STUDY ON APPLICATION OF MUNICIPAL SOLID BOTTOM ASH REPLACING SAND CUSHION BELOW STRIP FOUNDATIONS ON WEAK GROUND

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Abstract

So far, several publications on physical and mechanical properties of solid bottom ash have been reported, in which proposals on utilizing the bottom ash to produce lightweight concrete, backfill materials behind retaining walls, asphalt concrete additives and road embankment materials are also pointed out. In this study, series of laboratory experiments were carried out to determine the mechanical properties of the municipal solid bottom ash collected from Thanh Quang - Dan Phuong - Hanoi. Based on the results of the experiments, FEM analyses of a strip foundation on the bottom ash cushion which partially replaces the underlying soft soil layer were conducted. It is derived from the numerical results that the bottom ash could be used to replace the sand cushion in reinforcing of weak ground below foundation.

Keywords: *Municipal solid bottom ash; internal friction angle; apparent cohesion; finite element method; Mohr-Coulomb model.*

1. Introduction

The population of Vietnam has reached 97.58 million people by December 2020 according to statistics, equivalent to about 45,000 to 50,000 tons of waste per day. About 60% of the amount of waste is collected and treated by forms of landfilling, composting and burning. However, the effectiveness of waste fertilizer is not as obvious and rapid as chemical fertilizer, so it is not popular in the market. For the old landfills, harmful effects on the surrounding environment and community are inevitable due to the lack of bottom waterproof lining as well as the lack of collection and treatment system for waste gas and water. For the newly hi-tech landfill plants with the inclusion of collection and treatment systems for waste gas and water, the investment and the operating costs are also expensive.

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Garbage incineration is a chemical reaction in which carbon, hydrogen and other elements in the garbage combine with oxygen to form a number of completely oxidized and thermogenic products. The amount of fly and bottom ash obtained in the burning process ranges from 15-25%. The benefits of waste treatment with incineration technology are to reduce the volume of landfill waste, to generate energy for electricity production and to reduce garbage water and landfill gas. The disadvantages of incineration are as follows: expensive investment and maintenance costs; requiring high calorific waste, causing a secondary impact on the surrounding environment due to waste gas and ash after burning.

In European countries such as the Netherlands, Denmark more than 90% of the bottom ash from waste treatment plants is recycled, mainly in backfill applications, while France, Germany, UK, Spain, Sweden, and other countries are also making efforts to utilize bottom ash as a construction material in manufacturing lightweight concrete, backfilling behind retaining walls, manufacturing asphalt concrete, road embankment [5].

In Vietnam, apart from a few waste incineration plants for electricity generation are in operation, such as the waste treatment plant of Thanh Quang Investment Joint Stock Company in Phuong Dinh, Dan Phuong, Hanoi; waste treatment plant in Quynh Coi, Quynh Phu, Thai Binh or some waste power plants in Ha Nam, Can Tho, Quang Binh, many localities following this trend also have invested in electric waste incinerator such as: Vinh Tan garbage power plant project, Dong Nai province (capacity of 600 tons/day, generating capacity of 30 MW); Soc Son Waste Power Plant, Hanoi (capacity of 4,000 tons/day, generating capacity of 75 MW); waste treatment plant generating electricity in Tram Than, Phu Ninh, Phu Tho province (capacity 500 tons/day); 2 incineration plants for electricity generation in Cu Chi, Ho Chi Minh City (Vietstar and Tam Sinh Nghia, with a capacity of 1,000 tons/day for each).

Currently, bottom ash from waste incinerators in Vietnam can be utilized in many fields such as: used in the material industry as an additive for cement; additive for concrete; unburnt bricks; used in agricultural land reclamation; used in rehabilitation and restoration of limestone mines.

In the study, laboratory experiments on the bottom ash collected from Dan Phuong - Hanoi were carried out to investigate the physical and mechanical properties of the ash. Based on the results of the experiments, FEM analyses of a strip foundation on the bottom ash cushion were conducted to evaluate the application of the bottom ash in reinforcing weak soil below shallow foundation.

2. Experimental study

2.1. Brief description on bottom ash

According to [1], the content of Fe_2O_3, CaO and MgO in bottom ash in Vietnam is higher than that in China and America. It is explained that the garbage classification in Vietnam is not suitable and a lot of inorganic components are contained in the garbage. The content of hazardous substances according to analysis results, however, is still below the limit of QCVN 07:2009/BTNMT (National technical regulation on the limit of hazardous waste), so it is not harmful to the environment.

The bottom ash (total weight of about 40 kilograms) collected from Thanh Quang waste incineration in Dan Phuong district, Hanoi city was used in the experiments. Figure 1 shows the picture of the bottom ash.

Figure 1. Bottom ash was used in the study

2.2. Outline of experiments and results

A series of laboratory tests including sieve tests, soil particle determination tests, optimum water content tests, direct shear tests and oedometer tests were carried out on the bottom ash to investigate the physical and mechanical characteristics of the ash.

Figure 2 shows the results of the sieve tests. It is seen that the results of the samples are similar to each other indicating the consistency of all the samples used in the experiments.

To determine the optimum water content, the Proctor compacting tests with different water contents W = 15%; 20%; 25% and 30% were conducted. Figure 3 shows the testing devices used for the compacting tests. The results of tests for the optimum water content tests are presented in Table 1 and Figure 4.

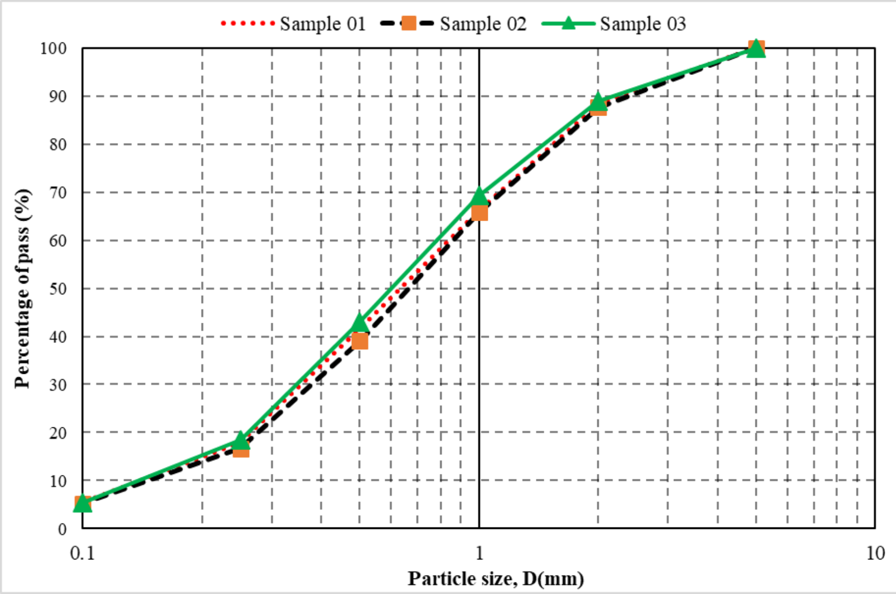

Figure 2. Soil particle distribution

Figure 3. Testing devices for Proctor compacting tests

Table 1. Results of the optimum water content tests

Sample	W (%)	m_{ash} (g)	$V_{mount}(cm^3)$	$\rho_w(g/cm^3)$	$\rho_k(g/cm^3)$
1	15	1445.5	956.04	1.512	1.315
2	20	1591.5	956.04	1.664	1.387
3	25	1685.0	956.04	1.762	1.410
4	30	1717.0	956.04	1.796	1.382

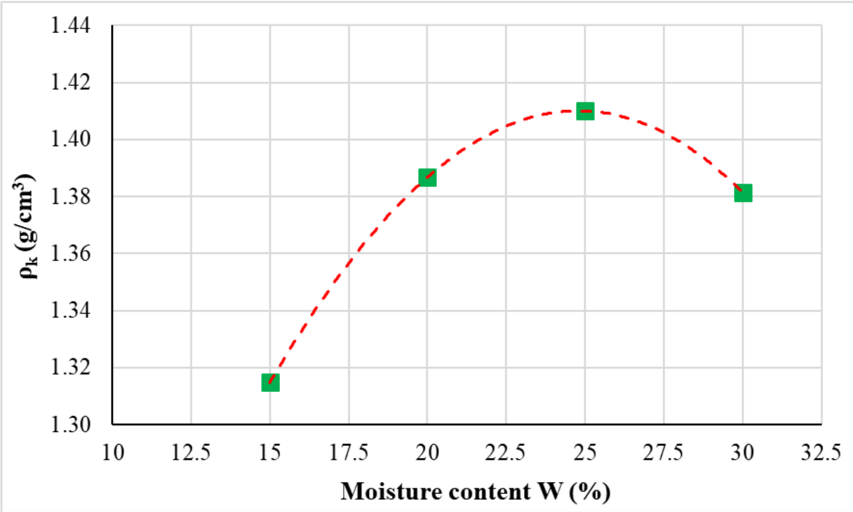

Figure 4. The relationship between dry density and water content

It is indicated from Figure 4 that the maximum dry density, ρ_k^{max} = 1.410 g/cm^3, is obtained at the water content W_{otp} = 25% (the aggregate with D_{max} = 5 mm). Tuan et al. [2] carried out similar tests with the same bottom ash but larger aggregate (having D_{max} = 100 mm) and determined γ_k^{max} = 1.60 g/cm^3 corresponding to the optimum water content W_{otp} = 22.8%. Hence, the maximum dry density and the optimum water content are dependent on the aggregate of the bottom ash.

A series of direct shear tests and oedometer tests were conducted on the bottom ash having the compacting ratios K = 0.90 and K = 0.95 to determine the strength and deformation characteristics.

Figures 5 and 6 show the relationship between shear force and horizontal displacement in the direct shear tests of the bottom ash with K = 0.90 and K = 0.95, respectively.

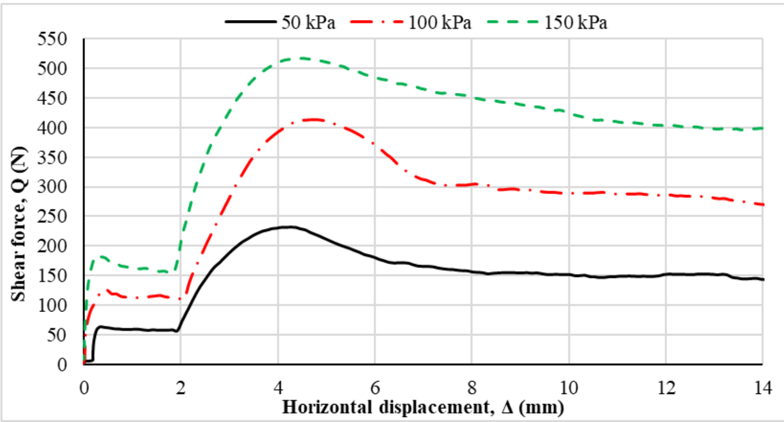

Figure 5. The relationship between shear force and horizontal displacement, K = 0.90

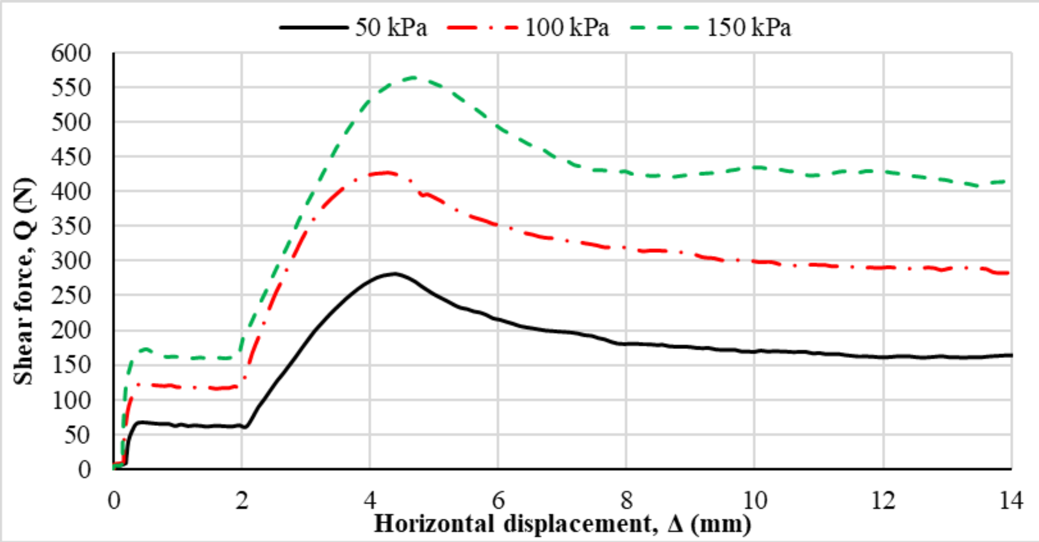

Figure 6. The relationship between shear force and horizontal displacement, K = 0.95

It is indicated from Figures 5 and 6 that the post-peak softening behaviour of the bottom ash is obtained and the peak of the curves occurs when the horizontal displacement varied from 4 to 5 mm.

Figure 7 shows the relationship between void ratio and normal stress in the oedometer tests for the cases of K = 0.9 and K = 0.95.

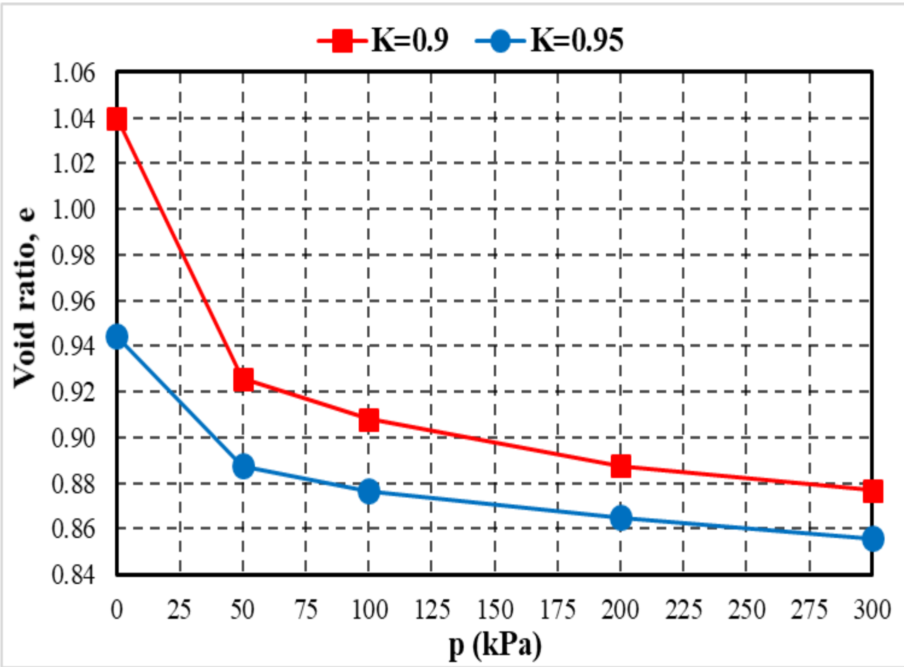

Figure 7. Variation of void ratio with compression stress for for K = 0.9 and K = 0.95

Table 2. Results of direct shear tests and oedometer tests

Results of this study				**Results of other studies**			
K	Apparent cohesion, *c* (kPa)	Internal friction angle *φ* (degree)	Young's modulus *E* (kPa)	References	Apparent cohesion, *c* (kPa)	Internal friction angle *φ* (degree)	Young's modulus *E* (kPa)
0.90	32.37	41.94	7539	C.Wiles [5]	14÷34	24÷50	
0.95	45.10	41.68	13054	D. Lentz [6]	0	38÷55	
				P. Cosentino [7]			3500÷35000

The results of the direct shear tests and oedometer tests are summarised in Table 2. It is derived from the results in Table 2 that:

- The shear characteristics of bottom ash include not only the friction angle, *φ*, as normal granular soils but also the cohesion force, *c*, (called apparent cohesion). The value of the internal friction angle, *φ*, of the bottom ash used in this study ranges from 41.68 degrees to 41.94 degrees. The cohesion, c, ranges from 32.37 kPa to 45.10 kPa. Observing the ash sample collected from the Waste Treatment Plant in Dan Phuong, Hanoi, it is seen that the ash particles have a porous structure due to the evaporation of pore water during the high temperature incineration process. It is also recognized that the particles of the bottom ash are in angular shapes. When increasing the compacting ratio, the bottom ash particles get closer together, leading to the increase of the internal friction angle and the increase of the apparent cohesion, also. Figures 8 and 9 [9, 10] clearly show the porous structure and the angular shapes of the bottom ash particles.

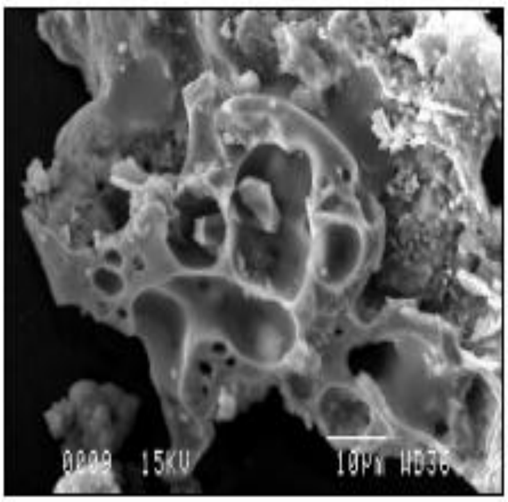

Figure 8. The porous structure [8]

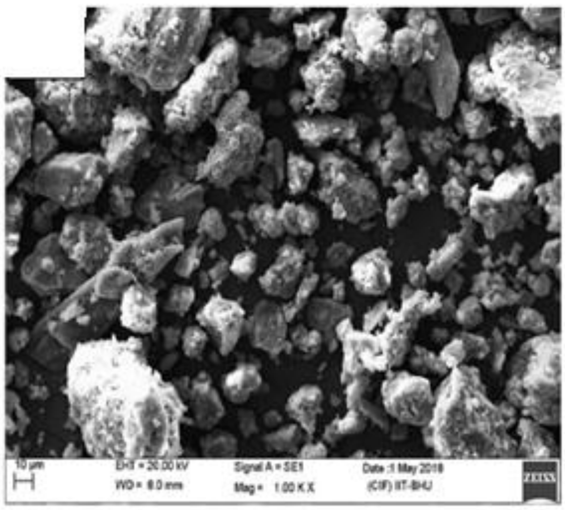

Figure 9. The angular shapes [9]

- Young's modulus of the bottom ash increases with the increase of the compacting ratio and varies in the range from 7539 kPa to 13054 kPa. The Young's modulus of the bottom ash is much lower than that of sandy soils (according to TCVN 9362:2012, E_s = 28000÷50000 kPa). However, this value range is in agreement with the research by Cosentino et al. [7]. The small Young's modulus of the ash could be caused by the porous structure and crushable particles, leading to large settlement under compressive load.

3. Numerical analysis on a strip foundation reinforced by bottom ash cushion

The experimental results indicate that the shear strength of the bottom ash is larger than sand materials. Hence, it is proposed to use the bottom ash as a cushion replacing sand materials to reinforce weak ground below a strip foundation. Figures 10 and 11 present the applications of the cushions in construction.

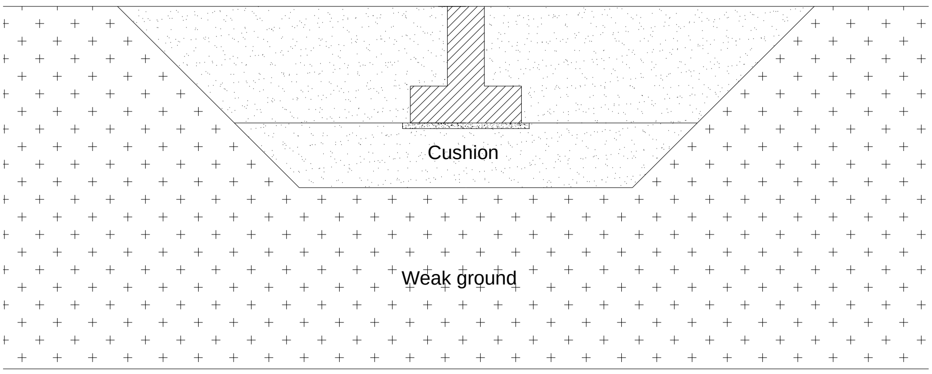

Figure 10. Bottom ash cushion in building foundation

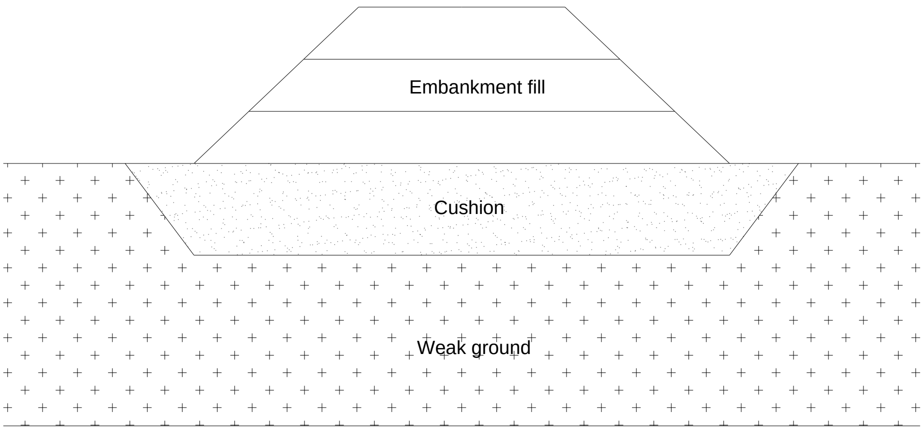

Figure 11. Bottom ash cushion in road embankment

In this section, Plaxis 2D software was used to model strip foundations having the width b = 1 m and depth h_m = 2 m (standard foundation size according to TCVN 9362:2012) which was placed directly on soft ground or the artificial cushion made of sand or bottom ash. The thickness of the cushion, h_d, was changed from 1.5 m to 3 m.

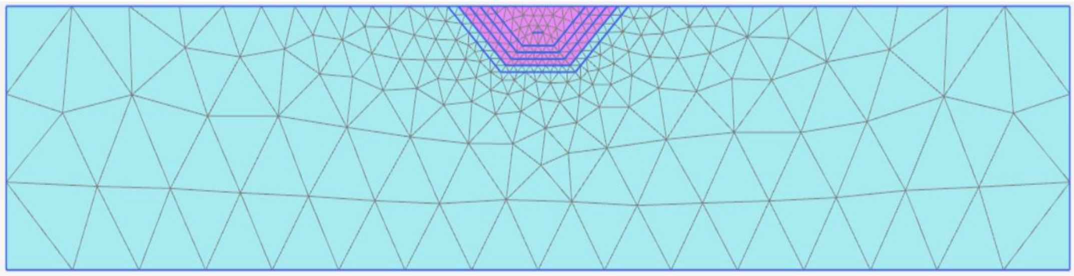

Figure 12. The model on Plaxis 2D with meshing grids and soil layer corresponding to reinforce strip foundations in weak ground

Displacement control method was used in the analyses for loading. Table 3 shows the properties of the soils in the numerical study.

Table 3. Properties of the soils

Type	Unit weight, γ (kN/m^3)	Cohesion, c (kPa)	Internal friction angle, φ (degree)	Young's modulus, E (kPa)	Soil model
Weak soil	16.0	15.00	10	4000	Mohr-Coulomb
Sand	18.5	1.00	30	30000	Mohr-Coulomb
Bottom ash K = 0.9	15.9	32.37	41.94	7556	Mohr-Coulomb
Bottom ash K = 0.95	16.7	45.10	41.68	13054	Mohr-Coulomb

Figures 13 to 16 show the relationship between compressive pressure and settlement of the foundation corresponding to different thickness values of the bottom ash cushion.

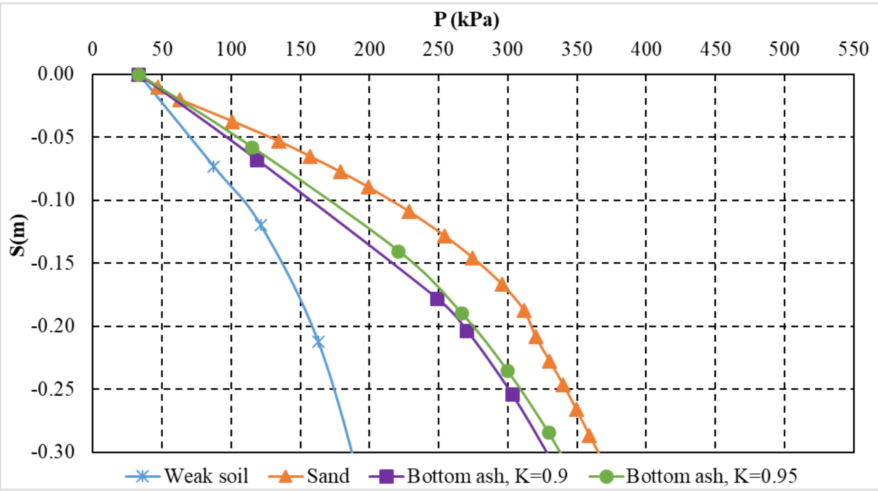

Figure 13. Relationship between pressure and settlement, in the case $h_d = 1.5$ m

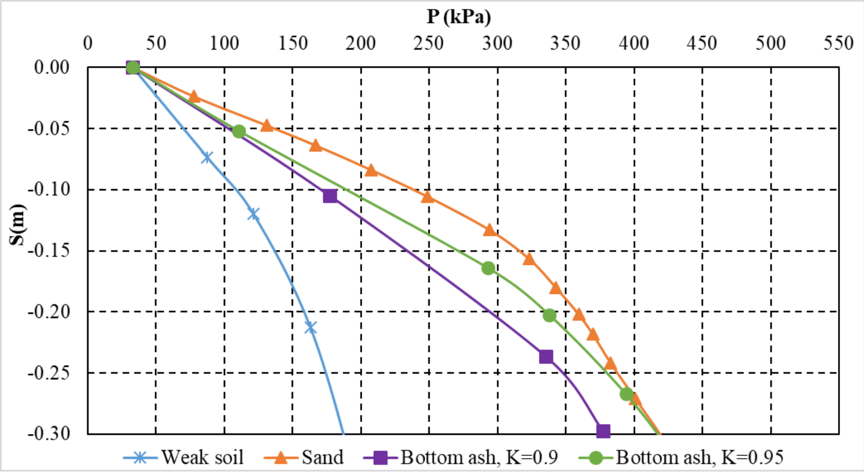

Figure 14. Relationship between pressure and settlement, in the case $h_d = 2$ m

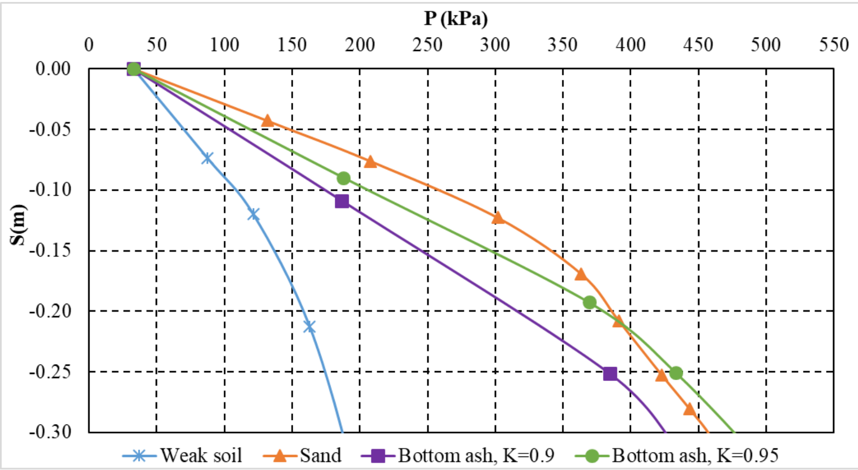

Figure 15. Relationship between pressure and settlement, in the case $h_d = 2.5$ m

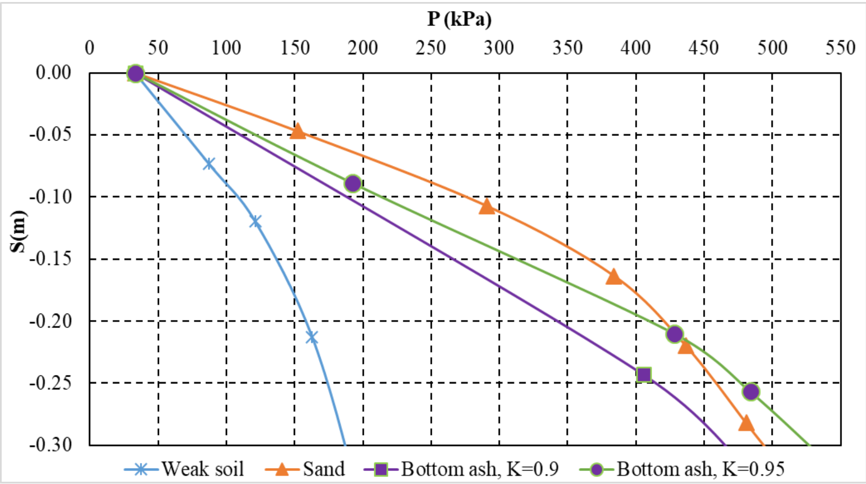

Figure 16. Relationship between pressure and settlement, in the case $h_d = 3$ m

It is indicated from the results in Figures 13 to 16 that the bearing capacity of the strip foundation placed onto the bottom ash cushion is significantly larger than that of the foundation directly placed onto the weak ground. Also, the bearing capacity increases with the increase of compacting ratio of the bottom ash layer.

- As for civil engineering works, the allowable settlement is 8 cm. In the settlement range, the deformation modulus of sand is greater than that of the bottom ash, so the resistance of the foundation on the sand cushion is larger than that of the foundation on the bottom ash cushion.

Table 4. Standard pressure of strip foundation on artificial cushion R_0 (kPa)

Thickness of cushion	Bottom ash, K = 0.9	Bottom ash, K = 0.95	Sand	Directly placed on weak ground
1.5	137	155	191	95
2.0	143	157	207	95
2.5	144	170	220	95
3.0	150	173	240	95

- For transportation engineering works according to 22TCN 262:2000 [4] on the design of embankment on soft soil, the remaining settlement after the completion of works should be controlled. The rest of the remaining subsidence restriction only relates to the rapid increase in the settlement of the roadbed (absorbent wick, sand wells,...). In the region of high settlement, the load-bearing strength of the foundation on the ash-slag bed increases very rapidly with the thickness of the buffer layer and is higher than that of the sand-cushion reinforced foundation. Therefore, the authors propose, when designing the roadbed on soft soil, it is possible to use a bed of ash, slag from domestic use with a thickness of 2÷3 meters and the compacting ratios K = 0.9÷0.95.

4. Conclusions

- The shear characteristics of bottom ash include not only the friction angle, φ, as normal granular soils but also apparent cohesion, c. The value of the internal friction angle, φ, of the bottom ash used in this study ranges from 41.68 degrees to 41.94 degrees. The cohesion, c, ranges from 32.37 kPa to 45.10 kPa.

- Young's modulus of the bottom ash increases with the increase of the compacting ratio and varies in the range from 7539 kPa to 13054 kPa.

- The shear strength of the bottom ash is larger than that of sand due to its angular particles. Meanwhile, the deformation modulus is smaller than that of the sand because of the porous structures of the bottom ash.

- The bottom ash could be used to replace the sand cushion in reinforcing weak ground below the foundation.

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NGHIÊN CỨU SỬ DỤNG TRO XỈ TỪ LÒ ĐỐT CHẤT THẢI SINH HOẠT THAY THẾ LỚP ĐỆM CÁT GIA CỐ NỀN CHO MÓNG BĂNG

Tóm tắt: *Hiện nay, trên thế giới đã có nhiều công bố đưa ra đặc trưng cơ lý của tro xỉ rác thải sinh hoạt và đề xuất hướng ứng dụng làm bê tông nhẹ, vật liệu đắp sau lưng tường chắn, phụ gia sản xuất bê tông atphan và vật liệu đắp nền đường. Trong nghiên cứu này, các tác giả tiến hành thí nghiệm xác định các đặc trưng cơ lý của tro xỉ rác thải sinh hoạt ở Thành Quang - Đan Phượng - Hà Nội. Trên cơ sở kết quả thu được từ thực nghiệm, sử dụng phương pháp FEM để mô hình hóa móng băng trên nền đệm tro xỉ để thay thế một phần lớp đất yếu ở bên dưới. Kết quả mô hình hóa khẳng định khả năng ứng dụng của loại vật liệu này để thay thế lớp đệm cát gia cố nền cho móng băng.*

Từ khoá: Tro đáy rác thải sinh hoạt; góc ma sát trong; lực dính đơn vị; phương pháp phần tử hữu hạn; mô hình Mohr-Coulomb.

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