required for the meaningful application of geosynthetics to the construction works; they are: (1) non-availability of conventional granular materials within 30 to 50 km in the vicinity of the work site, (2) roads and embankments are in the swampy areas (geotextile may work as a separate reinforcing material), (3) in a project where speed is essential, (4) for application to military works where speed is required, (5) when quality control is needed and (6) in adverse working condition where no alternative is available.

Since the early 1980s Datye has conducted studies on the use of jute and the application of bamboo to columns devising the Terre Armee for the natural material: bamboo.

Just recently Rao et al. (1991) has made laboratory studies on the lateral deformation of the HDPE-manufactured geogrid reinforced embankment with earth-bag facing testing under various surcharge loads.

Recently Singapore has made some joint-research on the test construction of jute-hemp composite vertical drains and plan to extend the usage of the materials to earth reinforcement, led by S.L.Lee.

8 CONCLUSION

With regard to the future trends and special characteristics of each country in Asia the following points can be summarized on the basis of the historical review of earth reinforcement and the application of natural and polymeric materials to the reinforcement.

(1) Japan: in Japan where the chemical industry is highly developed the experiences gained from the use of natural materials in the past have led to the easy use of polymeric products and the most

characteriastically Japanese method is the method of plastic-nets utilization for super-soft clay deposit. With respect to earth reinforcement the British nethod, the Frensh or USA methods all are introduced to Japan and it is expected that the use of polymer grids and the construction of geogrid-reinforced embankment will develop and advance more than ever with the domestic manufacturing of the material starting in the year 1990. It is presumed that all the introduced methods will be put to use and assimilated gradually in Japan.

(2) China: the Chinese method of utilization of old, traditional and natural materials should be highly evaluated and the engineers should study it thoroughly. At present in this country the western methods are pursued widely. The polymeric materials are tested rigorously and used to some extent in the structures for infra-structure development projects. In future it is expected that some effort will be made to manufacture the materials locally. It is hoped that the unique technology will be developed in this country in the field of reinforcement based on the abundant historical experiences.

(3) Southeast Asian Countries: in Hong Kong and Malaysia the engineers have fast studied the British methods and put them to actual practice. But like other countries the utilization of bamboo, jute and hemp will also be restored as the modern method of geotextile reinforcement gives the engineers a stimulus. These natural materials are also to be used in addition to the polymeric materials,and the geotextiles of medium cost, it is expected, will develop in the near future. And these developments will be useful for other developing countries too. It seems to the author that the time has come to organize a Southeast Asian Conference on Medium Cost Geotextiles. And accordingly the Southeast Asian Methods will be brought on debut.

(4) India: in South Asia India is mainly leading the research on polymeric materials and they have come up to the stage of practical utilization of plastic nets. Some unique methods of utilizing the traditional materials such as bamboo, jute and hemp are also in the stage of development. Attention should be given to the fact that a significant policy is likely to be established as to the research and development of geotextiles for the developing countries. And consequently the Indian method of earth reinforcement will appear on the technological stage.

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Note Figures 2, 4, 5, 6 and 7 are permitted to put in use by courtesies of four publishing campanies, respectively.