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The last decade of geosynthetics in Japan

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ABSTRACT: The use of geosynthetics in Japan during the last decade has been reviewed based on questionnaire survey results. The Japan Chapter of IGS conducted nationwide surveys five times, every two years, starting in 1991. These five surveys revealed a generally increasing trend in the use of geosynthetics, i.e., 80 million m^2 in 1991 to 101 million m^2 in 1999. Roughly two-thirds of geosynthetics used for various civil engineering purposes consist of woven and nonwoven geotextiles. While wovens have been on a declining trend, nonwovens have been markedly on a rise with a dominating share of 41 to 53% of the annual consumption of geosynthetics. Geosynthetics other than wovens and nonwovens showed a distinct growth trend during the 1991 to 95 period, but thereafter generally a downward trend or steady state. It is concluded that local IGS chapters are best suited to carry out such surveys to provide the geosynthetics community with much needed statistics.

1 INTRODUCTION

The history of geosynthetics in Japan may be traced back to 1959 when woven geotextile was used in large quantities for the reconstruction works of coastal dikes on soft clay damaged by a destructive typhoon. In 1960's wovens, nonwovens and nets gradually found their way in various civil engineering applications, but it was not until 1970's when geosynthetics won recognition as a generally accepted construction material. Thereafter various geosynthetic products rapidly reached the point where they were not only superior in terms of engineering properties and field performance but also more economical in many cases.

In 1982 the Japanese Geotechnical Society established a technical committee on geotextiles. Soon after the International Geotextile Society (IGS) was founded in 1983, a group of engineers and manufacturers related to geosynthetics was organized under the leadership of Professor M. Fukuoka, which was subsequently approved as the first local chapter of IGS in 1985. At that point the use of geosynthetics had been growing by leaps and bounds in Japan, but no information was available regarding the quantities utilized for civil engineering purposes other than rough estimates of somewhat dubious nature. Around 1990 we felt it was such an important task to have reasonably reliable statistics that we decided to conduct a survey by ourselves.

Since then the Japan Chapter of the International Geosynthetics Society conducted nationwide questionnaire surveys five times, every two years, starting for the year 1991 with the most recent one completed for the year 1999. Based on the survey results this paper reviews the use of geosynthetics in Japan during the last 10 years in terms of quantities and applications. In brief these five surveys revealed a generally increasing trend in the use of geosynthetics, i.e., 80 million square meters (m^2) in 1991 to 101 million m^2 in 1999 as summarized in Table 1. The survey results are further subdivided and more detailed data are given in the Appendix.

The total annual consumption remained at about the same level at 91 million m^2 in 1993 and 95, even decreased to 84 million m^2 in 1997, but increased markedly to 101 million m^2 in 1999. It was once considered that this seemingly downward trend during the 1993-97 period reflected the same trend of the total domestic investment in construction as may be seen in Fig. 1. However, the remarkable increase of the consumption of geosynthetics in 1999 indicated a significant deviation from the general declining tendency of the Japanese construction investment (82.4 trillion yen in 1991 to 70.9 trillion yen in 1999). This is due perhaps to growing recognition of the advantage and usefulness of geosynthetics in various civil engineering applications.

2 ANNUAL CONSUMPTION OF GEOSYNTHETICS

2.1 *Wovens and Nonwovens*

The survey results, Table 1, indicate that roughly two-thirds of geosynthetics used for various civil engineering purposes consist of woven and nonwoven geotextiles. While wovens have been on a declining trend (27 million m^2 in 1991 to 14 million m^2 in 1999), nonwovens have been markedly on the rise with a dominating share of 41 to 53% of total consumption of geosynthetics (34 million m^2 in 1991 to 54 million m^2 in 1999).

Table 1. Annual Use of Geosynthetics in Japan (in million sq. meters).

	1991	1993	1995	1997	1999
Woven	26.84	17.26	14.72	11.17	13.65
	(33.6)	(18.8)	(16.2)	(13.3)	(13.5)
Nonwoven	33.83	43.33	36.93	41.39	53.76
	(42.3)	(47.6)	(40.7)	(49.1)	(53.2)
Knitted	0.03	0.14	0.75	0.27	0.56
	(0.0)	(0.2)	(0.8)	(0.3)	(0.5)
Geonet	2.49	2.42	2.88	3.49	4.69
	(3.1)	(2.7)	(3.2)	(4.1)	(4.6)
Geogrid	3.54	7.84	10.22	7.92	10.55
	(4.4)	(8.6)	(11.2)	(9.4)	(10.4)
VerticalDrains	1.05	2.22	4.59	2.96	3.16
	(1.2)	(2.4)	(5.1)	(3.5)	(3.1)
Geomembrane	9.99	14.27	16.15	13.30	10.62
	(12.1)	(15.5)	(17.9)	(15.8)	(10.5)
Geocomposite	1.43	2.47	3.44	2.53	3.02
	(1.7)	(2.8)	(3.7)	(3.0)	(3.0)
Others	1.24	1.34	1.12	1.25	1.02
	(1.5)	(1.4)	(1.2)	(1.5)	(1.0)
Total	80.44	91.29	90.81	84.26	101.03
	(100)	(100)	(100)	(100)	(100)

Numbers in parentheses indicate percentages in the year investigated.

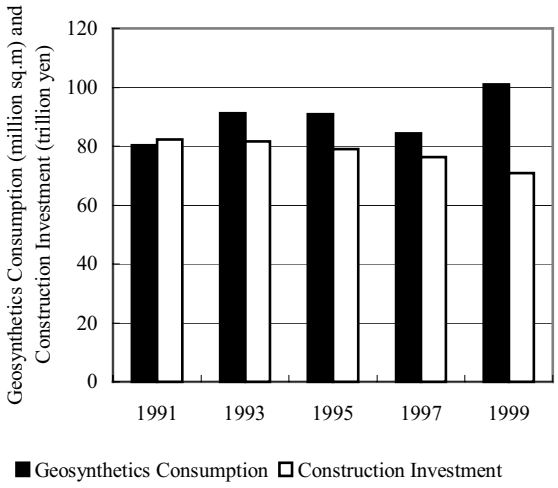

Fig. 1. Geosynthetics Consumption and Construction Investment in Japan 1991-1999.

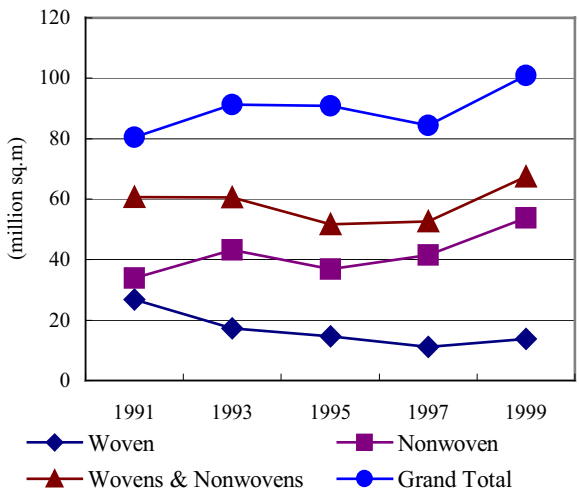

Fig. 2. Geosynthetics in Total, Wovens and Nonwovens.

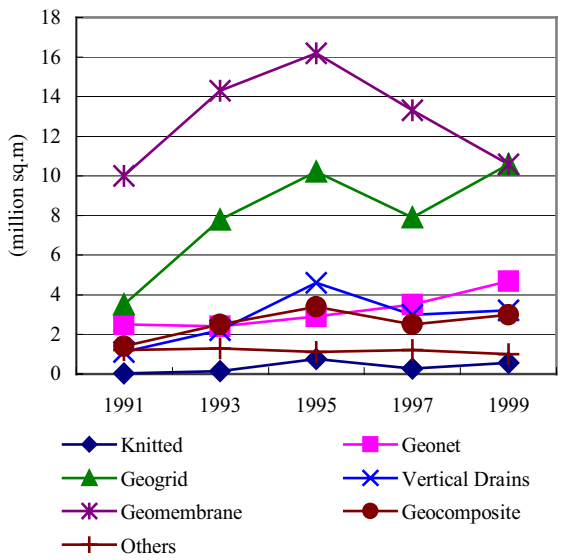

Fig. 3. Geosynthetics Other Than Wovens and Nonwovens.

The quantities of these geofabrics appear to fluctuate over a wide range from year to year, significantly influencing the grand total, see Fig. 2. As may be seen in the Appendix, wovens are mostly of sheet type, but roughly 10-20% are of net type. Most of nonwovens consist of spunbond, followed by staple fiber and recovered fiber. Nonwovens made of recovered fiber have been rapidly rising exceeding the staple fiber in 1997 and 99.

Geofabrics as well as the other types of geosynthetics that we have inquired about are limited to those used for civil engineering projects, or those being employed in direct contact with soils. Enormous amounts of the same fabric materials and synthetic products are being utilized for other purposes including various architectural applications, notably for roofs and walls of houses and buildings, but it has been our policy to exclude all of these and not to include them in the statistics in our survey results.

It would be of some interest to note the share of nearly 54 million m^2 of nonwoven fabrics used in 1999 for civil engineering purposes in the total nonwoven production in Japan. According to the All Nippon Nonwoven Association, the production has gradually increased over the recent years reaching 309,241 tons in 1999 and 314,123 tons in 2000. The shares by application in terms of mass in the year 2000 are estimated as follows: 1) Industrial 27%, 2) Medical and sanitary 23%, 3) Living related 22%, 4) Civil, architectural and agricultural 13%, 5) Clothing 4% and 6) Other uses 11%. On the basis of these data we estimate the civil engineering use is on the order of 5% being considerably less than a half of the 13% allotted for item 4) in the above. This rough estimate brings an interesting data; 314,000 x 0.05 = 15,700 tons of nonwovens for civil engineering uses and 15,700,000 kg/53,760,000 m^2 = 0.292 kg/ m^2 that is a likely density of nonwoven geosynthetics, although admittedly it is merely a crude calculation.

2.2 *Geosynthetics other than wovens and nonwovens*

Fig. 3 shows the annual consumptions of geosynthetics other than the two major categories of wovens and nonwovens, i.e., knitted geofabrics, geonets, geogrids, vertical drains (prefabricated band-shaped drains), geomembranes, geocomposites and others. The surveys detected a distinct growth trend in each category in this group during the 1991 to 95 period, but thereafter a downward trend or a steady state in all the categories except geonets.

Geomembranes were on a rapid increase in the first three surveys starting from about 10 million m^2 in 1991 and reaching 16.2 million m^2 in 1995, but quite unexpectedly subsided to 10.6 million m^2 in 1999. This trend appears to be in agreement with the observation that fewer landfills and fewer agricultural reservoirs have been constructed for the last several years. As noted in the Appendix geomembranes made of polyvinyl chloride (PVC), ethylene-vinyl alcohol copolymer (EVA) and synthetic rubber appear to be most predominant, while polyethylene and asphalt-coated geomembranes have significant shares.

Geogrids increased very rapidly from 3.5 million m^2 in 1991 to 10.2 million m^2 in 1995 and almost caught up geomembranes in 1999 reaching 10.6 million m^2. Geogrids have been increasingly utilized because more mechanically stabilized earth retaining structures are being built because their structural and economic advantages are more fully appreciated. In particular a good reputation was established of their earthquake resistant performance during the disastrous Kobe Earthquake in January 1995. Geonets have been steadily increasing from 2.5 million m^2 in 1991 to 4.7 million m^2 in 1999.

Prefabricated band-shaped drains (used as vertical drains) also showed a peak at 4.6 million m^2 in 1995 and maintained at a fairly high level at around 3 million m^2 in 1997 and 99. Prefabricated drains have been employed extensively in Japan since cardboard drains were introduced in late 1950's gradually replacing sand drains which, however, still remain as a principal means of stabilizing soft clay foundations in Japan. With the ex-

ception of 'Pack Drains' as indicated in the Appendix the vertical drains are essentially band-shaped geocomposites, typically 100 mm wide and several mm thick. The quantities are indicated simply in terms of the lengths multiplied by widths in square meters and in fact correspond to an enormous amount. For instance, 4.6 million m^2 consumed in 1995 implies a total length of roughly 46,000 km which well exceeds the circumference of the equator.

Geocomposites other than prefabricated band-shaped drains, consist mostly of drainage mats and block mats, and have been on a steady increase except a large increase in 1995, exceeding 3 million m^2 in 1999. Geosynthetic clay liners (GCL) have been notably on the rise in 1990's. As a geosynthetics related product, flexible forms for concrete are being utilized quite extensively, amounting to well over a million m^2 every year. Knitted geotextiles, although small in quantity, increased from 0.03 to 0.56 million m^2 during the 10 year period.

Expanded polysterene (EPS) was introduced to Japan in 1985 and polyurethane foamed in situ around 1990, both as light weight fill material. We did not include them in our surveys since the Japanese EPS Development Organization maintains accurate records of these two categories of geosynthetics, reporting that 352,851 cubic meters of EPS blocks and 29,309 cubic meters of polyurethane foamed in situ were employed principally for backfills and embankments during the year 2000. Table 2 summarizes the annual consumptions of these synthetic materials used in civil engineering projects in Japan during the 1991 to 99 period.

Table 2. Annual Use of EPS Blocks and Foamed Polyurethane in Japan (in cubic meters)

	1991	1993	1995	1997	1999
EPS Blocks	122,141	181,056	185,131	249,262	357,387
Polyurethane	0	889	2,394	4,785	9,006

(Courtesy of the Japanese EPS Development Organization)

In recent years some jute and coir products in the form of band-shaped drains and nets have been imported and utilized for stabilization of soft soils and erosion control, but do not seem to have significant shares yet.

3 QUESTIONNAIRE SURVEYS

Questionnaires for a geosynthetics survey can be directed to one of the following three groups; 1) manufacturers and suppliers of geosynthetics, 2) geosynthetic installers and 3) owners of projects utilizing geosynthetics. An installer can be any one of construction contractors, the number of which currently amounts to more than half a million firms in Japan. The project owners are the central and local governments, public and private organizations, etc, and are again too numerous to count. At the onset of our survey it appeared that geosynthetic manufacturers and suppliers in Japan were rather limited in number. It was decided, therefore, to mail the questionnaires to them rather than to a large number of promoters and contractors who undertake construction works utilizing geosynthetics for civil engineering purposes. It is true that some of the manufacturers and suppliers undertake installation works of geosynthetics, but those included in our surveys are considered primarily manufacturers or suppliers rather than construction contractors.

We prepared a list of manufacturers and suppliers dealing with geosynthetic products for civil engineering uses, the number of which ranged from 89 to 95 for our surveys. In the questionnaire we asked how much of each subdivided category of geosynthetics they sold during the designated year. We made it clear that their replies would be kept strictly confidential and only the finalized statistics would be made public. The survey committee assigned three members of neutral standing in each survey to handle individual replies collected.

In each survey 66 to 89% of these firms (63 to 83 in number) responded quite cooperatively indicating quantities of geosynthetics they had dealt with. Table 3 indicates numbers of the firms to which questionnaires are sent (Q) and from which replies received (R). The return rates (R/Q) have steadily increased reaching as high as 88 to 89% in the last three surveys, perhaps reflecting cooperative responses among the respondents who, in our somewhat optimistic interpretation, have come to realize the importance and benefits of such surveys. In Table 3, N indicates the numbers of the firms which reported they had dealt with no geosynthetics during the year investigated. It appears, therefore, that the number of manufacturers and suppliers which actually supplied their geosynthetic products in Japan (R-N) has gradually been on increase from 58 to 72 during the last decade.

Table 3. Numbers of Questionnaires Sent and Replies Received.

	1991	1993	1995	1997	1999
Q	95	93	90	94	89
R	63	73	79	83	79
N	5	6	12	11	7
R – N	58	67	67	72	72
R/Q (%)	66	78	88	88	89

Q: Number of firms to which the questionnaires were sent
R: Number of replies received
N: Number of firms reporting they dealt with no geosynthetics during the year investigated

The Survey Committee chaired by the writer summed up and analyzed the collected data and wherever possible, corrected them mainly for double counting. In fact a very considerable amount of the data had to be deleted, because they were apparently from the same sources or else they were not applied to civil engineering projects. It is true that the data not collected by our survey must have underestimated the grand total, but it is more likely the total quantities have been overestimated somewhat possibly because the same data might have been counted more than once in view of some complex manufacturer-supplier relationships. Admittedly we have to anticipate some errors in each survey result due to omissions and multiple counting. We believe, nevertheless, that the statistics obtained by these surveys are reasonably accurate and reliable, since we are confident we have covered practically all the major geosynthetics manufacturers and suppliers in Japan. In fact some of them were very helpful pointing out the possible sources of errors that must have remained unnoticed otherwise.

4 APPLICATIONS OF GEOSYNTHETICS IN JAPAN

The questionnaires also asked for what civil engineering purposes the geosynthetics they had supplied were used, but not the quantity for each application. Therefore, the responses to this question were not satisfactory. Somewhat to our dismay quite a few manufacturers and suppliers did not know for what specific purpose their merchandise was used other than the fact that they sold it to civil engineering projects. In this regard only descriptive answers were obtained with no quantitative information. Unfortunately, therefore, these surveys yielded no statistics by applications. Based on the results of the replies, however, typical applications of geosynthetics in Japan are summarized as follows:

Wovens:

a) Stabilize soft foundation soils
b) Reinforce embankment fills
c) Cover soft subsoil, riverbeds, reservoir beds before placement of fill, etc.
d) Protect slopes
e) Prevent erosion, scouring, and migration of soil
f) Use as silt fences and silt curtains
g) Prevent grass from growing

Nonwovens:

a) Stabilize soft foundation soils

b) Reinforce and drain embankment fills
c) Prevent erosion, scouring, and migration of soil
d) Prevent grass from growing
e) Use as separators, drainage paths, filters, cushions, shock absorbers typically in construction of landfills, tunnels, roof gardens, etc.
f) Reinforce asphalt pavement

Knitted:
a) Prevent scouring
b) Use as filters, substrates for waterproofing, forms for grouting, etc.
c) Purify soils

Geonets:
a) Stabilize soft foundation soils
b) Reinforce embankment fills
c) Construct hydraulic hurdles in rivers
d) Control fill thickness

Geogrids:
a) Stabilize and reinforce soft foundation soils
b) Reinforce embankment fills and retaining wall backfills
c) Reinforce asphalt pavement

Vertical Drains (Prefabricated Band-shaped Drains):
a) Drain and consolidate soft foundation soils
b) Drain solid waste landfills

Geomembranes:
a) Use as liners and covers for landfills
b) Waterproof tunnels, underground structures and roof gardens
c) Use as liners for reservoirs, canals and channels
d) Prevent scouring

Geocomposites:
Drainage Mats; Drain retaining wall backfills, tunnels, culverts, buildings, etc. & Protect revetment
Block Mats; Protect slopes, revetment, etc.
Other Geocomposites; Use for waterproofing, prevention of infiltration, covering river beds and reservoir beds, drainage of tunnels, covering slopes with vegetation, laying double liners in landfills, etc.

Related Products:
Flexible Forms; Use for casting concrete to protect slopes and revetments

5 CONCLUDING REMARKS

It is important to establish reliable statistics in any specialized field to review the past, to grasp the present and to forecast the future. In the past the statistics of the use of geosynthetics were based largely on estimates made by experts utilizing available data on related materials and products and therefore appeared to be of limited accuracy.

The Japan Chapter of IGS has been conducting questionnaire surveys every two years since 1991 and has been quite successful in winning respondents' understanding and in acquiring reasonably reliable data on the use of various types of geosynthetics.

It may be concluded that an organization such as a local chapter of IGS is best suited to carry out such a statistical study and can be instrumental in offering much-needed statistics to the geosynthetics community.

ACKNOWLEDGMENT
Appreciation is due to the support and encouragement to our questionnaire surveys extended by the Japan Chapter of IGS and in particular its Corporate Members throughout the last decade.

APPENDIX :
Itemized Quantities of Geosynthetics Used Annually in Japan
(in thousand square meters)

	1991	1993	1995	1997	1999
Wovens:					
Sheet	23990	12878	11935	9397	11229
Net-type	2850	3928	1780	1650	2228
Others	0	450	1000	120	193
Subtotal	26840	17256	14715	11167	13650
Nonwovens:					
Spunbond	21350	20160	26810	26798	31445
Staple Fiber	10930	20724	6132	4594	9006
Recov'ed Fiber	1250	2375	3160	7199	11005
Others	300	75	827	2796	2305
Subtotal	33830	43334	36929	41386	53762
Knitted:					
Sheet	10	65	647	30	425
Net-type	20	0	0	213	132
Others	0	70	100	30	0
Subtotal	30	135	747	273	557
Geonets:	2490	2421	2884	3490	4693
Geogrids:	3540	7844	10223	7915	10550
VerticalDrains:					
Band-shaped	980	2214	4507	2957	3149
Nonwoven	3	0	84	6	8
Pack Drains	70	4	2	0	0
Subtotal	1053	2218	4593	2963	3157
Geomembranes:					
PVC*	4780	5664	4555	3265	3791
Polyethylene	990	274	786	941	1222
SyntheticRub'r	2900	5398	5639	1950	1274
EVA**	300	2134	4344	4595	2440
Asphaltic	1020	634	619	2289	730
Others	0	167	208	255	1164
Subtotal	9990	14271	16150	13296	10622
Geocomposites:					
Drainage Mats	390	915	1546	852	1287
GCL***	0	204	324	468	411
Block Mats	1040	1014	990	1000	1200
Others	0	339	582	206	120
Subtotal	1430	2472	3442	2526	3018
RelatedProducts:					
Flexible Forms	1240	1292	1100	1247	1016
Others	0	49	23	0	4
Subtotal	1240	1341	1123	1247	1020
Grand Total	80440	91292	90806	84263	101029

* PVC: polyvinyl chloride
** EVA: ethylene-vinyl alcohol copolymer
*** GCL: geosynthetic clay liners