Geofoam: a potential for Indonesia’s soil problem

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Abstract. One major issue in construction is settlement. Building any structure above compressible soils without proper consideration can lead to considerable damage and maintenance cost. Geofoam is a type of light-fill material in the lightest category. Since the 1970s, geofoam has been used worldwide to address settlement problems. Unfortunately, geofoam has not received much attention in Indonesia, mainly due to its cost compared to traditional fill. This paper covers the application of geofoam for road construction based on real soil conditions in Indonesia. From the analysis conducted, the use of geofoam reduces the compacted fill required by 40%. This saves not only construction time, but also carbon footprint of the road design. When the reduction of time by using geofoam is considered, geofoam becomes a feasible solution economically as well as environmentally.

1. Introduction
Geofoam is a type of expanded polystyrene (EPS) which has material properties suitable to be used for construction. It has a unit weight of about 1-3% of traditional fill [1], which makes geofoam to be considered as a new category of light fill, i.e. “ultra-light” fill [2]. Despite its lightness, geofoam stiffness is comparable to loose sand. The usage of geofoam in engineering field commonly includes void filler for bridge approach, embankment fills and extension and slope remediation.

In this paper, the use of geofoam for geotechnical purposes, specifically embankment fills is discussed based on case studies in Indonesia. First, geofoam properties are described, followed by case studies of potential usage of geofoam in road construction. Lastly, potential for geofoam usage in Indonesia is summarised.

2. Geofoam properties, its advantages and disadvantages
Geofoam has the outlook of Styrofoam as shown in Figure 1. However, geofoam is much stiffer than Styrofoam, making it suitable for construction usage. The biggest advantage of using geofoam over soil or gravel fill is its unit weight. According to ASTM [4], the unit weight of geofoam commonly ranges from 12 kg/m$^3$ to 46 kg/m$^3$. Table 1 lists the minimum required material properties for each category of geofoam. For engineering purposes, the working load applied on geofoam is limited to 1% strain [3].

Using EPS19 from Table 1 as an example, EPS19 has similar stiffness to loose sand and can withstand 40 kPa before deforming by 1%. These properties are sufficient for typical road application where the combined pavement and traffic load does not exceed 30 kPa. Geofoam can be used to replace existing soft soils or used as embankment fills over soft soils as the subgrade for pavement. By utilizing geofoam as subgrade, additional stress-induced on existing soil can be minimized. Hence, settlement magnitude can be minimized.
Table 1. Material properties of Geofoam [4].

| Geofoam Type | Minimum density (kg/m³) | Stiffness at 1% strain (kPa) | Stiffness at 5% strain (kPa) | Stiffness at 10% strain (kPa) | Minimum flexural strength (kPa) |
|--------------|-------------------------|-----------------------------|-----------------------------|-------------------------------|--------------------------------|
| EPS12        | 11.2                    | 1500                        | 700                         | 400                           | 69                             |
| EPS15        | 14.4                    | 2500                        | 1100                        | 700                           | 172                            |
| EPS19        | 18.4                    | 4000                        | 1800                        | 1100                          | 207                            |
| EPS22        | 21.6                    | 5000                        | 2300                        | 1350                          | 276                            |
| EPS29        | 28.8                    | 7500                        | 3400                        | 2000                          | 345                            |
| EPS39        | 38.4                    | 10300                       | 4920                        | 2760                          | 414                            |
| EPS46        | 45.7                    | 12800                       | 6000                        | 3450                          | 517                            |

Figure 1. The outlook of geofoam [5]

Geofoams are manufactured in blocks. Depending on the moulding machine, the geofoam blocks can be produced in sizes such as 2.0 m x 1.0 m x 0.5 m, some larger moulding machines can manufacture produce blocks as large as 8.0 m x 1.0 m x 1.0 m. The blocks are easily machinable to all sorts of shapes and sizes. For a typical EPS19 block size of 3.0 m x 1.0 m x 0.5 m, its weight is under 30 kilograms and can easily be transported and installed by a pair of workers without any heavy equipment. This makes geofoam installation quick and cheap, saving construction time and cost.

Degradation of geofoam is also minimal. The first geofoam project in the world was started in Norway. Geofoam was used as embankment fill in order to reduce settlement. Ever since its installation, every several years, the geofoam blocks are excavated and tested. The tests show that the geofoam blocks still performs satisfactorily, and tests which were below required specifications was within the tolerable variation of material quality [6].

The main benefit of geofoam property is also its shortcoming. As geofoam is much lighter than water, it floats when submerged underwater. This generates an uplift force. If the weight of the pavement is lower than the uplift force, it will induce damage to the pavement. This problem can be overcome by making sure geofoam used is above the anticipated flood level. If geofoam is designed to be under the flood level or water table, it can be anchored to counteract the buoyancy force. Another weakness of geofoam is petroleum [5]. When geofoam comes into contact with petroleum, it will turn into liquid and loses its strength. Exposure to petroleum can be prevented by covering geofoam with petroleum-resistant geomembrane [6]. The other disadvantage is the cost. Geofoam can be 2-4 times more expensive than traditional soil fill. The additional cost is used to “buy” time, as geofoam usage can minimize ground improvement works. Construction time can also be greatly reduced as geofoam can be installed in any weather conditions, unlike soil fill, which cannot be compacted when wet. The
installation of geofoam also does not require any heavy machinery or equipment, this further reduces the construction cost. Feasibility assessment of geofoam should cover not only the material cost, but also construction time and cost.

3. Geofoam as embankment fills

One of the major issues faced in embankment construction is settlement. Building an embankment on compressible soil without any treatment or reinforcement, will result in excessive settlement, damaging the roads on the embankment. If the compressible soil layer(s) is/are clay, the embankment will experience prolonged settlement. The maintenance cost for road embankment built on soil undergoing settlement is costly.

In Indonesia, soft soils can be found throughout, especially on Java, Sumatra and Borneo island. Typical solutions used are ground improvement, such as prefabricated vertical drain with preload, deep cement mixing, stone/sand column. Other options include deep foundation. Geofoam has never been used for any road projects in Indonesia.

In the case study discussed in this section, a 7.5 m embankment is to be built on very soft soil. As the final design has not been finalized by the highway authority, the location of the project is not disclosed in this paper.

3.1. Soil profile and parameters

In the section considered, the soil consists of 2.5 m of soft sandy clay, underlain by 3.0 m of loose sand. Underneath the loose sand layer is a 14 m thick very soft clay, having SPT (Standard penetration test) values of 0-1. From -19.5 m to -32.0 m below the ground surface is medium sandy clay, underlain by 2.5 m of very dense sand. Stiff clay is then found until the final depth of soil investigation. The water table is located 3 m below the ground surface. Soil parameters used for analysis are derived from the SPT values and laboratory test results. The soil parameters are summarized in Table 2. They are all modelled using Mohr Coulomb.

| Soil Type           | Depth From To | Saturated Unit Weight | Young’s Modulus | Poisson’s Ratio | Cohesion (kPa) | Friction Angle | Dilation Angle | Permeability |
|---------------------|---------------|-----------------------|-----------------|----------------|----------------|----------------|----------------|--------------|
| Soft sandy clay     | -0.0 to -2.5  | 15.0                  | 4000            | 0.3            | 5              | 23             | 0              | 1x10^-6      |
| Loose sand          | -2.5 to -5.5  | 16.0                  | 10000           | 0.3            | 1              | 30             | 0              | 1x10^-3      |
| Very soft clay      | -5.5 to -19.5 | 14.0                  | 3000            | 0.3            | 1              | 22             | 0              | 1x10^-6      |
| Medium sandy clay   | -19.5 to -32.0| 16.5                  | 8000            | 0.3            | 10             | 30             | 0              | 1x10^-6      |
| Very dense sand     | -32.0 to -34.5| 20.0                  | 45000           | 0.3            | 1              | 35             | 5              | 1x10^-3      |
| Stiff clay          | -34.5 to -50.0| 19.0                  | 20000           | 0.3            | 15             | 30             | 0              | 1x10^-6      |

Note: $\gamma_{sat}$ = saturated unit weight; $E^\prime$ = Young’s modulus, $\nu^\prime$ = Poisson’s ratio; $c^\prime$ = cohesion, $\phi^\prime$ = friction angle; $\psi$ = dilation angle; $k$ = permeability.

3.2. Embankment geometry and design requirement

The embankment height varies from 2.5 to 7.5 m. At the road level, the embankment width is 34.5 m. The embankment slope is 1V:2H (1 vertical to 2 horizontal ratio). For 7.5 m high embankment, the base of the embankment a width of 64.5 m. The schematic diagram of the embankment and soil layers is shown in Figure 2.

There are several design criteria required for the embankment, both during construction and after operation. During construction, the required factor of safety (FoS) is 1.35. At the start of traffic
operation, FoS of 1.5 is required. In addition, the settlement of the road is limited to 10 cm in 10 years of operation. The traffic load is taken as a surcharge of 20 kPa and the flood design level is at 2.0 m.

3.3. Traditional solution

To limit the settlement during 10 years of traffic operation to 10 cm, preloading is usually a more economical solution compared to other methods such as piles, stone columns or deep cement mixing. In this particular case, the embankment has to be preloaded an additional 2.5 m to 10 m height. The preloading scheme is shown in Figure 3. It can be seen that the preload is to compensate the settlement during the preloading period (light shaded area), which is estimated to be more than 1 m, and traffic load (grey shaded area). The embankment also needs to be widened by additional 6 m during the preload period. The original embankment requires 371.25 m$^3$ of compacted fill per meter run, assuming no compensation is required for settlement. For the preloading scheme, 505 m$^3$, or an additional 35% of compacted fill is required.

![Figure 2. Schematic diagram of the embankment](image1)

![Figure 3. Traditional Preloading scheme](image2)
The extra time required to compact the preload, releveling after the completion of preload and dumping the extra soil translates to a lot of additional cost and time. Moreover, to maintain a FoS of 1.35, the fill cannot be built to quickly to allow the soft clay layer to consolidate and gain strength. Prefabricated vertical drains can be installed to quicken the consolidation process.

3.4. Solution incorporating geofoam

As stated previously, unless the geofoam is anchored, geofoam cannot be submerged underwater. As the flood level is at 2 m, the compacted fill is still required up to 3 m height. Additional 1 m added as a precaution. This solution follows the construction procedure shown in Figure 3.

First, to allow quick construction of embankment, ground reinforcement is required. For this case, geocell is chosen. 0.4 m of existing soil is removed and replaced by geocell filled with aggregates (Figure 6). Next, the embankment is constructed to 5.5 m height (Figure 4a). After 6 months of consolidation, the embankment is cut to 3 m elevation (Figure 4b). The cut fill can be kept aside to be used as cover/landscaping soil for the geofoam. When releveling is complete, geofoam blocks can be stacked to 6.6 m elevation (Figure 4c). The geofoam supplier for this project has a moulding block of 4 m x 1 m x 0.6 m (length x width x height). Therefore, six stacks of geofoam are required for 3.6 m height. The geofoam is then covered with geomembrane and cover soil (Figure 4d). The cover soil not
only serves as protection for the geomembrane and geofoam, but also as a medium for vegetation to grow on. Finally, the pavement can be built to the design level of 7.5 m (Figure 4e).

With this solution, by using 145.8 m$^3$ of geofoam, the compacted fill required is reduced to 294.25 m$^3$ per meter run, 42% reduction when compared to the traditional preloading solution. Although 145.8 m$^3$ of geofoam is still more expensive than 294.25 m$^3$ of compacted fill, the significant reduction in construction time and cost makes geofoam a feasible solution. In environmental point of view, the saving of construction time and the absence of heavy machinery leads to lower carbon footprint in the construction of this road.

3.5. Numerical analysis

Numerical analysis is carried out using PLAXIS 2D [7] To evaluate the performance of the solution incorporating geofoam. Figure 6 shows the mesh used for the numerical analysis. The geometry of the embankment and soil layering follows the schematic diagram shown in Figure 2. The soil parameters are listed in Table 2, and are modelled with Mohr-Coulomb. As stated in Section 3.4, geocell is used as reinforcement. The geofoam used is EPS19. The parameters and constitutive model used for compacted fill, geocell and geofoam are given in Table 3. Slight simplification was used when modelling the geofoam layers. The geofoam geometry follows that of the embankment (Figure 1) instead of block stacking in Figure 4. This simplification does not alter the results significantly.

The modelling procedure follows the scheme written in Section 3.4. The procedure is as follows:
1. Install geocell layers at elevation 0.0 m to -0.4 m
2. Build embankment to 2.0 m height (10 days)
3. Build embankment to 4.0 m height (10 days)
4. Build embankment to 5.5 m height (10 days)
5. Consolidate for six months (180 days)
6. Excavate 2.0 m of the embankment (10 days)
7. Build embankment using geofoam to 7.0 m height (10 days)
8. Install pavement to design level of 7.5 m height (10 days)
9. Traffic operation for ten years (3650 days)

Factor of safety analysis follows each construction step, except for installation of geocell layers.

![Mesh for embankment model]

**Figure 6.** Mesh for embankment model

| Soil Type   | Constitutive model | \( \gamma \) (kN/m³) | \( E' \) (kPa) | \( v' \) | \( c' \) (kPa) | \( \phi' \) | \( \psi' \) | \( k \) (m/sec) |
|-------------|--------------------|----------------------|----------------|--------|---------------|--------|----------|-------------|
| Compacted fill | Mohr Coulomb       | 18.0                 | 20000         | 0.3    | 10            | 35     | 0        | \( 1 \times 10^{-3} \) |
| Geocell      | Mohr Coulomb       | 20.0                 | 200000        | 0.3    | 35            | 40     | 0        | \( 1 \times 10^{-3} \) |
| Geofoam      | Linear Elastic     | 0.2                  | 4000          | 0.15   | -             | -      | Non-porous |

3.6. Numerical results

The output of the numerical results include settlement and factor of safety (FoS) at all stages. Figure 7 shows the numerical results for vertical displacement at stage 8 and 9, i.e. after completion of pavement and after ten years of traffic operation respectively. From the figure, it is known that the embankment has settled by 46 cm when the pavement is completed. After 10 years of traffic operation, the embankment settled a further 9 cm, making a total settlement of 55 cm. Therefore the design meets the requirement of limiting settlement up to 10 cm in ten years of traffic operation.

The results are summarized in Table 4. The duration and settlement for each stage are given along with the total duration and total settlement for ease of interpretation. As can be seen from the table, FoS above 1.35 are maintained throughout the construction stages. The embankment settle half a meter due to the preloading of 5.5 m embankment. When the preload is removed, 0.12 m heave occurs. When the geofoam is placed, slight heave still occurs as there is still negative excess pore water pressure from the unloading. Installation of pavement induced a 0.04 m settlement, and finally ten years of traffic operation induced a further 0.09 m settlement.
Figure 7. Vertical deformation after: (a) completion of pavement; (b) 10 years of traffic operation
Table 4. Numerical results.

| Construction Phase        | Duration Days | Total duration Days | Settlement m | Total settlement m | FoS |
|---------------------------|---------------|---------------------|--------------|--------------------|-----|
| Install Geocell           | -             | -                   | -            | -                  | -   |
| Embankment to 2.0 m       | 10            | 10                  | 0.09         | 0.09               | 2.9 |
| Embankment to 4.0 m       | 10            | 20                  | 0.10         | 0.19               | 2.0 |
| Embankment to 5.5 m       | 10            | 30                  | 0.18         | 0.37               | 1.5 |
| Consolidate 6 months      | 180           | 210                 | 0.22         | 0.55               | 1.7 |
| Excavate 2.0 m            | 10            | 220                 | -0.12        | 0.43               | 2.5 |
| Geofoam to 7.0 m          | 10            | 230                 | -0.01        | 0.42               | 2.5 |
| Pavement to 7.5 m         | 10            | 240                 | 0.04         | 0.46               | 2.6 |
| Traffic load              | 3650          | 3900                | 0.09         | 0.55               | 2.3 |

4. Conclusions and discussion

The above analysis based on real soil conditions in Indonesia shows the effectiveness of using geofoam to improve road performance under traffic conditions. Geofoam usage significantly reduces the compacted fill required also saving the construction time and cost (5.5 m versus 10 m embankment). By reducing the compacted fill required, less quarry is required, leading to less destruction of native soils. The backhoe to excavate and trucks to transport the soil from the native location to project site can be removed. Backhoe, tractors and rollers used for soil compaction can also be removed. The energy savings is much more significant when compared to the energy required for the production of geofoam. This means that geofoam is an environmentally more friendly solution when compared to traditional preload. Although the construction cost using geofoam may still be higher than conventional preload, the significant reduction in construction time makes geofoam worth considering. Hopefully this paper shed some light to the benefits of geofoam in road construction.

5. References

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