

Influence factors for using hydraulic binders for soil stabilisation of fine-grained soils in cold environment

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Abstract. The stabilization of soft soils with hydraulic binder is a common technique all over the world. By means of stabilization the engineering properties of fine-grained soils can be improved, where settlements or stability problems have to be handled. Lime and cement are usual binders. The use of industrial by-products as binders has been investigated and some are already established on the market in combination with cement, as e.g. fly ash or slag. Nowadays the reduction of CO_2 is in focus, leading to a search for more by-products from the industry that are suitable to use as hydraulic binder. One of these is cement kiln dust (CKD) that is started to be used commercially as a binder in combination with cement.

Fine-grained soils are often frost susceptible i.e. they show frost heave and/or thaw weakening. These typical problems are handled by improvement with hydraulic binder in countries with moderate climate [33]. In countries with cold climate, near surface soil stabilization with hydraulic binder is less used. One reason for this reduced usage are uncertainties about the influence of low temperature on the expected stabilizing effects of the hydraulic binder. Previous research has shown that the strength of the stabilized material is decreased by frost impact, when compared to without frost. New research results have shown a recovering of the strength after a reduction due to frost [1; 2].

In the present contribution, a multiple linear regression analysis is presented for identifying significant influencing factors for soil stabilization of fine-grained subgrade with hydraulic binders in cold environment. The regression analysis is based on the results from three earlier published laboratory studies [3–5], where the unconfined compressive strength (UCS) was used as a measure of strength. The laboratory studies involved different soil types, different binders (mainly by-products), and varying binder contents.

The results from the laboratory studies show that the strength increases during curing in cold environment. After twelve freeze-thaw-cycles the strength is reduced for several samples, compared to without freeze-thaw-cycles, but it is higher than without stabilization. A recovering of strength after a subsequent curing time after the freeze-thaw-cycles is visible in some cases for the stabilized samples. The multiple linear regression analysis presented here shows the influence of the binder content, as well as the freeze-thaw-cycles and the curing time, on the strength.

1. Introduction

Fine-grained soils are often a challenge for the needs of infrastructure because of their low bearing capacity as well as their high frost susceptibility. The stabilising effect of lime or cement, so-called "hydraulic binder", is commonly used to improve the engineering properties of such soils. The binder reacts with water and forms new minerals. These new minerals improve the properties of the soil by connecting the soil particles together [6–10].

The reactions of the binder with the soil are influenced by several factors, mainly the amount and type of binder, the type and mineral composition of the soil, the water content, the homogenisation of the soil-binder-mixture, time, and temperature [11]. The reactions of lime and cement are comparable in their effect on the soil properties and consist of the following: (i) the initial exotherm reaction with the water, (ii) the pozzolanic reaction, and (iii) the ion exchange [8; 12; 13]: The heat released by the initial reaction with water can be beneficial in the short run if the soil need to be dried to get stiffer. This drying is reversible, but depending on the hydraulic conductivity of the soil, it takes some time for the soil to get weak again. The pozzolanic reaction forms the new minerals over time: lime has a slower reaction that continues longterm (years) compared to cement, which reaches the final strength within months. In soils with clay minerals, ion exchange can take place between the binder and the clay and change its behaviour to stiffer. The ion exchange builds connections between the layers of the clay minerals on atomic level.

By-products from the industry are more and more common to be used as binder for soil stabilisation. They have shown a similar strength-raising effect as lime and/or cement, especially in combination with them [14–16], and save the environment at the same time by reducing the needs for landfill and new binder (the production of cement and lime is highly energy-consuming). The new European standard for Earthworks [17] includes lime and cement but also fly ash and granulated blast furnace slag as well as mixtures of those, so called hydraulic road binders.

In regions with cold climate and seasonal frost, frost heave and thaw weakening are typical challenges for road constructions on fine-grained soils [4; 18; 19]. When a soil is classified as high or very high frost susceptible, the soil has to be replaced or improved to be allowed to remain under a planned construction (road, parking area, etc.) [5]. Some countries allow soil improvement by stabilisation with hydraulic binders as a permanent solution in the part of the soil that is reached by frost action [20], but other countries are doubtful since the frost susceptibility of the improved soil is not easy to determine [21].

So the usability of near-surface soil stabilisation in regions with seasonal frost is dependent on the changes of their behaviour caused by frost impact. The influence of frost on soft soils stabilised with hydraulic binders has been investigated both for cement [1; 22–24] as well as for lime [2; 25; 26], for a combination of cement and lime [27–31] and for some alternative materials alone [14; 32]. The strength after freezing and thawing is decreased but still several times higher than the one of the untreated material. The curing temperature in the above named research has mostly been room temperature or is not mentioned in the publications. Two recent publications [1; 2] show a healing potential or recovering of the UCS values at a certain time after freeze-thaw for cement-stabilised silty sand as well as for lime-stabilised clay.

2. Previous studies

Three different laboratory studies were conducted to investigate the influence of a low curing temperature on the strength increase of soil stabilised with hydraulic binder [3–5]. Further aspects to investigate were how much the strength is reduced after twelve freeze-thaw-cycles and if the strength can recover within 28 days of curing after the last thawing. The hydraulic binders used in the investigations were Petrit T, a by-product from sponge iron production that is not commercially used for soil stabilisation yet, and MultiCem, a binder that is commercially used for soil stabilisation and consists of 50 % cement and 50 % cement kiln dust. The studies contained three different fine-grained soils: a postglacial clay, a silty sand and a silt. Petrit T was used as binder for the two more fine-grained soils, clay and silt; Multicem was used for the silty sand. The binder content was chosen according to the German recommendations for soil improvement [33]: 4% and 7% for the Petrit T with the clay and the silt as well as 6% and 8% for the MultiCem.

The curing temperature was +4°C to represent curing conditions in northern Sweden. The

samples were cured for 14, 28 or 90 days before twelve freeze-thaw-cycles as well as for 28 days after the last thawing. The unconfined compressive strength (UCS) was measured at the end of the respective test time. Three individually samples were tested per binder content and respective test schedule, they were produced from the same blend at the same time: 81 samples for the clay and the silty sand, respectively, as well as 54 samples for the silt - 216 samples in total. The details of the study of the clay with the Petrit T are described in [3], those of the silt with the Petrit T in [4] and those of the silty sand with MultiCem in [5].

All three laboratory studies show that the UCS values of the tested samples increase in the given cold environment. The samples of clay with Petrit T show UCS values of at most 100 - 300 kPa, the silt samples with Petrit T 130 kPa and the silty sand samples with MultiCem 3000 - 4000 kPa. These values are reached after 28 days of curing for the samples with Petrit T and after 90 days of curing for the samples with MultiCem, respectively.

The UCS values are reduced to about one-third after the freeze-thaw-cycles in the case of the clay samples with Petrit T. The study of the silt samples with Petrit T shows also a strength reduction of the UCS values after the freeze-thaw-cycles, the reduction varies between one-third and two-third. The silty sand samples with MultiCem show reduced UCS values after the freeze-thaw-cycles only for the samples with lower binder content after 90 days of curing.

An increase in UCS after the recovering time is visible for the younger samples (14 and 28 days of curing before the freeze-thaw-cycles), and in the case of the clay with Petrit T also for the 90-days-samples. The other samples show no further changes after the recovering time. Instead, the 90-days-samples with MultiCem show UCS about half of the value before the freeze-thaw-cycles.

The results of the samples of clay with Petrit T show a high influence of the water content. As this clay used in this study had the largest spreading of the water content, the binder content was added for three ranges of water content (28 - 33 %, 34 - 39 % and 40 - 45 %). In addition, the results of the samples of clay and silt with Petrit T seem to be influenced by a complex binder reaction in cold environment: slow strength increase and a lower total strength after a longer curing time. This is caused by a process called 'conversion' and is described in the previous publications [3; 4].

The results of the samples of silty sand with MultiCem as well as of the clay with Petrit T show a sort of remaining strength at the end of the test series. The UCS values seem to be the same for the same amount of binder after the freeze-thaw-cycles and the recovering time. The time of curing before the freeze-thaw-cycles seem to be less important for the strength at the end of the test series.

3. Regression analysis

3.1. Goals

A multiple linear regression analysis is a method to evaluate data with several input variables and one output variable. The linear regression analysis examines linear relations between metric data consisting of values of one dependent variable (also called response variable or measurement) and of one or more independent variables (also known as explanatory variables or predictors) [34]. The multiple linear regression analysis presented here is conducted on the data that is generated by the combination of the three previous studies [3-5]. Since the test setup of the laboratory analysis is similar, the comparability of the data is assured. The significance of the tested four influencing factors in the studies is analysed. The significance is later compared with the interpretation of the results from the previous studies. Additionally, the influence of the water content is studied, because the water content changes the behaviour of natural fine-grained soil significantly. The water content was measured for all samples. It was needed for the determination of the amount of binder to be added (given in % of dry mass) but not chosen beforehand as a variable in the test setup.

3.2. Preparing the data

The data from the three different laboratory studies are summarized in individual matrices. Each matrix contains the unconfined compressive strength (UCS) as output variable as well as the input variables from the test setup: binder content (Bc), days of curing (db), freeze-thaw-cycles (ft), days of curing after freeze-thaw-cycles (da). The water content (w) at the time of the UCS test is added to the respective matrices as an input variable for the regression analysis as well. The UCS range differs several decades for the different soil-binder-combinations. To be able to compare the data in terms of significance, the data needs to be normalized. This means that the data range of the UCS for each matrix is converted into a range between zero and one for each soil-binder-combination separately. The data is normalized in the following way: the maximum UCS is set to “1” and the minimum to “0”. The UCS values in between are set to a value below one, corresponding to the percentage of the respective value in relation to the difference between the maximum and the minimum value, according to the following formula:

$$output_{norm} = (output - output_{min}) / (output_{max} - output_{min}) \quad (1)$$

The input variables were normalized in a similar way.

A correlation indicates the strength and direction of a linear relationship between two random variables. The coefficient of correlation is tested for the UCS and all individual input variables (Bc , db , ft , da). If a correlation is found between the respective input variables, they cannot be seen as independent of each other. However, correlation of independent variables leads to multicollinearity and jeopardises the regression analysis model. In this case a threshold of 0.7 was chosen, i. e. independent variables were only chosen if their correlation coefficient with any of the other independent variables was below 0.7.

3.3. Results of the multiple linear regression analysis

The regression analysis is conducted for the three different laboratory studies individually including the binder content “zero”, i. e. the soil without binder. The outcome of a multiple linear regression analysis is an equation that describes the dependent variable as a linear function of the independent variables with their respective coefficients (b-values). For the data used in the present contribution, this model can be used to estimate the UCS being calculated with the different influencing factors meaning binder content (Bc), curing time in days before freezing (da), presence of freeze-thaw (ft), curing time in days after freeze-thaw cycles (da) and the water content (w):

$$UCS_{norm} = b_0 + b_1 * Bc_{norm} + b_2 * db_{norm} + b_3 * ft_{norm} + b_4 * da_{norm} + b_5 * w_{norm} \quad (2)$$

The coefficients can be positive or negative, depending on the direction of influence of the respective input variable on the output variable. In the test setup presented here, the binder content (Bc), the days of curing before (db) and the days of curing after the freeze-thaw-cycles (da) are expected to have a rising effect on the UCS, that means the b-values of these independent variables are expected to be positive. The freeze-thaw-cycles (ft) and the water content (w) are expected to have a lowering effect on the UCS, which means the b-values of these independent variables are expected to be negative. The higher the absolute b-value of the respective independent variable, the higher the influence of this variable on the UCS.

The b-interval gives the lower and upper confidence bounds for coefficient estimates, which describes the uncertainty of the coefficient (b-value). If the b-interval reaches from a negative to a positive value, the direction of the influence is unclear.

The p-value presents the probability for the null-hypothesis being able to be rejected. The threshold usually is 5%. So if the p-value is below 5% it can be assumed that the null-hypothesis (no correlation existing) can be rejected (i. e. correlation exists).

The R^2 value gives the percentage, how much of the output value that can be explained by the tested independent variable(s). When the R^2 value is close to 1, and the p-value is less than the default significance level of 0.05, a significant linear regression relationship exists between the response and the predictor variables.

Table 1 presents the results of the multiple linear regression analysis for the three different laboratory studies including the soil without binder. The table shows the b-values and b intervals for the combination of all independent variables on the UCS of the samples tested for the three different soil-binder-combinations, clay with Petrit T [3], silt with Petrit T [4] and silty sand with MultiCem [5].

Table 1. Coefficients with their confidence interval for the multiple linear regression analysis about the influence of the independent variables on the UCS of the tested samples for different soil-binder-combinations

Independent variable	Clay with Petrit T			Silt with Petrit T			Silty sand with MC		
	b_{low}	b	b_{high}	b_{low}	b	b_{high}	b_{low}	b	b_{high}
Binder content	0.17	0.23	0.29	0.38	0.45	0.53	0.45	0.52	0.58
Days of curing before FT	-0.07	-0.01	0.04	-0.24	-0.16	-0.07	0.08	0.14	0.20
Twelve Freeze-thaw-cycles	-0.28	-0.23	-0.18	-0.28	-0.19	-0.09	-0.05	0.02	0.09
Days of curing after FT	-0.03	0.02	0.08	-0.08	0.01	0.10	-0.09	-0.03	0.03
Water content	-0.47	-0.36	-0.25	-0.56	-0.37	-0.18	-0.33	-0.19	-0.06

The b-value with the highest absolute value for the results of the clay samples with Petrit T is -0.36 for the water content. For the results of the silt samples with Petrit T and the silty sand samples with MultiCem, the binder content has the highest b-value with 0.45 and 0.52, respectively (marked in bold in table 1).

The b-intervals show also some intervals with a negative lower and a positive upper value, as e.g. the days of curing before the freeze-thaw-cycles in the case of the results of the clay samples with Petrit T. So the direction of influence is not clear in these cases (marked in grey in table 1). Therefore, the regression analysis was performed stepwise adding one independent variable at a time. The binder content is supposed to be the main influence factor, so therefore the binder content is tested alone first. Then the binder content is tested in combination with one of the other independent variables, then a combination of the binder content with two of the other and finally the combination of all independent variables. Table 2 shows the R^2 -values for the different steps of this multiple linear regression analysis of the three different laboratory studies including the water content (w) at the time of the UCS test as well as the soil without binder. The other independent variables and their combinations listed in the first column are binder content (Bc), days of curing before the freeze-thaw-cycles (db), freeze-thaw-cycles (ft) and days of curing after the freeze-thaw-cycles (da).

The R^2 values for the results of the clay samples with Petrit T to the left reaches from 0.35 to 0.77, those for the silt samples with Petrit T (in the middle) are between 0.60 and 0.81 and the R^2 values for the results of the silty sand samples with MultiCem to the right are between 0.69 and 0.81. The p-values are all very small and far below 0.05.

The independent variables with an uncertain direction of influence in table 1 (marked in grey there) show also a small increase of the R^2 -values in table 2 (marked in grey there as well). The small increase in R^2 -values is another indicator that the influence of this independent variable is low. The independent variables with b-intervals with an uncertain direction of influence were therefore excluded from the analysis. The combinations of a few independent variables that show the same R^2 -value as the combination of all independent variables were investigated

Table 2. Results of the stepwise multiple linear regression analysis about the influence of the independent variables: binder content (Bc), days of curing before the freeze-thaw-cycles (db), freeze-thaw-cycles (ft) and days of curing after the freeze-thaw-cycles (da) on the UCS of the tested samples for different soil-binder-combinations

	Clay with Petrit T R^2	Silt with Petrit T R^2	Silty sand with MultiCem R^2
Bc	0.35	0.60	0.69
Bc & db	0.36	0.63	0.78
Bc & ft	0.63	0.71	0.69
Bc & da	0.40	0.61	0.70
Bc & w	0.52	0.66	0.75
Bc & db & ft	0.64	0.74	0.79
Bc & db & da	0.40	0.64	0.79
Bc & db & w	0.52	0.72	0.81
Bc & ft & da	0.64	0.71	0.70
Bc & ft & w	0.77	0.75	0.75
Bc & da & w	0.56	0.68	0.75
Bc & db & ft & da	0.64	0.74	0.79
Bc & db & ft & w	0.77	0.81	0.81
Bc & db & da & w	0.57	0.74	0.81
Bc & db & ft & da & w	0.77	0.81	0.81

Table 3. Detailed results of the multiple linear regression analysis for the combination of relevant independent variables (bold values in table 2) on the UCS of the tested samples

	Clay with Petrit T			Silt with Petrit T			Silty sand with MC		
	b_{low}	b	b_{high}	b_{low}	b	b_{high}	b_{low}	b	b_{high}
Binder content	0.17	0.23	0.28	0.38	0.45	0.53	0.45	0.52	0.58
Days of curing before FT	—	—	—	-0.24	-0.16	-0.07	0.09	0.14	0.20
12 Freeze-thaw-cycles	-0.26	-0.22	-0.17	-0.26	-0.18	-0.10	—	—	—
Water content	-0.47	-0.37	-0.26	-0.56	-0.37	-0.19	-0.31	-0.19	-0.08

further. The R^2 -values for these relevant combinations of independent variables are marked with bold numbers in table 2. The table 3 presents the b-values and b-intervals of the multiple linear regression analysis for these combinations of independent variables.

3.4. Clay

Table 2 shows that in the case of the investigations on clay samples with Petrit T, the independent variable “freeze-thaw-cycles” (ft) explain one third of the UCS: the R^2 value rises from 0.35 to 0.63 only by adding this input variable to the independent variable “binder content”. The independent variable “water content” shows the second highest factor: R^2 value rises from 0.35 to 0.52 for the combination of the independent variables “binder content” and “water content”. The maximum R^2 value reached with all independent variables is 0.77, and this is already reached by the combination of “binder content”, “freeze-thaw-cycles” and “water content”. The adding of the independent variables “days of curing before the freeze-thaw-cycles”

(db) or “days of curing after the freeze-thaw-cycles” (da) do not rise the R^2 value appreciably.

The b-values presented in table 3 instead clearly mark the independent variable “water content” as the highest influence factor with -0.37. The independent variables “binder content” as well as “freeze-thaw-cycles” have lower b-values, 0.23 and -0.22, respectively. This means that the influence of these independent variables on the UCS of the tested clay samples with Petrit T is lower than the influence of the independent variable “water content”.

3.5. Silt

Regarding to the R^2 -values in table 2, for the investigations on silt samples with Petrit T, the independent variables that explain the most of the UCS are the same as for the clay samples: “freeze-thaw-cycles” followed by “water content”. By adding the independent variable “freeze-thaw-cycles” to the independent variable “binder content” in the regression analysis, the R^2 rises values from 0.60 to 0.71. By adding the independent variable “water content” to the independent variable “binder content” in the regression analysis, the R^2 rises values from 0.60 to 0.66. The maximum R^2 value is 0.81 when all the independent variables are included. The influence of the days of curing before or after seems to be much lower, they do not rise the R^2 value appreciably.

This picture is also given by the b-values in table 3: the independent variable “binder content” shows a b-value of 0.45, which is the highest absolute value of b, followed by the independent variable “water content” which shows a b-value of -0.37. This means that the influence of these independent variables on the UCS of the tested silt samples with Petrit T is the highest one of all of the tested independent variables. The b-values (interpreted as the influence on the UCS) of the independent variables “freeze-thaw-cycles” as well as “days of curing before the freeze-thaw-cycles” are much lower and very close to each other, -0.18 and -0.16, respectively.

3.6. Silty sand

For the results of the investigations on silty sand samples with MultiCem, the independent variable that rises the R^2 value is different, see table 2: the R^2 values rises the most (from 0.69 to 0.78) by adding the independent variable “days of curing before the freeze-thaw-cycles”. But the independent variable “water content” has an almost similar high factor: the R^2 values rises from 0.69 to 0.75. The maximum R^2 value of is 0.81 when all independent variables are included, and this is already reached by the combination of “binder content”, “days of curing before the freeze-thaw-cycles” and “water content”. The adding of the independent variables “freeze-thaw-cycles” as well as “days of curing after the freeze-thaw-cycles” to the regression analysis do not rise the R^2 value appreciably.

The b-values presented in table 3 instead clearly mark the independent variable “binder content” as the one with highest influence factor (0.52). The independent variable “water content” shows a much lower absolute b-value of -0.19, followed by the independent variable “days of curing before the freeze-thaw-cycles” with a b-value of 0.14.

4. Discussion

The strength increase in cold environment can be seen in the results of the multiple linear regression analysis in the b- and R^2 -values for the independent variable “binder content” alone. In the case of the results of the investigations on clay samples with Petrit T, the b-value of the independent variable “binder content” (0.23) is lower than the absolute one for the independent variable “water content” (-0.36), and has the same absolute value as the independent variable “freeze-thaw-cycles” (-0.23). The R^2 -values for the independent variable “binder content” is 0.35, so the binder content describes in this case approximately one third of the maximum strength. In addition, the results of the investigations on silt samples with Petrit T and silty sand samples with MultiCem show the highest b-value for the independent variable “binder content” (0.45 and 0.52, respectively). Also the R^2 -values are much higher than the ones from

the clay samples with Petrit T, 0.6 and 0.69, respectively, so the independent variable “binder content” in the case of the investigations on silt samples with Petrit T and silty sand samples with MultiCem explains about two third of the maximum strength.

The strength reduction due to freeze-thaw-cycles is clearly visible in the R^2 -value for the results of the investigations on clay samples with Petrit T, where the adding of the independent variable “freeze-thaw-cycles” to the independent variable “binder content” rises the R^2 -value from 0.35 to 0.63. In the case of the results of the investigations on the silt samples with Petrit T, there is still a rise in the R^2 -value from 0.60 to 0.71, which indicates an influence. On the contrary, for the results of the investigations on the silty sand samples with MultiCem the R^2 -value remains the same, so there is no influence of the independent variable “freeze-thaw-cycles” on the UCS shown in the multiple linear regression analysis. The b-values show an influence of the independent variable “freeze-thaw-cycles” on the UCS for the results of the investigations on the clay samples with Petrit T (-0.23) and the one on the silt samples with Petrit T (-0.19), but not for the silty sand samples with MultiCem (-0.02).

An influence of the curing time after the freeze-thaw-cycles on the strength can not be seen in general in the multiple linear regression analysis, both the b-values and the change in R^2 -values are small (0.05 at the most).

The more fine-grained a soil, the lower the hydraulic conductivity, and the higher the water content can become. So the influence factors shown for the water content are partly based on the content of fine grains in the soil. The stabilisation with hydraulic binder is dependent on the water content: both too little and too much water lead to a lower strength than the maximum possible strength. The water content has an influence on the effect of the freeze-thaw-cycles as well: the stress on the surrounding soil matrix created by the expanding volume during ice formation is rising with increasing degree of saturation. The higher the degree of saturation, the less air volume. The air volume is the space where the ice can expand to without creating pressure on the surrounding soil matrix. If there is no air volume left, the whole expansion pressure stresses the surrounding soil matrix.

But that the freeze-thaw-cycles show the highest influence in the case of the Petrit T as binder can also, partly, be depending on the complex binder reaction mentioned above. Therefore the dependency of the UCS of the tested samples on the independent variable “days of curing before the freeze-thaw-cycles” is not as clear as for the MultiCem with the usual cement reaction. The Petrit T reaches in total lower strength values as the Multicem. Lower strength is often combined with a lower amount of connections between the soil grains, formed by the reaction products of the hydraulic binder. The pressure of the expanding ice during freezing has less resistance in a stabilised soil with lower strength than in one with higher strength. This can explain why the freeze-thaw-cycles have a high influence on the soils stabilised with Petrit T. A higher binder content could possibly change this dependency.

The MultiCem (with a faster reaction even in cool environment) shows the “days of curing before the freeze-thaw-cycles” as independent variable with the highest influence. This is interpreted as a prove that soil stabilised with a binder with a faster reaction and a higher strength development is less affected by freeze-thaw-cycles. With a faster reaction, a higher strength is reached before the freeze-thaw-cycles starts - for the samples with MultiCem, the strength is by factor 10 higher than in the samples treated with Petrit T. With more and stronger connections between the soil grains, formed by the reaction products of the hydraulic binder, the impairing effect of the freeze-thaw-cycles is reduced.

5. Conclusions

The results of the multiple linear regression analysis show that:

- (i) the strength increase in cold environment can be seen clearly in the results for the coarser soils with binder and also, but less distinct, for the finest soil-binder-combination tested.

- (ii) the strength reduction due to freeze-thaw-cycles is clearly visible for the clay with binder, to a lower extent also for the silt with binder, but not for the silty sand with binder.
- (iii) an influence of the curing time after the freeze-thaw-cycles on the strength can not be shown in general in the soil-binder-combinations tested here.

The results above confirm most of the observations described in the investigations on the stabilised soil samples in the previous publications [3–5].

The multiple linear regression analysis show also that the strength of the finest stabilised soil is depending not only on the binder content, but to a similar degree also on the water content. The water content is still important for the other two soil-binder-combinations.

Acknowledgement

The authors thank the Swedish research council for sustainable development (FORMAS) and the Swedish Transport Administration (Trafikverket) for the funding.

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