History and development of polymer grid reinforced earth structures – Development since Henri Vidal

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SYNOPSIS F. Brian Mercer of England invented in the year 1979 the polymer grid earth reinforcement method to be used not only for steep embankments, capable of incorporating grass turfed front surface, but also for rigid front-face retaining walls. The method was based on the principle which is quite different from that of "Terre Armee" , invented in 1963 by Henri Vidal of France. In that the author would like to note that the method is a significant one developed after Henri Vidal. This paper describes history and development of F. B. Mercer's method as viewed by a Japanese researcher who has exerted great effort to introduce the method to Japan since 1983. Japanese researchers' group studies started in 1988 with due cooperation from relevant technologists and field engineers. Adopting guidelines and standards for both laboratory and field tests, two volumes of guidelines on polymer grid earth reinforcement method were published in 1990. Domestic polymer grid manufacturers were inaugurated in 1992 as the third largest producing group in the world and the dissemination of polymer grid reinforcement method is taking place at an unprecedented pace all over Japan.

INTRODUCTION

Undoubtedly "Terre Armee" developed by Henri Vidal of France in the year 1963 has triggered the development of a number of new earth reinforcement methods. Terre Armee is a method that makes use of frictional resistance between the sandy back-fill soil and galvanized metal strips to retaining of soil-wall structure. In contrast to this, the method of reinforced soil structure has the passive resistance of reinforcement upkeep the soil in equilibrium condition. Moreover, the fact that the tensile strength of reinforcement is playing a vital role in the design means a great difference from the previous method. The polymer grid (the trade name is Tensar), made by stretching punched sheet of a selected polymer has a special molecular structure accompanied by a high tensile strength equivalent to that of a mild steel. It was developed in U. K. in the year 1979 as a new product originally designed for use as reinforcement in the back-fill soil of the retaining structure or in the near vertical (steep) embankment.

After nearly 5 years' intensive research on material properties, design method and construction procedure, the product was officially announced to the geotechnical engineers. They are the delegates of the 1984 London Symposium, and the product enjoyed instantly a world wide popularity among the users of the world. It may not be an exaggeration if we say that the polymer grid method has been an epoch making soil reinforcement method since Terre Armee was first developed in 1963.

1. INVENTION OF POLYMER GRIDS

The inventor of high tensile stretch-made polymer grid, Dr. F. B. Mercer (Photo 1) is a graduate of England's chemical engineering school and he is the president of the Netlon Limited which is located in Blackburn, Lancashire. He was also the inventor of the plastic net made of high density polyethylene which is called Netlon by its trade mark in 1958.

Dr. F. B. Mercer came to realize the fact that the plastic net that he originally designed for ordinary use has been applied to civil engineering structures only when Mr. M. Akiyama, the Senior Managing Director of Mitsui Petrochemical Industrial Products, Ltd. (formerly Tokyo Polymer Co., Ltd.) delivered to him during the Netlon Conference held in Barcelona in 1968 a special additional issue to the author's paper presented in a conference held in United States in 1967 (Yamanouchi, 1967).

Photo 1. Dr. F. B. Mercer (1984)

Afterward Dr. F. B. Mercer was awarded the coveted title of fellow of the Royal Society to honor his invention of polymer grid. And in his record of the Philips Lecture in 1986 (Mercer, 1987), he stated the active cooperation of Prof. Yamanouchi of Kyushu University as a reference to the above chain of events. At the request of the sponsors, the researchers from North America attended the London Symposium on Polymer Grids Reinforcement in Civil Engineering. From Japan Mr. M. Ikegami of Mitsui Petrochemical Industries Ltd. and the author attended the symposium.

The money required for the polymer grid research was contributed by Netlon Limited as a kind of foundation . It was in fact increased to three times by the Science and Engineering Research Council

(SERC), the British Government, and distributed to universities, namely Oxford, Newcastle Upontyne and Strathclyde (Scotland) and others. The results or achievements from these universities and Netlon Company were announced in this symposium. The Science and Engineering Research Council of U.K. and Netlon Limited took the leading role as sponsors of the symposium.

Before the beginning of the symposium, Mr. Ikegami and the author visited Netlon Company Office in Blackburn. This small city in the countryside has been known to the world for its textile industry since prewar days. The textile industry seems to be transformed into plastic production after the war. It is a sort of good example for a small remote town to advertise itself to the world by means of an invention. Such example is also true to Japan's medium size enterprise which can sell its product by means of an excellent innovation or invention.

During the visit, Dr. Mercer was delighted to meet us before the beginning of the symposium and asked me, "For what purpose did you apply the plastic net to the foundation" . This is the issue that the author has solved in the past.

After visiting Netlon, Mr. Ikegami and the author went to see Prof. K.Z. Andraws and Dr. A. McGown of Strathclyde University in Glasgow and had the chance of studying the experimental research on stretch-made polymer grids. In the normal temperature test room, the creep test machines are lined up orderly. And the low temperature melting alloy is used as grips at the end of the test sample (Photo 2). The service life of a reinforced earth structure (permanent) is assumed to be 75 - 100 years. The creep characteristics which is a salient feature of polymer grids is a very important issue, and even now creep tests are conducted as stated above.

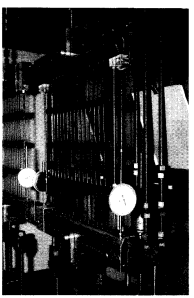

Photo 2. Creep experiments for uniaxial stretch-made Tensar (SR Type) in Strathclyde University (1984)

During the visit, when inquired as to the number of Terre Armee, practically constructed in Scotland, the answer is only three. This fact reveals the characteristics of British people who are not inclined to easily adopt other country's technology. And I came to realize that the stretch-made polymer grid reinforced earth method is in fact an internationally competitive earth reinforcement technique.

From Glasgow, Mr. Ikegami and the author headed for the symposium in London, and at the symposium, apart from the proceedings, the guide lines for the use of polymer grid were presented by Netlon Company. These guide lines are "Test Methods and Physical Properties of Geogrids", "Design and Construction of Embankments over Stable Foundation Using Tensar Geogrids" and "Design and Construction of Reinforced Soil Retaining Walls Using Tensar Geogrids". This kind of information sharing lead especially to the rapid dissemination of reinforced earth embankment method.

As to the design method of rolled-up polymer grid (stretch-made) reinforced embankment and retaining wall shown in Fig. 1 and Fig. 2 respectively, the technique proposed by Dr. R.A. Jewell (Oxford University, Photo 3) is considered to be the most excellent one. Although other methods were proposed by other experts, the contribution by Dr. Jewell et al. (1984) is considerable.

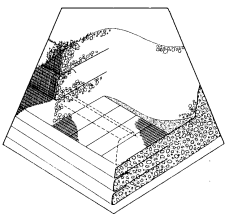

Fig. 1 Proposed model of rolled-up type stretch-made polymer grid (SR-Type) reinforced embankment (1984)

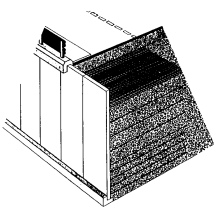

Fig. 2 Proposed model of reinforced retaining wall using bi-axial stretch-made Tensar (SS-Type) (1984)

Photo 3. Dr. R. A. Jewell (1992)

2. INTRODUCING POLYMER GRIDS TO JAPAN

The introduction of polymer grids to Japan has begun in the year 1980 with the active participation of Mitsui Petrochemical Industries Ltd. At the beginning some people seemed to be doubtful as to the applicability of the product.

In 1983, the director of overseas business division of Netlon Limited, Mr. J. Templeman paid his second visit to Fukuoka. Using his visit to Fukuoka as a stepping stone for starting point, Kyushu University Research Group headed by the author and the Professors by the name of Prof. H. Ochiai, Prof. S. Hayashi and Saga University Prof. N. Miura , Yamaguchi University Prof. H. Murata and Nishi-Nippon Institute of Technology Prof. K. Yasuhara initiated the first polymer grid study meeting, and this activity of meeting and discussion continues for several times till the Research Board on Geogrids was founded in the year 1988.

The above mentioned activity c oncerning with polymer grid was made possible to succeed in Japan. This is not only due to the fact that the author was enthusiastically taking part in the activity after receiving information from London Symposium, but also due to our historical background of practical application of plastic nets in western Japan. The presence of Mr. Ikegami and the author at the London symposium was crucial to dictate the future possibility or applicability of stretch - made polymer grids especially in Japan.

After coming back to Japan, the author used to tell to the Vice President, Mr. S. Hayakawa (Doctor of Engineering) of Mitsui Petrochemical Industries Ltd. that the product, Polymer grid, will inevitably become an internationally accepted material in future.

After coming back to Fukuoka City, the material, Tensar, was shown to a Professor specializing in the field of synthetic material. He noted that such a product is comparatively easy to produce. I cannot help wondering why those specialists in Japan did not have an idea of making use of it to Civil Engineering.

3. DEVELOPMENT OF POLYMER GRIDS IN JAPAN

In Japan, the first application of polymer grids to major engineering structure was carried out at the reinforced back-fill retaining wall of a reversed Y-type retaining wall with 4 stages of berms, height 20m, for the construction of Kyushu Expressway at a place near Yatsushiro City in August 1984. It is the first type of reinforcement of gravity concrete retaining wall where the interconnection of grids with retaining wall is incorporated. Photo 4. is the external view of

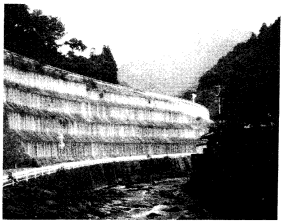

Photo 4. 4-Berm reversed Y type stretch - made polymer grid (SR) reinforced retaining wall (the foremost one in 1984)

the structure and it was used as a cover photograph of the Proceedings of IS Kyushu '88.

The foremost rolled-up polymer grid reinforced embankment is the one for the slope of Hoshigamine New Town road construction in Kagoshima undertaken by Kagoshima Development Corporation in September 1984 (Photo 5). The type of soil retained by the structure is an unusual one called Shirasu and the structure is rather small in scale with a height of 7 m only. In this construction work, some design innovations have been introduced. The observation by instrumented measurement to assess the behavior of the reinforcement is unprecedented in this kind of structure (Yamanouchi et al.,1986). This is actually a kind of experimental study that attracts attention of numerous researchers relevant to this field of study. And it was successfully completed with the energetic cooperation of a Kagoshima local company.

In the year 1985, Mr. Fukuda of Fukken Co., Ltd. (Consulting Engineers) was awarded the degree of Doctor of Engineering in the field of polymer grid reinforcement. He was the first and foremost researcher who has been hornoured with the degree of Doctor of Engineering on polymer grid reinforcement. In introducing him to foreigners, he was clearly understood when we say, "Dr. Fukuda, the First Japan's Specialist (Doctor) on Polymer Grid Tensar".

Photo 5. Stretch-made polymer grid (SR) reinforced embankment in Japan (the foremost one in 1985)

Since the year 1986, the research reports on polymer grid reinforcement have come out intensively from Kyushu University and others. In the year 1986, a reinforced embankment, height 6.0 m and length 360 m, was practically constructed encircling the Tanegashima Space Launching Station. During that year two test embankments were constructed in Iwakuni City; one is a vertical face rolled-up polymer grid reinforced embankment of height 4.0 m (by Mitsui, see Photo 6) and the other is a concrete-block face (developed by Okasan Kogyo Co., Ltd.) retaining wall having a height of 6.0 m (Photo 7). Both test structures were subjected to intensive observation using measuring instruments.

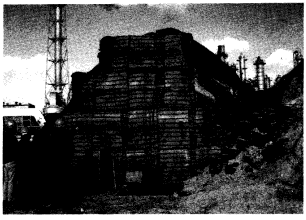

Photo 6. Vertical front-face stretch-made polymer grid (SR) reinforced embankment (for testing in 1986)

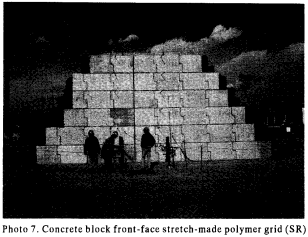

Photo 7. Concrete block front-face stretch-made polymer grid (SR) reinforced retaining wall (for testing in 1986)

The same year, polymer grid was used as a permeable sheet (trade name: "Tafnel") for the drainage purpose of an embankment. With the approach of 1987 the group research on stretch-made polymer grid plummeted temporarily and the experimental and practical experience at the site increased; the symposium on polymer grid, IS Kyushu was held under these circumstances in Oct. 1988. The Geogrid Research Board was organized by 70 individual researchers together with General Contractors and Consultants Companies, 18 in all, in the year 1988. The objective of the association is to lay down guidelines for Japan's engineers concerning the polymer grid design and construction fixing a time limit of two years. It was actually a cordial cooperation of civilians and government officials such as Prof. F. Tatsuoka of Tokyo University and the late Director K. Kutara of Public Works Research Institute of Ministry of Construction. The Board was in fact headed by the author. Volume I and Volume II on Geogrid Guidelines were published in Nov. 1990 with a delay of 7 months, and afterward the association was dissolved as its mission was completed.

In the year 1992, the above mentioned institute could issue its Research paper No.3117 by the title of "Manual of Design and Construction of Geotextile Reinforced Embankment". In this manual the stability analysis by slip circle method during earthquake was recommended. It was different from the one stated in Guidelines. Two methods of stability analysis proposed may lead to confusion for the design engineers.

The authorized approval certificate for the polymer grid Tensar as an earth reinforcement material was issued by the Civil Engineering Research Center in response to the permission request made jointly by Mitsui Petrochemical Industries Ltd. and Mitsubishi Kagaku Sanshi Corp. (former Mitsubishi Yuka Industrial Products Co., Ltd.) in the year 1992.

In autumn in the same year, Japan Tensar Corporation was established, and it started local production of SR and SS types of polymer grids (uniaxial and biaxial stretched types) in the factory of Kuki City. This factory is the third largest factory in the world after Netlon Factory in U.K. and North America Tensar Corporation Factory in U.S.A.

Fig. 3 and Fig. 4 are prepared by Mr. K. Tuksoka. These figures show the comparison of relative unit costs per slope area to height of reinforced embankment in 1992 with those of other three types of reinforcement usually adopted in 1987. From this figure it is obvious that the construction of comparatively high reinforced embankment was made easy with the incorporation of Terre Armee in 1992.

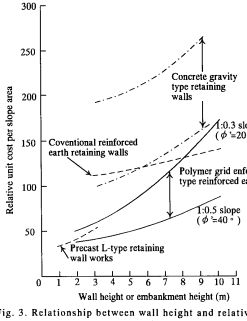

Fig. 3. Relationship between wall height and relative unit cost per slope area in Japan (1987)

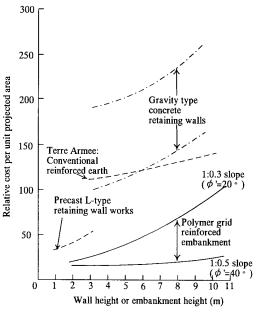

Fig. 4 Relationship between wall height and relative unit cost per solope area in Japan (1992)

The rolled-up stretch-made polymer grid reinforced embankment was first subjected to earthquake forces during the Loma Prieta Earthquake in 1989 (M=7.1). From the disaster investigation it was reported (1992) that the embankment could withstand dynamic seismic forces during earthquake. The earthquake resistance capability of polymer grid reinforced embankment was reported too in the case of Hyogo Southern Region Earthquake in 1995 (Kobe Earthquake M=7.2).

Originally the seismic forces were not taken into consideration in Dr. Jewell et al.'s design technique. It is, however, understood that the design by this method is on the safe side against seismic forces. It is assumed that the visco-elastic characteristics of polymer grid that is the resistance against a short-duration additional loading plays an important role in withstanding seismic forces (Yamanouchi et al.,1986). These facts have been already reported in several research papers.

The height of stretch-made polymer grid reinforced embankment has practically gone up to 15 m in the early 1987 and it is increasing gradually. Recently it was made possible to design grid reinforced embankments with the height exceeding 40 m combining mild-slope face with steep one.

4. COMPARISON OF POLYMER GRID WITH OTHER REINFORCING MATERIAL

A review of bibliography on reinforcement reveals that some other reinforcing materials apart from polymer grid have been developed as a kind of competition inspired after the invention of Terre Armee. In United States of America, the following types of earth reinforcing material are now in use.

* Metal Products: Steel Grids, Woven Wire Grids
* Polymer Products: Simple Polymer, Perforated Polymer Strips, Interconnected Polymer Grids or Polymer Grid Strands
* Textile Materials: Woven and Non-woven textile

The first polymer grid reinforced embankment was constructedin the United States in 1981 three years earlier than Japan. Hence the United States is three years ahead of Japan technically in the field of polymer grids. And polymer grid production took place in the year 1983.

Table 1.Comparative Study On Reinforced Soil System
(Adapted from Jewell,1984 and NCHRP 290)

Imported Embankment Type Application	Reinforcement Type		Allowable Slope Angle (30 60 90)	Recommended Soil Type* (Clay .002 Silt .02 Sand .20 Gravel 2mm)	Stress Transfer Mechanism (Surface Friction / Passive Resistance)	Reinforcement Material (Metal / Non-metal)	Extensibility (Yes / No)	Proprietary System/ Product Names
	Strip	Smooth	—	—	●	●	●	Reinforced Earth
						●	—	
		Ribbed	—	—	●	●	●	Reinforced Earth
						●	●	Paraweb
	Grid		—	—	●	●	●	VSL, MSE, GAE, RSE, Welded Wire Wall
						●	●	Maccaferri Gabion
						●	—	Tensar, Mirafi and Tenax Geogrids
	Sheet		—	—	●	●	—	Geotextile
	Bent Rod		—	—	●	●	●	Anchored Earth
	Fiber		—	—	●	● ●	—	

* Based on stress transfer between soil and reinforcement. Other criteria may preclude use of soils for specific applications.

If sheets (fabrics) are quite strong enough to reinforce earth as reinforcing materials, the structural advantages of polymer grids that are gained through vigorous effort may not be justifiably proved right, but the author evaluates polymer grids as much highly as the plastic nets called Netlon. Such reinforcing material called polymer grid functions properly with its three-dimensional structure and its active resistance against earth pressure. Here it is to be noted that high tensile strength is not the only one characteristic that is demanded or required. Polymer grids are in fact excellent both in its production technique and in quality.

The application of high tensile sheet to reinforcing of embankment is carried out not only in America, but also in Japan. In that it is widely known that a group of researchers headed by Prof. Tatsuoka has conducted intensive studies since 1985 on its (tensile sheets) application using clayey Kanto loam as back-fill.

The comparison of the U.S.A's reinforcing methods, conducted by Mitchell and Christopher (1990), will be introduced here using Table 1. Attention should be given to the fact that in every method the front face can be erected vertical,but the disparity exists between the methods as to the scope or range of soil type recommended. The polymer grid reinforcing method has an extensive range of usability as far as the type of soil is concerned.

In Japan, after introducing the stretch-made polymer grid reinforced embankment, the multi-anchor retaining wall, the foam-web retaining wall (1980 U.K.) and the continuous long fiber method (trade name: Texol 1982 France), are discussed and debated as earth reinforcing methods on equal terms.

In United States a test was successfully conducted on 12 m high wall proving that the embankment can be constructed by means of sheet (fabric) instead of polymer grid. But this may be the limit of height for the sheet only reinforced embankment.

5. CONCLUSION

The geosynthetics fiber is an industrial product which comes out from the industry relying on combined effort of the makers, namely the petrochemical industries and the users, namely geotechnical researchers. The great merit that can be derived from using the ready made biaxial polymer grids as a part of the structure is a sort of achieving technical breakthrough in embankment structure assuring tangible results.

The geosynthetics have undergone a rapid process of development beyond the expectation of the engineers; this is considered to be on account of the following points of view. One is the fact that the geosynthetics were viewed and used as a kind of newly developed product as far as the matured foundation engineering is concerned. Another point is a new development of environment oriented foundation engineering in the field of landfills for waste disposal sites. In the case of the latter the geosynthetics play an important role in the construction of embankments for waste disposal site, where the reinforced earth technique is indispensable.

It is undoubtedly true that the geosynthetics have developed as it is empowered by the International Fund for Oil, the so-called "Majors" in the background. It has been a long time since the year 1982 when the Second International Symposium on Geosynthetics was held in Las Vegas under the sponsorship of the Industrial Fabrics Association International (IFAI). This event is also considered as an event that has expedited the development of geosynthetics.

The development of geosynthetics is also due to the fact that Dr. J.P. Giroud, the first President of the International Geosynthetics Society (IGS) has offered his strong leadership after he has come over to United States from France.

With such scenario of geosynthetics in the background, the reinforced earth (embankment) method is an infant-stage technology that is so new that it has not been taken up in the curriculum of the civil engineering subject on construction materials and construction technique. However the reinforced earth method will eventually be established with the beginning of the introduction of stretch-made polymer grid reinforced embankment, and it is the author's firm belief that this method will be practically much more useful in various ways in the near future.

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