# Recent development of lightweight geomaterials in Japan

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ABSTRACT: Based on the activities of the research committee in Japanese Geotechnical Society (JGS) from 1998 to 2000, the present paper outlines the recent situations in development and application of the lighteweight geomaterials (LGM) from design to execution as well as the basic geotechnical properties at laboratory. The special emphasis was placed on the successful case study at the coastal area using LGM. The items for further investigation are also pointed out in the paper, particularly in relation to long-term durability of structures or foundations made of these lightweight material and influences to environments.

## 1 INTRODUCTION: A BRIEF HISTORICAL REVIEW

Generally speaking, there have been two techniques for upgrading the infra-structures and building structures for safety and comfort: the one is to improve or reinforce foundations or the ground, and the another is to reduce the self-weight of the super-structures or the earth structures. In the field of geotechnical engineering, this technique has started at almost the same period at the dífferent two countries. In 1972 in Oslo, Norway, the Expanded Poly-stylene (EPS) was adopted for road embankment on soft ground (Frydenlund, 1994). This was so called "dawn of the Light-weight Geomaterial". On the other hand, in 1974 at the Port and Harbor Research Institute, Yokosuka, Japan, an attempt was made to use the styro-foam as the back-flll material possibly used to reduce the lateral earth pressure for quay-walls which was in process of technical development as the research program (Nakase, 1974). Those were successful in reducing the vertical loads on soft ground and the lateral earth pressures on wall structures. The air foamed mortar and glass which have been recently attempted to develop can be included in this category of lightening techniques in the Public Organizations in Japan such as in Ministry of Construetion (Miki, 1996) or Japan Highway Corporation (Mishima and Nagao, 1994).

In the above-two cases, the materials being developed at the field of high polymer chemistry were used for civil engineering practices instead of the usually used geomaterials such as sand and clay. Recently in Japan, on the other hand, so called "composite geomaterials" have been developed by mainly adding or mixing the air foam and EPS beads with cement to reduce the unit weight of the naturally existing geomaterials to be below at least 9.81 kN/m' to avoid floating in water. In addition to these, the industrial wastes such as coal fly ashes, slag, tire chips, and saw dust have been required to be utilized as the light-weight geomaterilas, because we have faced a number of the environmental issues from flood of garbage and wastes. As shown in Fig. 1, therefore, it can be emphasized that through the combined usage of three kinds of materials, geomaterials, nongeomaterials and waste materials the lightening techniques for geomaterials have the possibility to soave the issues on: (i) the reduetion of environmental impacts, (ii) the cost saving with life cycle taken into consideration. Although in general use of light-weight geomaterials (LGM) as above-mentioned, attention is paid to avoiding the floating of materials in water, it would be more advantageous in construction of floating island on sea if the light-weight geomaterials are endowed with below 9.81 kN/$m^3$. this could also widen the dream of successful construction of new type of infra-structures such as the floating airport, since this attempt has already been successful at laboratory (Horiuchi et al, 1996). This paper attempts to outline the recent Japanese situations and future perspectives of light-weight geomaterials for civil engineering practices from field to laboratory. The paper also includes some aspects of the activities of the research committee on Light-weight Geomaterials by the Japan Geotechnical Society, which has been done in 1998 through 2000. Those are :

i) to summarize the State-of-the-Art review based on the results from literature survey,

ii) to carry out round robin tests on two kinds of light-weight soils prepared by mixing both materials of the EPS beads and the air-foamed agent,

iii) to explore the constitutive models suitable for analysis of behaviour of LGM and

iv) to perform the unified model tests which are used for ascertaining whether and how the suitable constitutive models should predict deformation and bearing capacity of light-weight soils when they are adopted in practice at field.

## 2 ADVANTAGES OF LIGHTENING THE GEOMATERIALS

As was illustrated in Fig. 1, there have been many field situations, because of owning several advantages of LGM, in which application of the light-weight soils or super-light weight polymer materials ìs feasible. Because of the lower unit weight, they can reduce the vertical pressure on soft ground or buried structures, and the horizontal earth pressure even during earthquakes. In addition, they play a role of the countermeasure against landslides and the shelters against traffic-induced vibration and noise.

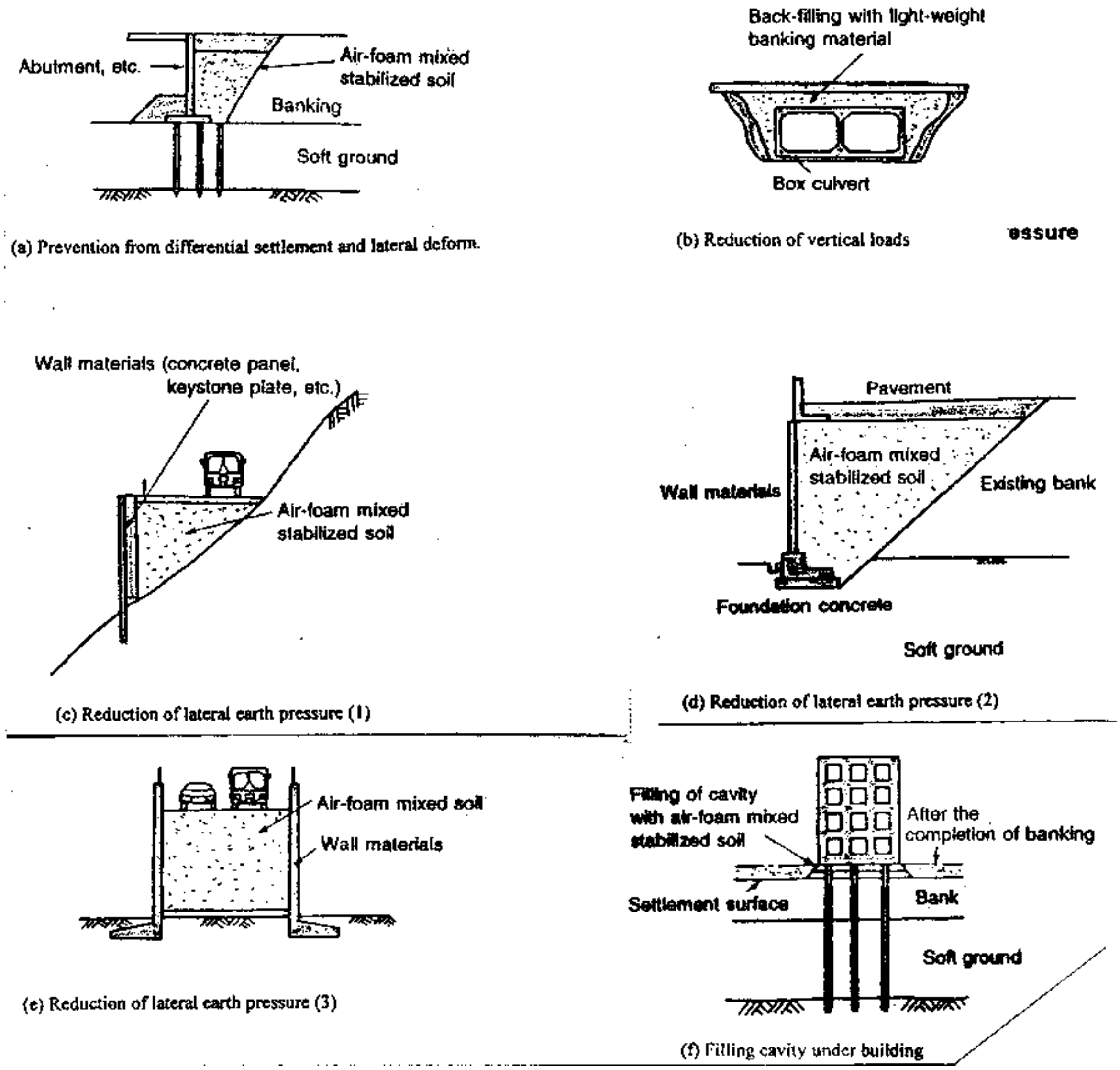
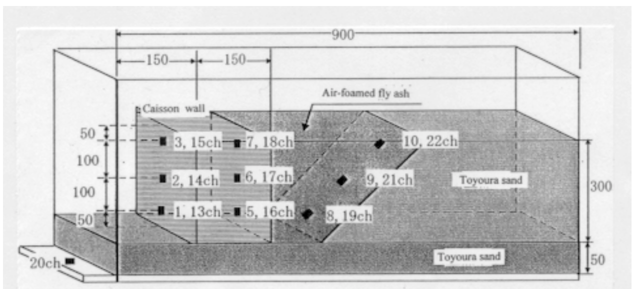
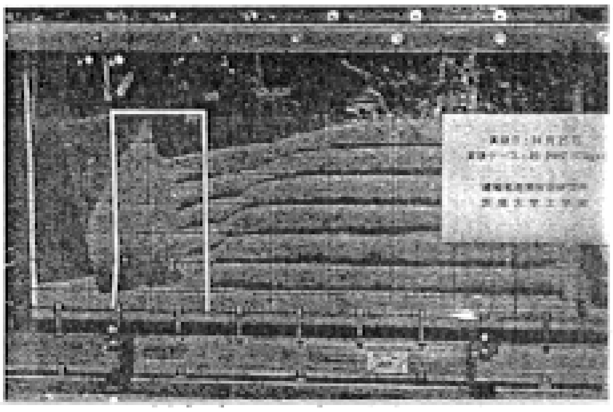


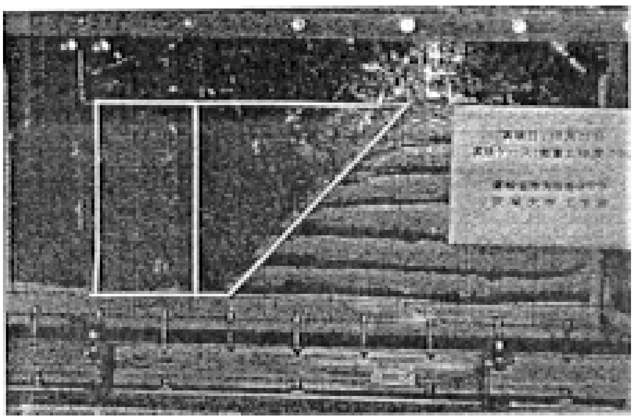

Figure 1. Serveral usage of LGM (Miki,1996)




■ Earth pressure indicator,accelerator (mm)



(a) In the case of sand (f=20Hz)



(b) Inthe case of air-foamed LGM (F=20Hz)

Figure 2. A Typical result from model shaking table tests on earth pressure acting on caisson wall

As an example for explaining the advantageous features, let us show the results from 1g shaking table tests in Fig. 2 whi chare intended to simulate the behaviour of caisson wails during earthquakes. In this series of model tests, air-foamed lightweight fly ashes were used as the backfill material. It can be seen from Fig. 2 that less lateral movement of the caisson wall with the LGM as the backfill material is observed in comparison with the case of sand used instead. Additional advantages in the real situation will be described in the coming chapter as the typical successful case histories at field.

## 3 OUTLINE OF LIGTENING TECHNIQUES IN EARTH STRUCTURES AND FOUNDATIONS

There have been several techniques proposed for lightening the geo-materials. These are classífled into four categories: (i) use of the light weight chemical products such as EPS and airfoamed uretyne, (ii) mix the EPS beads with natural soils and cement (Pradhan, et al., 1994), (iii) add the airfoam agents with soils and cement, and (iv) utilize the light waste materials (fly-ash (Yasuhara et al., 1998: 2000), slag (Kikuchi, 2000) and tire-chips (Humphrey et al., 1998). Fig. 3 shows a typical procedure for lightening the soils by means of mixing the airfoamed agents with cement which gives birth to stability of LGM with the sufficient stiffness and strength. Since materials belonging to the first category are completely different from the materials in the other three categories and these have already been spread for civil engineering uses in the world, they are eliminated from the review in the present study.

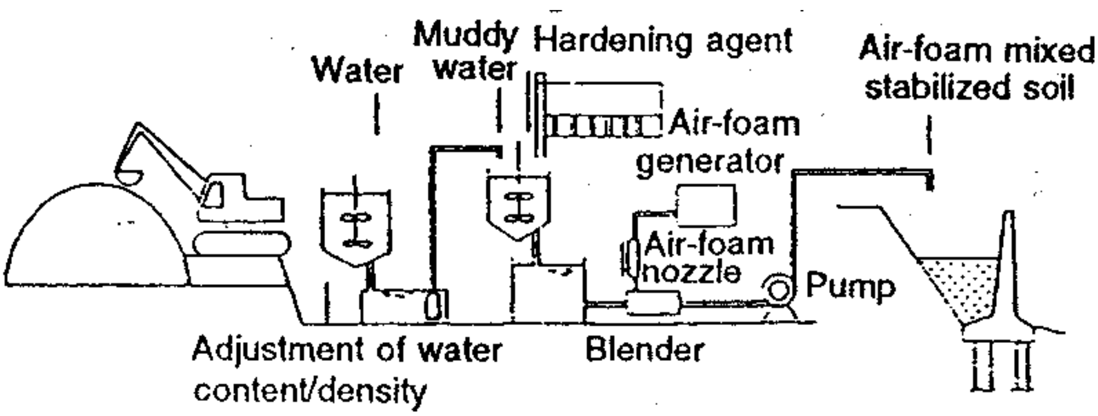



Figure 3. Manufacturing plant for air-fomed LGM (Miki,1996)


Figure 4. Floating LGM in water at laboratory placement (Horiuchi et al.,1996)

As the special case pertaining to the category (iii), the flash setting light weight material which has aimed at construction of floating islands (Horiuchi et al., 1996) is the innovative new material for possible use in the future. Fig. 4 illustrates an horizontal view of floating LGM (y=0.6tf/$m^3$) in water at laboratory. The volume of floating portion only decreased from 40% to 30% in 30 days after the start of testing.

## 4 SUCCESSFUL CASE STUDIES

As is well known, many facilities for waterfront such as quay walls, piers and retaining walls at the port of Kobe were devastatingly damaged by the Great Hanshin Earthquake which took place in 1995. This earthquake was triggered by the sudden movement of the fault traveling towards the right direction under the city which had resultantly caused the strongest intensity among the past records of earthquake motions in Japan.
Urgent restoration of the function of the port was required in order to retum to the original situations in the economy and everyday life of the citizens. The restoration works for public facilities and infrastructures were progressed as fast as possible. At the same time it was required that the higher anti-earthquake resistance and durability than before the earthquake should be was provided to the restored facilities.

The case study reported here is an example for restoration work of a gravity type seawall for a container berth which was attempted in a reclaimed land in Kobe using the lightweight geomaterial technique. The cross sectional view of the objective area is shown in Fig. 5. It was reported that the concrete caisson in this area suffered from lateral movement of several meters foreword from the original position during the earthquake.
Reclaimed sand behind the rubble stone was improved with Sand Compaction Pile (SCP) Method in order to prevent the liquefaction during an earthquake possibly occurred in the future. Over the SCP-improved ground area lightweight geomaterial with the air-foamed agent was spread in order to reduce the lateral earth pressure acting on the back of the seawall. The lightweight clay soil was dredged from the seabed close to the site. Two mixing conditions differently employed in the project for above and below the sea level, respectively, are presented in Table l. Since the targeted density of LGM above the sea level is smaller than that below the sea level, LGMs with different proportions of mixing the materials were applied. Compression strength shown in Table 1 was determined by unconfined compression test (UCT).

Table I. Mix design of the light-weight geo-material at Kobe project

| | Dredging (kg/m³) | Cement (kg/m³) | Air foam (ℓ/m³) | Design | |
|---|---|---|---|---|---|
| | | | | Strength (kPa) | Density (t/m³) |
| Above sea level | 849 | 140 | 279 | 198 | 1.00 |
| Below seal level | 952 | 140 | 196 | 198 | 1.20 |

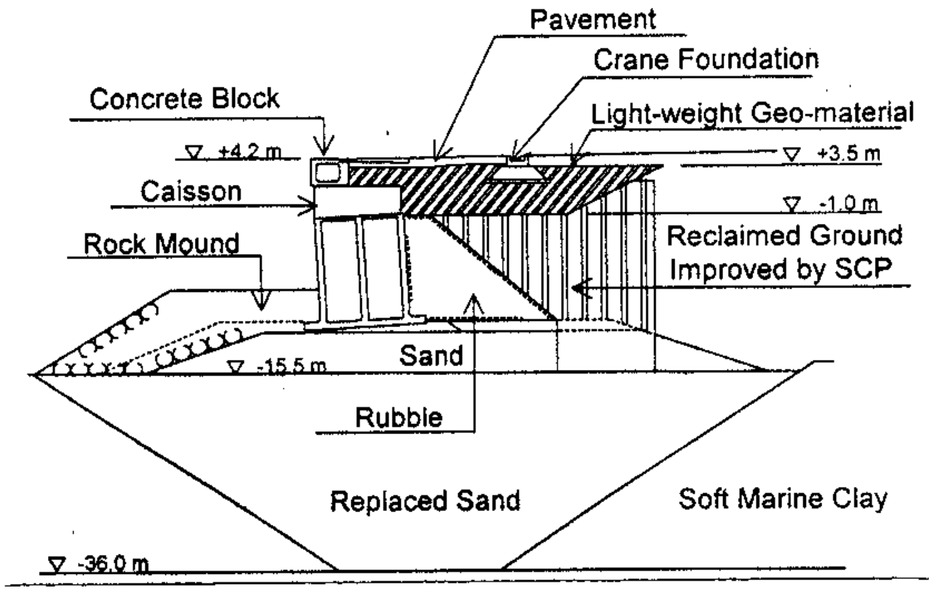



Figure 5. Cross section of the reconstruetion seawall in Kobe project

Core sampling was carried out after the completion of the work in order to verify the actual quality of the poured LGM. The values of unit density are plotted against elevation in Fig. 6. They are almost constant through the elevation as shown in the figure. Unit density above the sea level is slightly larger than the targeted value, and the average value is 1.03 t/m$^3$. On the other hand, unit density below the sea level is a little bit less than the targeted value with the average of 1.15 t/m$^3$. Fig. 7 shows the results of UCT. Although the actual values of unconfined compression strength show considerable scatter, all the values seem to satisfy the required strength. Fig. 8 presents the change of density of LGM with time. Because this material was used in order to reduce the lateral earth pressure acting on the seawall, it was very important to maintain the unit weight constant and observe its variation with time. Fortunately, however, the unit density of LGM used in this work was confirmed to be constant with clapsed time as demonstrated in Fig. 8. In the same line as in the results in Fig. 8, Fig. 9 shows the increase of compression strength with time.

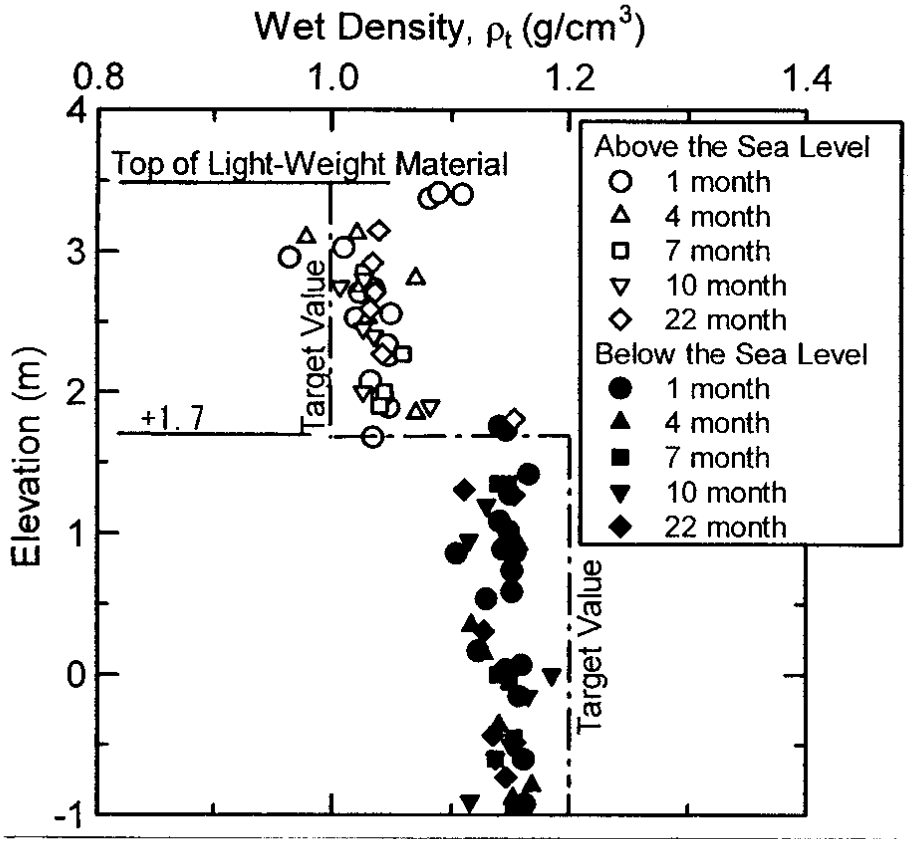



Figure 6. Distribution of the density with elevation

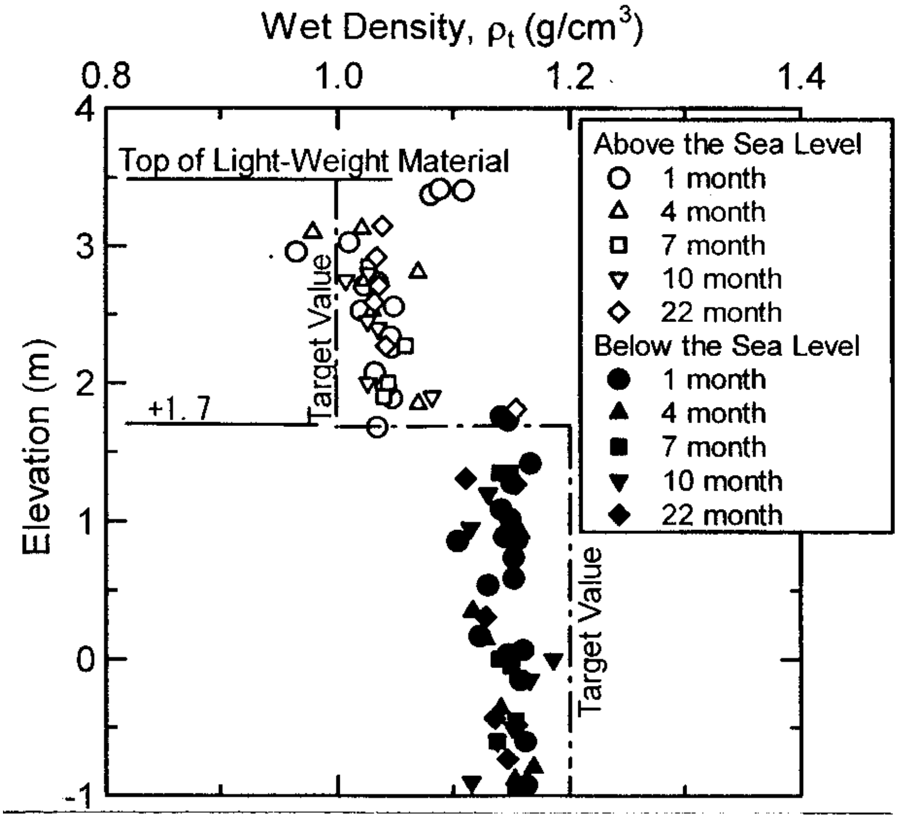



Figure 7. Distribution of the strength with elevation

The volume used in this project was 22,00Om$^3$ and it took only two and a half months to finish the pouring work of the material including mobilization and demobilization of machines for mixing and transporting the materials. In this sense, the work using LGM is very economical from the viewpoint of cost saving. Therefore, this case study has been counted as the first successful attempt as the use of LGM at the coastal area in Japan. After the successful application in Kobe, the use of lightweight geomaterials has widely been prevailed in the construction works around the coastal area in Japan. Table 2 summarizes the projects in which lightweight geomaterials were successfully adopted as the coastal works after this project up to the present time.

Table 2. Summary of the projects in which light-weight geo-material was used

| Project Site | Construction Period | Volume of construction ( $m^3$ ) | Design | | | Application |
|---|---|---|---|---|---|---|
| | | | Strength (kPa) | Density ($g/cm^3$) | | |
| Tokyo International Airport | 5/96 – 6/96 | 1,930 | 200 | 1.1 | Above the water | Back fill for sea wall |
| Kumamoto Port | 5/98 – 8/98 | 890 | 200 | 1.1 | Above the water | Field study |
| | | | | 1.2 | Below the water | |
| Tokyo International Airport | 9/98 – 12/98 | 35,560 | 200 | 1.1 | Above the water | Filling for taxiway |
| Ishikari Port (Phase I) | 11/98 – 3/99 | 3,000 | 200 | 1.1 | Above the water | Back fill for sea wall |
| | | | | 1.3 | Below the water | |
| Tokyo International Airport | 2/99 – 3/99 | 12,790 | 200 | 1.1 | Above the water | Back fill for culvert tunnel |
| Tokyo International Airport | 2/99 – 3/99 | 10,780 | 200 | 1.1 | Above the water | Filling for runway |
| Tokyo International Airport | 9/99 – 11/99 | 23,550 | 200 | 1.1 | Above the water | Filling for taxiway |
| Ishikari Port (Phase II) | 10/99– 11/99 | 4,110 | 200 | 1.1 | Above the water | Back fill for sea wall |
| | | | | 1.3 | Below the water | |
| Tokyo Port | 10/99 – 4/00 | 11,200 | 200 | 1.2 | Above and below the water | Back fill for sea wall |
| Tomakomai Port (Phase I) | 12/99 – 3/00 | 2,600 | 200 | 1.3 | Below the water | Back fill for sea wall |
| Tokyo International Airport | 5/00 – 6/00 | 6,760 | 200 | 1.1 | Above the water | Back fill for culvert tunnel |
| Tomakomai Port (Phase II) | 5/00 | 2,000 | 200 | 1.3 | Below the water | Back fill for sea wall |
| Yokohama Port | 7/00 – 3/01 | 43,878 | 200 | 1.2 | Above and below the water | Back fill for sea wall |

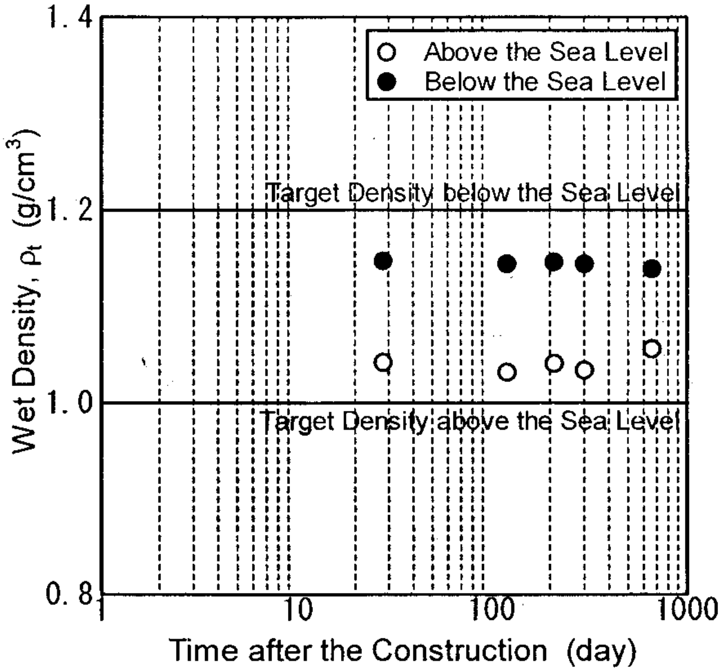



Figure 8. The change of the density with time

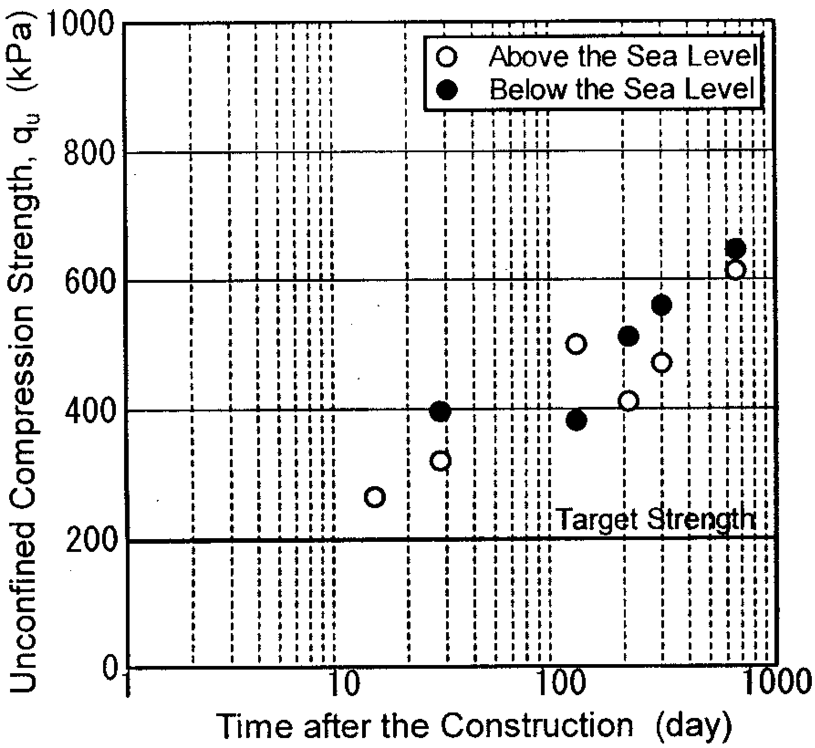



Figure 9. The change of the strength with time

## 5 PECULIALITIES OF GEOTECHNICAL PROPERNES

### 5.1 *Applicability of Mohr-Coulombs Failure Criteria*

In designing the earth structures and foundation where lightweight geo-materials are adopted for overcoming civil engineering difficulty, the geotechnical parameters are needed. Among them, parameters pertaining to permeability, compressibility, and shear strength and deformation are most necessary. Unfortunately, however, there have not been accumulated data from laboratories and fields to assure whether the presently available knowledge and concepts in geotechnical engineering can be applicable or not. For example, we cannot answer whether the Mohr-Coulomb's failure criteria could be available for these complex materials. Let us show an example of Mohr's circles in Fig. 10 which were obtained from drained triaxial tests on the air-foamed light-weight clay (Watanabe and Kaino, 2000). It is noted in Fig. 10 that the failure envelope seems to decrease with increasing the effective normal stress. This cannot be explained by the Mohr-Coulomb's failure criteria.

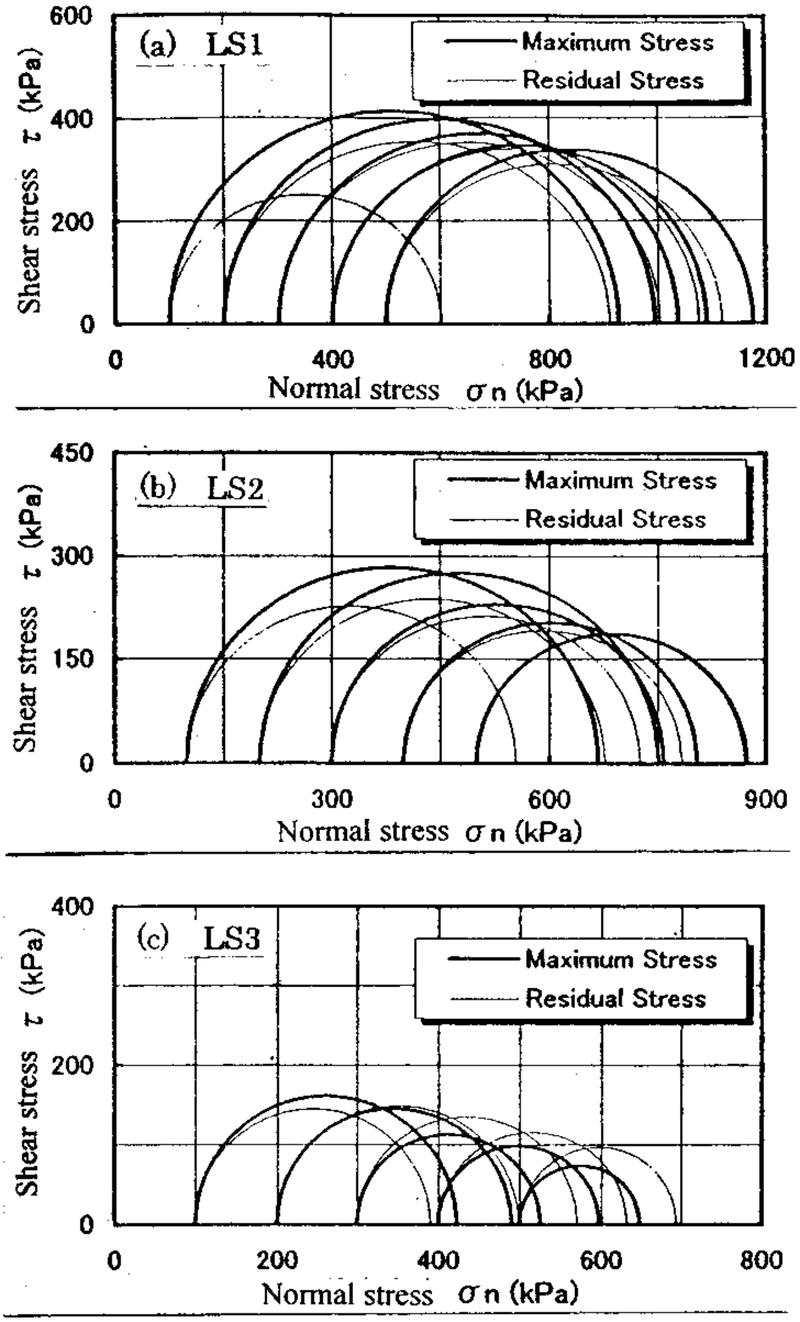



Figure 10. An example of Morh's círcle for air-foamed LGM (Watanabe and Kaino, 2000)

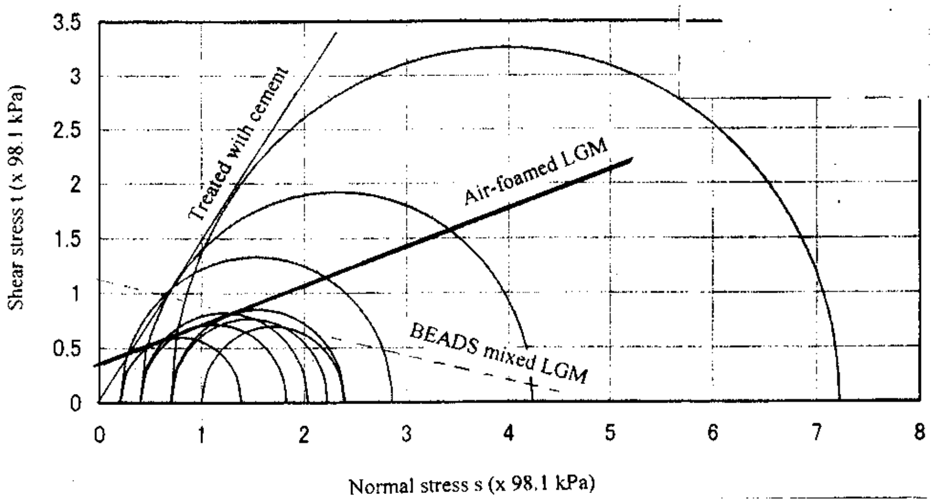



Figure 11. A comparaison of Morh's circles between cementtreated soils and LGM with cement

5.2 *A comparison of shearing behaviour in between soils with and without air-foam addition*

As one of the activities of the Research Committee on Light-weight geomaterials by JGS (1998-2000), two kinds of drained triaxial tests were carried out on cement stabilized sandy soils with and without air foam to make sure of the above-mentioned behaviour of Mohr's circle. It can also be seen from Fig. 1 1 that the failure envelopes cannot smoothly be drawn along the Mohr's cireles on lightweight soils with air foam and EPC beads, while they can be on the soil stabilized with cement without air foam. Tendencies in Fig. 11 indicate that the MohrCoulomb's failure criteria should be improved for deseribing the stabilità of lightweight geomaterials. To realize this, one possibilità is to adopt the two-phase mixture modei proposed by Omine, et al. (1996) as shown in Fig. 12.

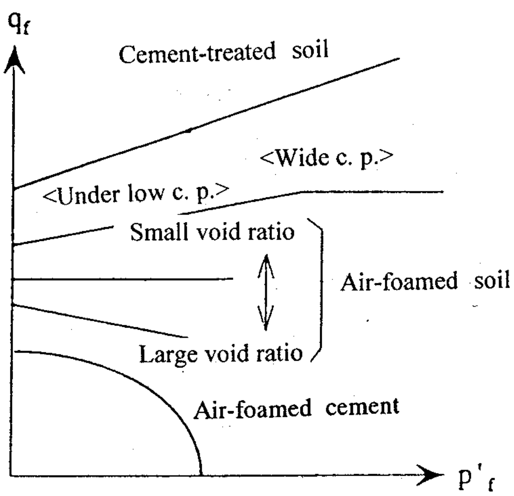



Figure 12. A key sketch of failure crieria for LGM (Omine et al.,2000)

5.3 *Applicability of Cam-clay type model to shearing behaviour of air-foamed light-weight soils*

An another important aspect included in lightweight geomaterials is to explore the constitutive model suitable for analysis of deformation and settlements of foundations. For this purpose, the above-mentioned Research Committee made an attempt to predict stress-strain behaviour of the lightweight sand with cement and EPS beads using the original Cam-clay model and the extended

cam-clay model proposed by Yasufuku, et al. (1999) which takes the bonded effect into consideration. The results are shown in Fig. 13 together with those observed in triaxial tests. When we compare the stress-axial strain-volumetric strain relations predicted by the extended model with those observed in drained triaxial tests, both are in well agreement.
This implies that behaviour of the lightweight soils with EPS beads can better be predicted by the Cam-clay concept than that of LGM with air-foam.

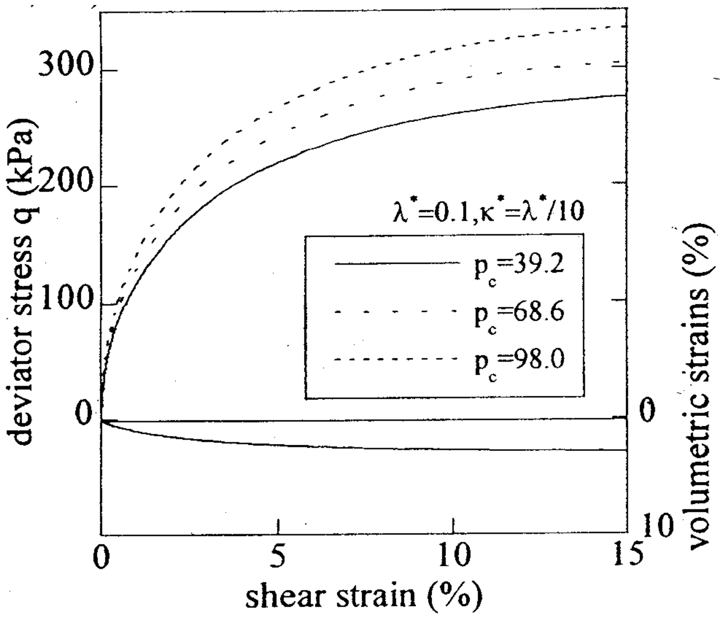



Figure 13. Calculated deviatoric stress, strain and volumeric strain relations calculated by the extended Cam-clay model (Yasufuku et al.,2000)

5.4 *An insight into micro-structures of LGM with air-foam using Computerized Tomography Scanning (CTS)*

The geotechnical properties of LGM depends on the homogeneous distribution of density and water content. The Computerized Tomography Scanning (CTS) is a powerful tool in this aspect. The results from X-ray CTS on air-foamed LGM using fly ash are shown in Fi.g. 14a to Fig. 14e as an example (Yasuhara et al., 2000). The pictures of three specimens cured in air, fresh water and seawater for a prolonged period of 430 days were taken using X-ray Computerized Tomography Scanning (CTS) owned by the Geotechnical Engineering Group, Department of Civil Engineering, Kumamoto University, Japan (Otani, et al., 1999 : Otani, et. al., 2000). The main purpose of this investigation is to examine the existence of cracks inside the specimen and cross sectional images of density. Fig. 14a to Fig. 14c illustrates the distribution of density and CT-value through a specimen cross section. The CT-value for cross sectional images is defined by:

CT-value = $(m_t,-m_W,)K/m_W$ (1)

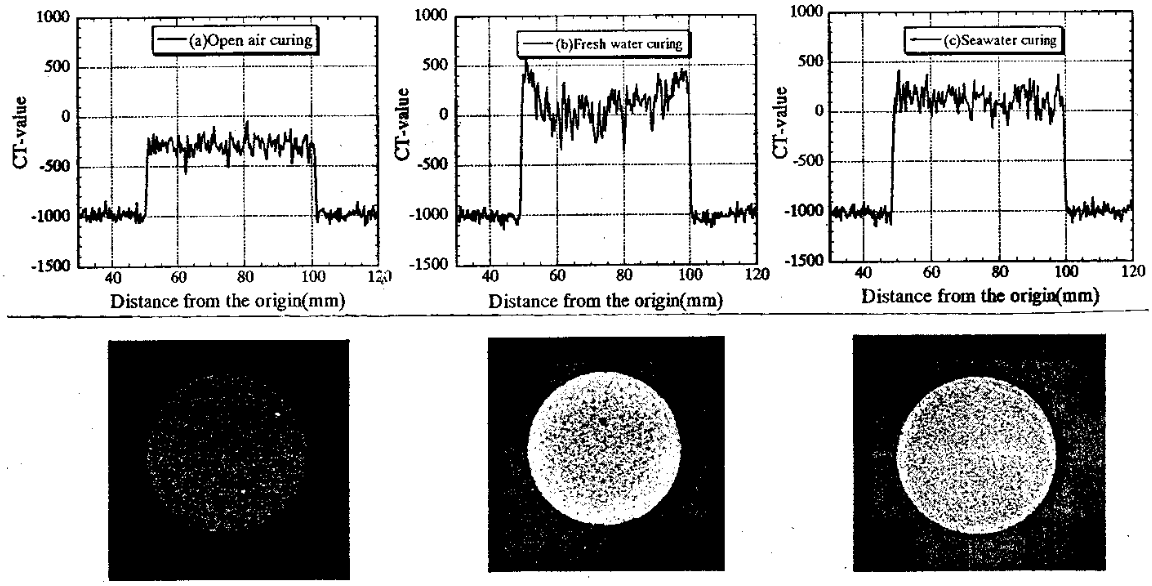
where $m_t$ is coefficient of absorption at scanning point, $m_W$ is coefficient of absorption for water and K is material constant. It is noted that the coefficient of absorption for air is zero. Therefore, when K is assumed to be 1000, the CT-value of air becomes zero. The CT-images are black colour for low CTvalues and white for high values. Thus the following is pointed out from comparisons in Fig.14:

1)The density of the specimens cured under water is higher than those that were air cured.
2)The distribution of density through the cross section in the seawater cured specimen is better than other two specimens cured under fresh water and air. This must be caused by homogeneous infil-

tration of seawater through the specimen.

## 6 ISSUES FOR FURTHER INVESTIGATION

Since the compounded light-weight geomaterials described here are considered to belong to new materials even in the field of soil improvement, there have still been left the some important




(a)Open air curing (b)City water curing(With lid) (c)Seawater curing(With lid)

Figure 14. The results of X-ray CT scanning for LGM using fly ash (Yasuhara et al.,2000)

issues for further investigation.
The following is counted as the examples:

i) to establish the constitutive relation suitable for these materials
ii) to homogenize the possible scattering data from field and laboratory investigation
iii) to investigate the long-term durability of geotechnical properties
iv) to clarify the effects of added chemical materials and mixed industrial sub-produets on the environments of ground
v) to find the way how to connect these techniques with the cost saving in public execution.

## 7 CONCLUSIONS

In the current paper, light-weight geomaterials produced by adding air-foamed agent and super light polymer materials such as expanded polystylene beads are described as a new material in soil improvement. In particular, it is emphasized that this technique can overcome the previously encountered difficulties inmany situations civil engineering practices. By making clear the important and essential problems from geotecnical point of view, in comparison with the similarities to and differences from behaviour of ordinary soils, it is emphasized that they would be more promising in the use of more difficult situations in the civil engineering praetices. Currently, one of the most important issues is to ciarify the environmental impacts because these materials include the chemical additional materials. Besides this, the concept of life cycle cost (LCC) should be included in development of these materials for the purpose of the cost saving in practices.

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