發泡스치로－루(EPS)의 力學的 特性과 盛土材로서의 問題点

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MECHANICAL CHARACTERISTICS OF EXPANDED POLYSTYRENE (EPS) AND PROBLEMS IN THE USE FOR A ULTRALIGHTWEIGHT FILL MATERIAL IN ROAD CONSTRUCTION

1. Introduction

The expanded polystyrene (EPS) material has been ordinarily using as the ultra-lightweight fill material in road construction in Norway where peat and quick-clay are widely distributed under the guidance of Norwegian Road Research Laboratory (NRRL) since the year of 1972. One-day Symposium titled "Plastic Material using for Road Embankments" held in Oslo, 1985, gave a big influence to many countries where geotechnical engineers have been in trouble with respect to embankment settlements on soft grounds.

The EPS plate has been applying laying it on subgrades beginning from the United States of America on the basis of studies by Purdue University (Hortlon et al., 1973) and the formed cement mortar (FCM) has been applied in an in-situ test in Kyushu, Japan, by the author et al. for a restoration of damaged pavements (Yamanouchi et al., 1966). The both materials are certainly very light, however, these materials were applied not for receiving their light weight properties but for insulation effects against frost for the purpose of prevention of frost failures of roads.

Being influenced by the above-introduced Symposium, there has been in Japan organized "Development Organization of EPS for Civil Engineering Work Method" (DOEPS) nominated Professor G. Miki as the President and the author et al. as the Technical Advisers in 1986, and the Organization has experienced the field tests of the EPS embankments on soft grounds as many as more than ten.

The EPS embankment method is well known in Japan as the newest work method as well as the use of polymer grids (geogrids) for construction of earth structures. This short paper treats of mechanical characteristics of the EPS material made clear in the author's laboratory and the problems in the use for road embankments discussed there in last a year together with a Research Fellow, Mr. E. Hamada (Hamada and Yamanouchi, 1987).

The author must write here a fact that the fundamental mechanical study has not been carried out even in NRRL, and the above Japanese Organization is necessary to make clear fundamental mechanical characteristics of the EPS material coming from Japanese characters unlike in Europe where new work methods had been often applied at fields without obtaining the basic data of the new materials to be interested.

2. The Use of EPS Material in Norway and Japan

Main applications of EPS material for the embankment fills in construction of roads in Norway are shown by Figure 1 (Aabφe, 1986). Meantime, Japanese field tests of the EPS material are as seen by Figure 2 (DOEPS), 1987).

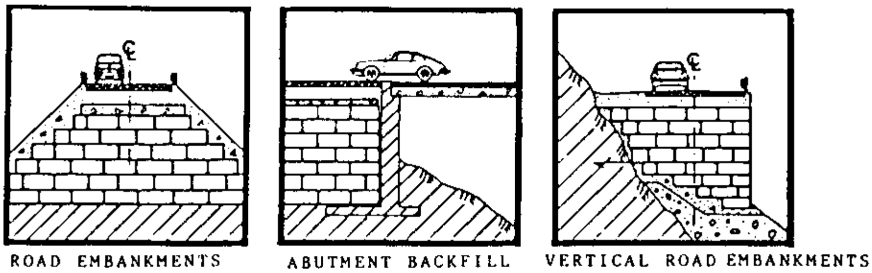
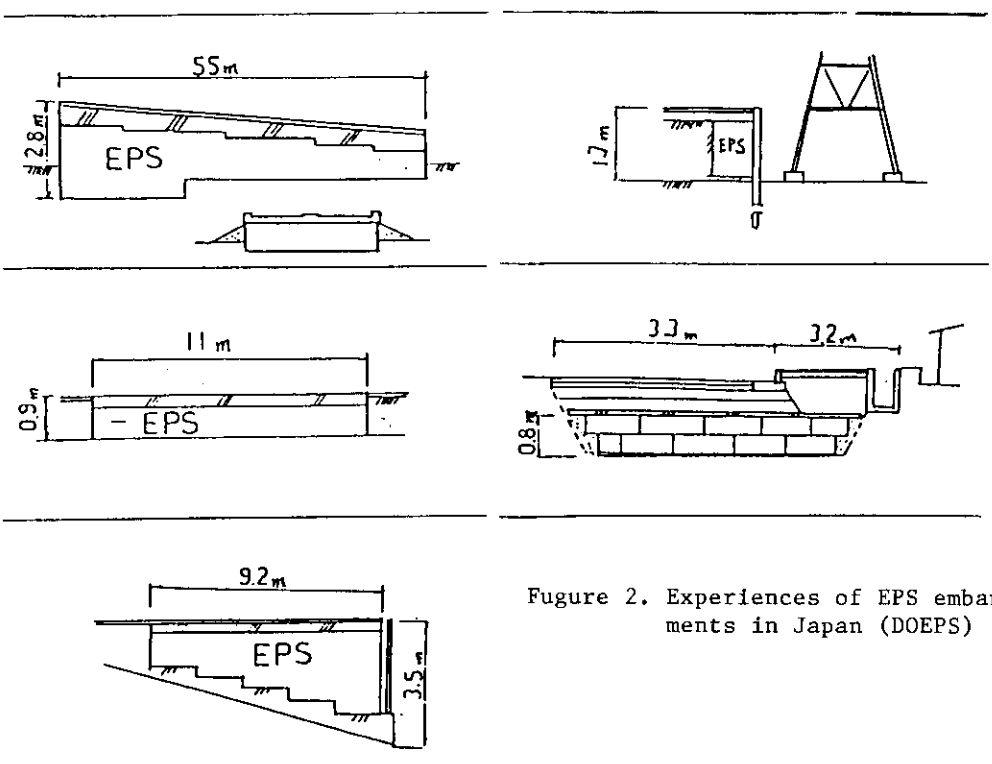


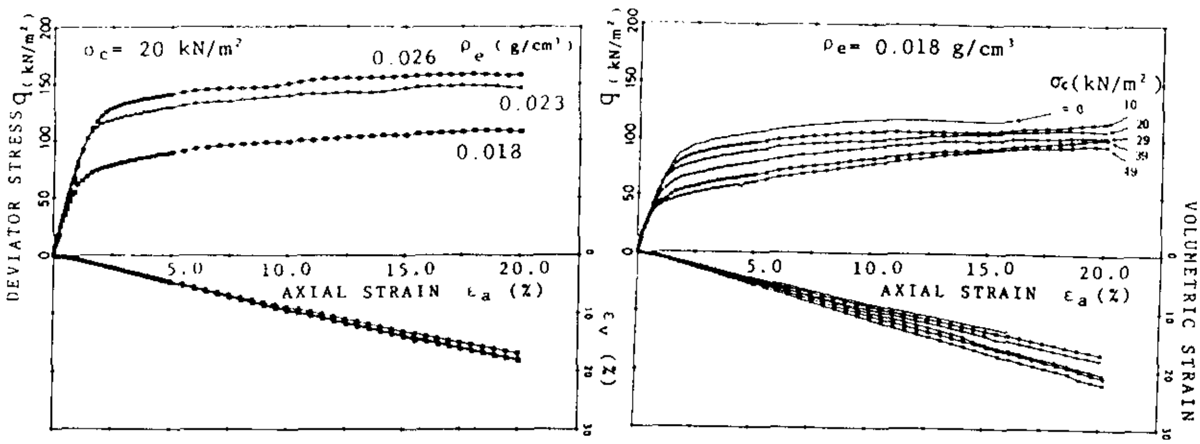
Figure 1. Applications of EPS embankment in Norway



Fugure 2. Experiences of EPS embankments in Japan (DOEPS)

3. Static Experiments of EPS Material

Figure 3 shows the typical results of triaxial compression test on EPS cylindrical specimens. When three deviator stresses are plotted on the $\sigma \sim \tau$ coordinates, we obtain the relationship at ε_a = 5%, as seen by Figure 4 which is distinctly unlike the ordinary relationship in soil mechanics.



(a) Effect of EPS density (b) Effect of confining pressure

Figure 3. Stress vs. strain curves of EPS material in triaxial compression tests

Tensile strength of the EPS material reaches originally about three times of the compressive strength and the author shows its yield criterion as shown in Figure 5 which compares with those of soils and rocks. On the contrary that the yield criteria of soil and rocks do belong to the first quadrant that of the EPS material must be exceptionally plotted in the second quadrant. The author wonder if the second quadrant criterion will be useful in civil engineering structures.

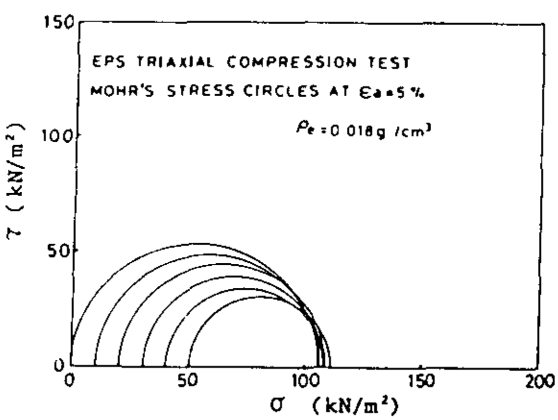


Figure 4. σ vs. τ relationship on EPS material

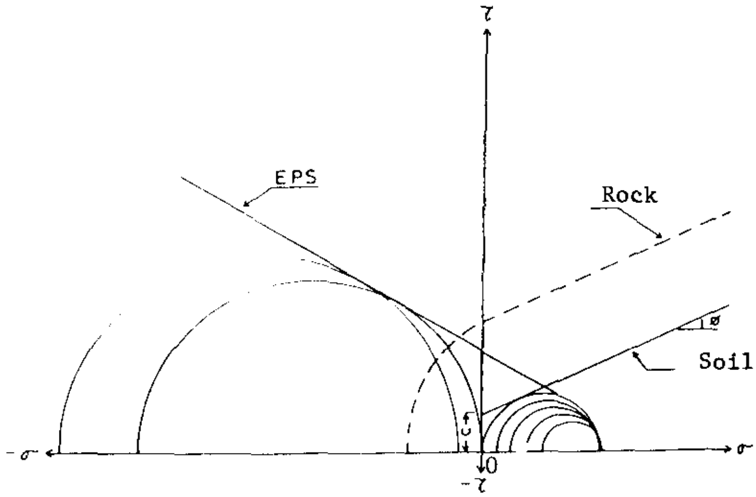


Figure 5. Yield criteria in comparison of EPS material with rocks and soils

To be emphasized, the EPS material must be substantially used as a kind of tensile-resistant material, but the material is being used as a kind of compressively resistant material in road embankments. This seems to be strange in considering our conventional structures so as to be able to prove by the typical example, reinforced concrete structures in which concrete receives its characteristic as the compressive material while steel does as the high tensile material. Therefore, the EPS material can be said to have abondoned its tensil-resistant property adopting its ultralightweight characteristic only.

4. Mechanical Characteristics of EPS Material Subjected to Cyclic and Repeated Loadings

Figure 6 shows the relationship between axial strain and compressive stress obtained from cyclic unconfined comression tests on the EPS material, and there is found a fact that the residual strain is largely increased with the increase in compressive stress exceeding about 80 kN/m^2 ($\fallingdotseq$ 0.8 kgf/cm^2). This is supposed to be problematic although the EPS material is so light that the texture is easy to be broken under such a comparatively low load.

Figure 7 shows the section of pavement model, applied the EPS material to the embankment, in which gauges and meters are installed for observations. The road model was placed in a steel-made box of 200 cm x 200 cm in section, and the road model was placed with the depth of 80 cm. The loading plate was 20 cm in diameter and the plate was able to impose the model surface not only statically but also cyclically and repeatedly.

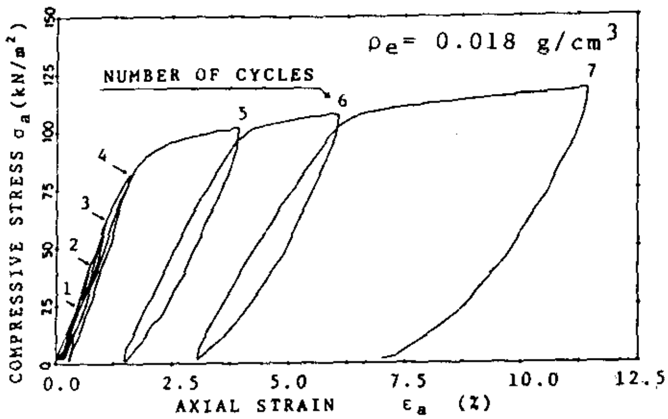


Figure 6. Stress vs. strain in cyclic unconfined compression test

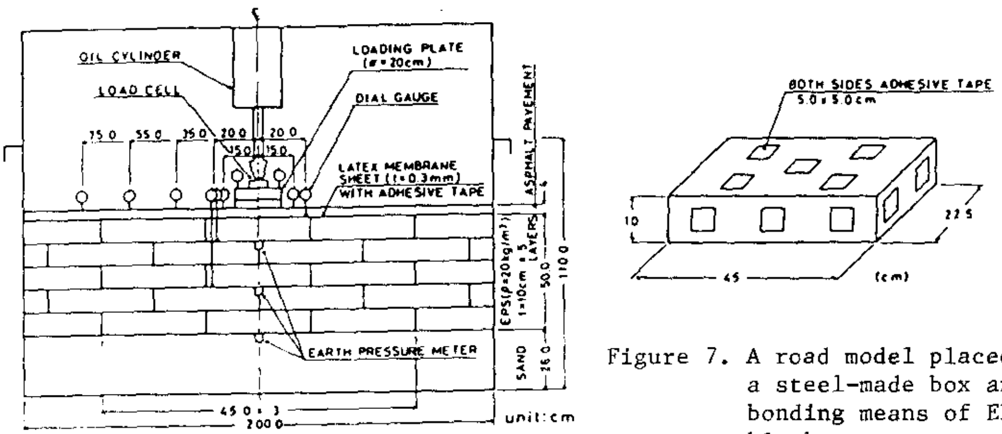


Figure 7. A road model placed in a steel-made box and bonding means of EPS blocks

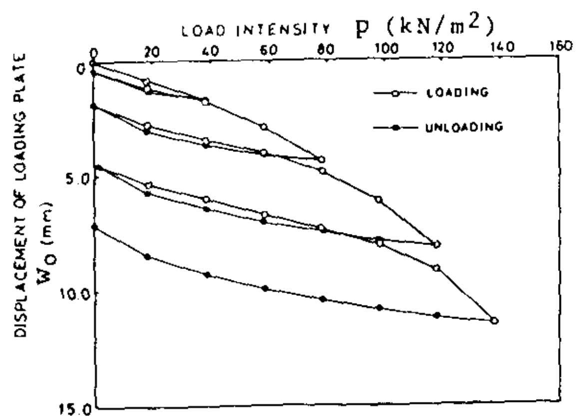


Figure 8. Result of cyclic plate loading test

(a) In the case of bonded EPS blocks vertically only, subjected to cyclic loading

Figure 8 shows the relationship between load intensity and displacement of loading plate, obtained by a cyclic loading, and there is learned a large residual displacement of the loading plate at the respective load intensity like in the former Figure 6.

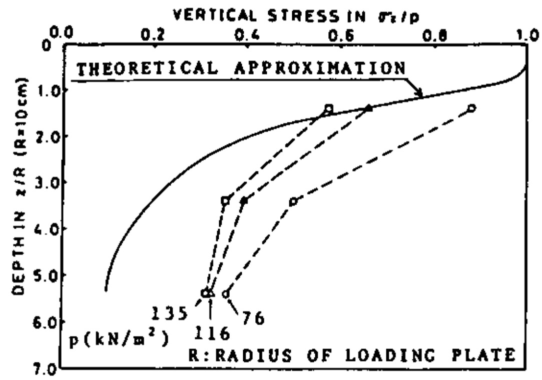


Figure 9. Load diffusion in EPS deposit
bonded vertically only

(b) In the case of bonded EPS blocks vertically and horizontally, subjected to repeated loading

Figure 10 shows the relationship between loading number and residual and elastic displacements, and it is found how residual displacement is accumulated continuously, keeping a constant amount of resilient displacement, as far as the loading number was up to 100,000 times, though the test cannot be satisfactorily simulated the actual road.

Regarding the effect of load diffusion due to bonding horizontally, too. Figure 11 can prove its large effect even though this treatment has not been done in the EPS embankments in Norway. Converting the data obtained from the repeated loading tests, Figure 12 can be obtained to show the relationship between vertical displacement at the unloding instant, namely, the vertical residual displacement (Hamada and Yamanouchi, 1987).

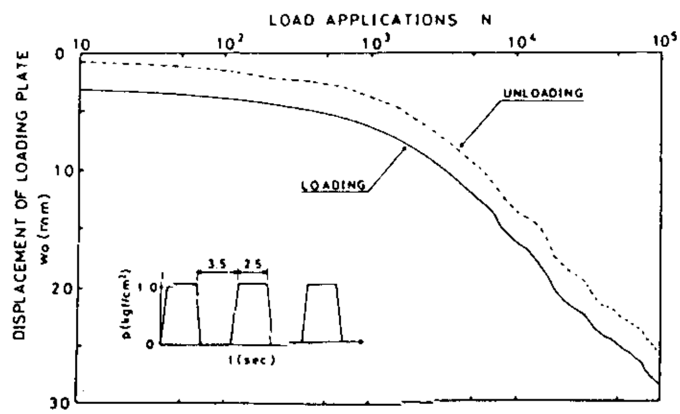


Figure 10. Accumulation of displacements
in repeated loading test

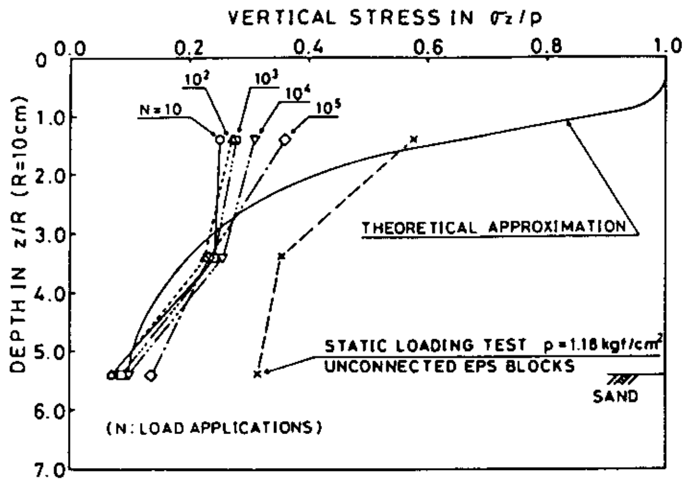


Figure 11. Load diffusion in EPS deposit bonded both vertically and horizontally in repeated loading tests

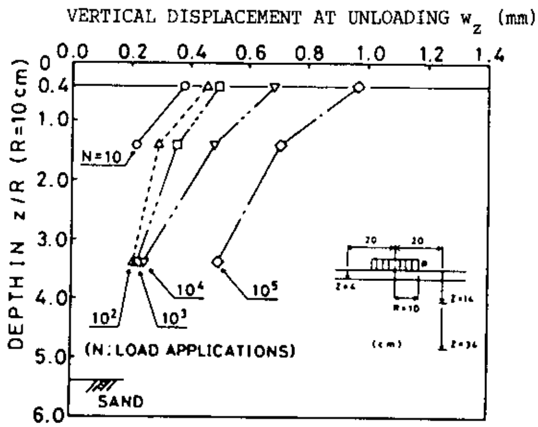


Figure 12. Relationship between vertical displacement and depth in each loading number

5. Teaching from the Experiments

As described until the last section, we are given some teaching from the mechanical experiments of EPS material conducted on both cylindrical and a road model in laboratory.

(1) The EPS material cannot be avoid a reasonably large residual strain or displacement when the material is subjected to cyclic or repeated loading even if the blocks are bonded in both directions as much as the strain or displacement accumulates seriously. Hereby, EPS embankments must incorporate a concrete slab beneath the pavement for providing a good wheel-load depthwise diffusion, as seen by the actual project works in Norway, even though the EPS material is undoubtedly abondoned its ultralightweight characteristic with the heavy weight of the concrete slab that cannot be ignored especially in relatively shallow EPS embankments.

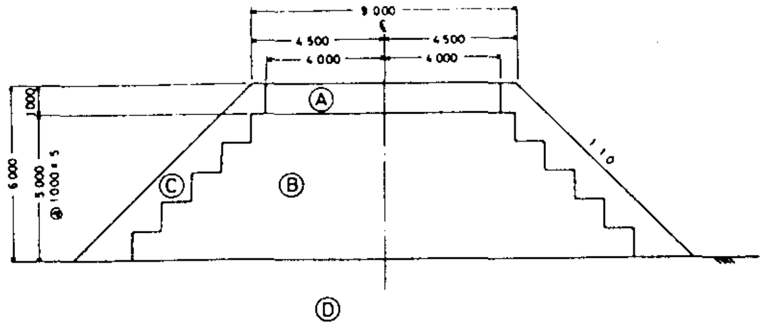


Figure 13. A road model sevtion for FEM analysis

Table 1. Property constants of respective material for FEM analysis

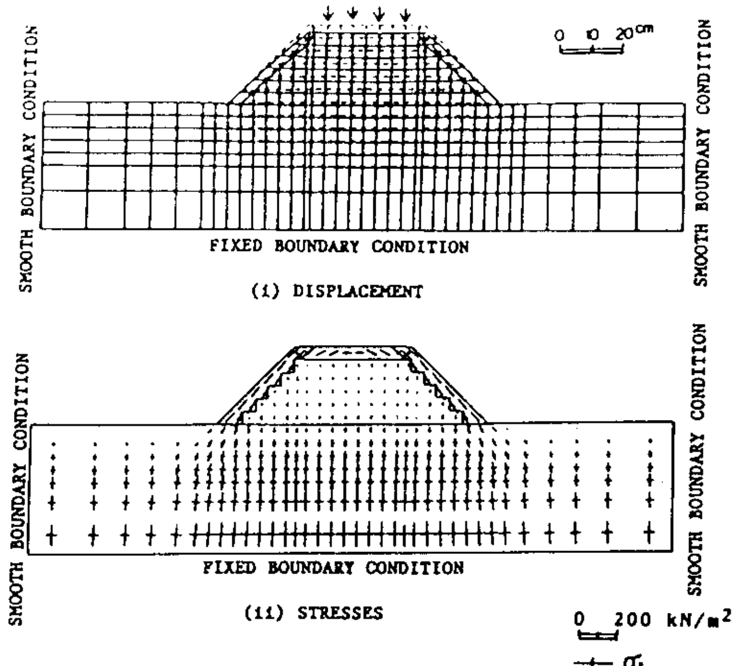
parts		Unit weight γ (kN/m³)	Modulus of elasticity E (kN/m²)	Poisson's ratio ν	Cohesion c (kN/m²)	Internal friction ϕ (deg)	Comp. strength σ_{cv} (kN/m²)	Tensile strength σ_{tv} (kN/m²)
(A)	A. Pavement + Gravel	19.6	2.0×10^6	0.3	–	–	980	98
(B)	EPS	0.2	5.4×10^3	0.1	–	–	118	343
(C)	Reinforced Soil	17.6	4.9×10^4	0.25	98	35	–	49
(D)	O.C. Clay	3.9 (γ')	9.8×10^3	0.3	49	0	98	0

(2) EPS blocks as the embankment material are desired to be connected horizontally, too, unlike in Norway where the blocks are connected using metal dowels vertically only.

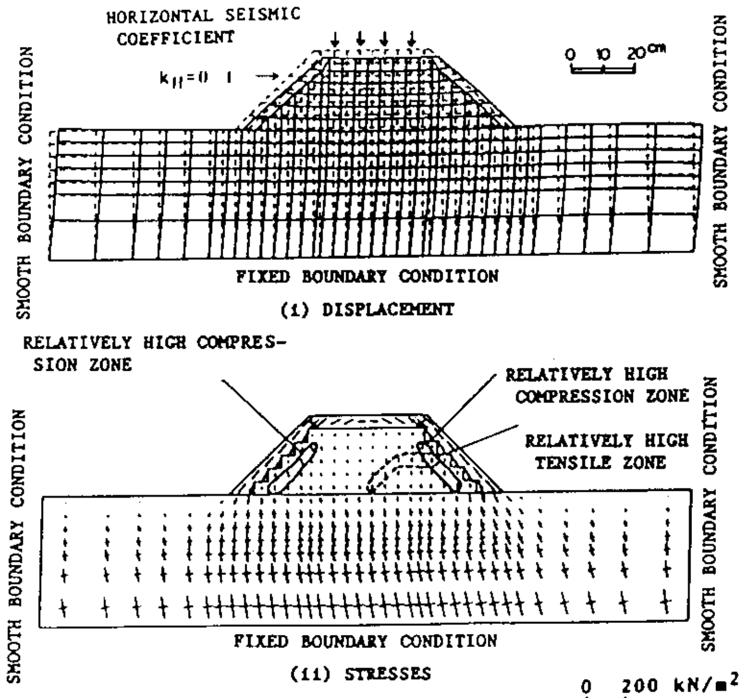
6. Mechanical Interaction between EPS Embankment and Soils Covered in Roads

The EPS material is extremely light compared with soils which must be covered on it in trapezoidal section roads besides a pavement at the top surface part so that the author worries about a mechanical interaction between the two materials in the section coming from a large diffusion of the unit weight between the two.

Figure 13 shows a typical trapezoidal section of the EPS embankment road, and the respective properties of the materials in the section are given in Table 1. Figure 16 shows the results obtained from the FEM analysis, using the above properties, and we can recognize the incontinuity of displacement and stresses between the EPS embankment deposit part and the slope soil parts, on the both



(a) In the case of ordinary time



(b) In the case of earthquake with seismicity coefficient of 0.1

Figure 14. Results of FEM analysis of a road model section on soft clayey ground

cases of the orninary time (Figure 14 (a)) and the earthquake time subjected to its horizontal force with the seismicity coefficient of 0.1 (98 gal) (Figure 14 (b)).

Besides such a mechanical problem, we must take consideration of seepage action causing during heavy rains into the slope stability as a flow nets problem because the EPS material is impervious one. Therefore, it is emphasized to provide any countermeasure between the EPS embankment and the soil slope parts to be able to make the road one body. This is regarded to be important especially in Japan where most lands are subjected to micro-earthquakes always unlike in Norway where has never been suffered not only from heavy rain but also from earthquake.

As its countermeasure, the author proposes a reinforcement as shown by Figure 15. The road embankment is reinforced not only about the two parts as described above but also about the soft ground which is soft, sensitive and deep. Vertical drain pile works can be avoided if the softness of the ground is not so serious. Even though the proposed section is highly costed, this will be the final techniques achieved until the end of the 20th Century.

The section adopts a concrete slab as in Norway, but English engineers are being adopting geotextiles instead of the slab while Swedish engineeers are carrying out the same section as in Norway.

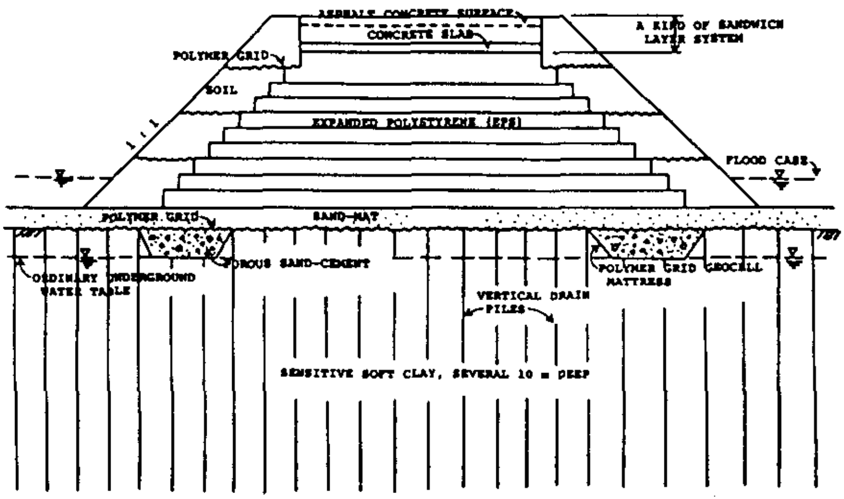


Figure 15. Proposed road section with EPS embankment built on soft grounds, reinforced with polymer grids

The author's laboratory has already commenced the mechanical study of FCM material which the unit weight remains to be about 1/10 of that of soils (Furutani, 1986), and the material is really cheaper than the EPS material besides the merit of being able to place hot asphaltic concrete mixtures directly on the FCM material. The FCM embankment will be able to resist the buoyant floating-up causing during the flood time due to its proper unit weight.

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