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Sediments valorisation (recycling) has revealed limitations due to different restrains and practical difficulties. When it comes to different recovery methods, the possibility of valuing diverse types of sediments still needs to be defined. Using a statistical approach, the present study aims to quantitatively estimate the mechanical resistance of stabilized sediments. A data base that included twenty-two fine sediments is selected and assembled from literature. These sediments were treated with distinct types and quantities of additives (fillers and/or binders). The present study includes two parts. On one hand, using multivariate linear regression tool of XLstat software, an analytical model that highlights effects of various parameters influencing the mechanical resistance of treated sediments after 28 days, is obtained. This model showed that organic matter content and plasticity index are the most significant factors of sediments characteristics, while cement is the best mechanical strength booster. On the other hand, evolution of treated sediments mechanical resistance over time is modelled by an exponential relationship using a least square regression method. Both models showed acceptable accuracies compared to a panel of selected experimental values.

Keywords: Dredged sediments, mass stabilisation, unconfined compressive strength, statistical approach, multivariate linear regression

1. Introduction

Dredging operations of sediments are necessary to maintain harbours and waterways navigability as well as to maintain energy production from hydropower plants in dams. In France, 24.69 million tons of dry matters of sediments were dredged in 2011 [1]. Due to limiting environmental regulations, the deposits of dredged sediments are strictly controlled, and managing these materials

became an environmental concern. Recovery of dredged sediments is an alternative to its disposal at sea and to on-land storage. Moreover, due to the contamination of sediments, their valorisation (recycling) became an environmental and social constraint [2–4].

The complexity issue of ashore sustainable management of sediments is explained by the fact that several combined aspects must be considered *i.e. regulatory (legislations), scientific (characterization, valorisation), technical (implementation), socio-economic (cost of operations, acceptability of sediment based products)*. Partial solutions were suggested mostly for contaminated sediments. Relevant studies are based on multi-criteria analysis methods; common criteria are first concerned with the environment, and sometimes also with economic and/or social aspects [5–13]. However, practical and technical considerations still need to be evaluated.

Many studies have been put forward concerning the valorisation of dredged sediments since 1970. Rozière et al. [14] used 7.9 dwt% (percentage from total dry mass) of pre-treated sediments (thermo-chemical treatment) as filler in self-consolidating concrete. Aouad et al. [15] incorporated 25.74 dwt% of sediments to be introduced into the kiln for Portland cement clinker production. After a thermo-chemical pre-treatment, Lafhaj et al. [16] produced clay bricks substituting clay by pre-treated sediments (from 25 to 45 dwt%). Zdiri et al. [17] substituted 12 to 14.6 dwt% of ordinary limestone aggregates by marine and fluvial sediments to produce roller compacted concrete (RCC). Results showed that the use of sediments in RCC improved its workability and reduced hydration heat.

In valorisation of sediments, the main concern is to recover considerable volume of sediments, with least treatment cost. Chemical and thermal pre-treatments at laboratory scale may not be applicable in full-scale due to technical and cost limitations, and due to environmental concerns (CO_2 emission). *Mass stabilization* involves sediments as main constituent in mixtures. In such recovery method, treated materials can be used for dyke construction [18], fill material [19] or road sub-grade construction [20]. It requires a process of solidification-stabilization (S/S), a well-known treatment approach of fine grained soils by cement and lime admixtures [21–24]. However, sediments recovery methods such as: substitution in concrete, bricks and ceramic materials fabrication do not allow to use significant quantity of sediments. Furthermore, there is no interest in treating sandy sediments, which can be directly reused for beach nourishment without any treatment expenses. Consequently, *mass stabilization* of raw fine sediments without any chemical or thermal pre-treatment, is the most reasonable and attractive solution for sediments valorisation.

Anger [21] developed a tool to preselect the most appropriate recovery method for fine sediments *i.e. cement industry, concrete manufacturing, road engineering, ceramics industry and agricultural*

use. This tool qualitatively predicts the compatibility of sediments to be recycled in the beforementioned recovery methods, to select the most convenient afterwards. Nevertheless, there is a need for a quantitative understanding of the treatment process. In case of sediments *mass stabilisation*, a quantitative approach *i.e. analytical, statistical or empirical* is needed, that allows to estimate the mechanical resistance of treated sediments.

Based on a statistical calculation, the suggested approach permits to estimate the mechanical resistance of treated sediments considering the properties of raw sediments and applied treatment (type and quantity). Unconfined compressive strength (UCS) is the most commonly used parameter to evaluate the mechanical resistance of construction and road materials. To use an alternative material for road sub-grade layer construction, depending on traffic intensity, UCS of 1 MPa to 1.5 MPa is required [22]. However, UCS of 100 to 300 kPa is sufficient for fill materials [19,23]. Therefore, UCS of treated sediments is chosen as a criterion in the present study. From literature and available reported studies, UCS at 28 days (UCS_{28}) is a recurrent proposed parameter. Moreover, cementitious materials reach approximately the maximum resistance at 28 days. Thus, UCS_{28} is undertaken to model the mechanical resistance of treated sediments as function of sediment's characteristics and applied treatment. After identifying the main effective parameters, UCS_{28} is modelled using multivariate linear regression tool of XLstat software. Furthermore, LCPC-SETRA [22] prescribed to assess time needed to develop necessary mechanical resistance of treated materials. Subsequently, UCS development of treated sediments is modelled *versus* time using a least square method.

2. Input data

In case of road and related materials recovery method, according to the tool described by Anger [21], three physical properties were pointed out to influence treated sediment's UCS mechanical performance. These were sediment organic matter content (OM), plasticity index (PI) and D_{50} *i.e. grain's median diameter*. In the present study, the physical properties of raw sediments, types and quantities of used additives, quantity of water in mixtures, all have been considered.

The expected quantitative formula helps to reach three goals:

(1) A better understanding of raw sediment's properties effects over UCS,

(2) A better understanding of treatment effectiveness,

(3) Based on predicted mechanical resistance, a selection and/or orientation of sediments into the most convenient recovery method can be conducted, according to required UCS.

Before running through the statistical analysis, it is necessary to expand the effect of each parameter over the physical and geotechnical properties of treated sediments. A literature review has

allowed a better understanding of positive or negative effects of these parameters over mechanical resistance of treated sediments.

2.1. Physical properties of raw sediments

2.1.1. Grain size distribution

Sediment is a complex matrix made up of inorganic matters, anthropic composites and water. Usually, sediments are described by their structure and mineralogical composition. The grain size distribution (GSD) provides necessary parameters used for soil classification.

2.1.2. Organic matter content

Origin of organic matter (OM) in sediments varies widely. It can contain vegetal debris, humic colloids, and microorganisms. The organic fraction interacts with the mineral clayey particles providing a clayey-organic complex of various chemical stability levels [24]. This interaction, modifies soil characteristics such as the plasticity and the consolidation behaviour [25], and prevents the agglomeration of clay particles after the addition of cement [26]. When organic matter content increases from 0 to 4%, the void index increases and consequently the compressibility of a factor 10 [27]. OM has low density with respect to mineral fraction, thus OM leads to decrease the density of sediments, consequently increasing the optimal water content by compaction [28]. Organic matter can retain up to 20 times of its self-weight in water as reported by [29]. Le Guern et al. [30] reported that, as OM content increases, UCS of treated sediments decreases.

2.1.3. Atterberg limits

It is well known that fine soil is sensible to water. The Atterberg limits *i.e. plastic limit PL, liquid limit LL and plasticity index PI* are indicators of soil plasticity and allow investigating its behaviour under hydric variations. The values of PL, LL and PI depend on proportion and activity of clay in soil. PI defines the interval of water content in which soil remains flexible and deformable while maintaining certain shear resistance [21].

2.1.4. Methylene blue value

Clay minerals found in the sediments are mainly depending on the physical and chemical weathering of rocks. The laminated crystalline structure of clays gives them a set of behaviour properties called *activity i.e. swelling phenomena, plasticity, cohesion, water affinity,…* [31].

Methylene blue value (MBV) corresponds to the quantity of blue methylene absorbed on the external and internal surfaces of the clay particles contained in sediments. The adsorption of significant amount of methylene blue indicates the presence of swelling clay in sediments.

Both tests, Atterberg limits and Methylene blue value MBV, help to evaluate the sensibility of soil to water. However, in case of medium to high clayey soils, MBV becomes less sensitive while plasticity index more sensitive. Beixing et al. [32] studied the effect of clay content of manufactured sand on concrete performance, where MBV is used to quantify clay activity in blended concrete mixtures. They reported that MBV is affected by clay content present in aggregates and its liquid limit. The increase of MBV decreased compressive resistance, workability and flexural strength as well it promoted shrinkage of concrete. Therefore, to estimate the effect of sediments substitution in concrete, one should consider MBV value. Nevertheless, knowing PI is very useful for earthworks designing (fills, banks, dykes, roads…) [21], then Atterberg limits should be considered to assess soil water sensitivity in case of sediments treatment or *mass stabilisation*.

2.1.5. Water content in tested mixture

Sediments are dredged with very high initial water content, from 100 to 300 dwt% even more, depending on dredging method and sediment's mineralogy. This high initial water content is an important brake on the application of most recovery methods. From a technical and economic point of view, in the best-case scenario, sediments are treated at its initial water content. However, the mechanical strength of treated materials is inversely proportional to the water/cement content [33]**.** Consequently higher water content requires higher quantity of binders to solidify the sediments [34], and therefore more expensive treatment.

2.2. Additives

2.2.1. Cement

Cement is the worldwide well known binder for fine soil treatment [35–38]. The dissolution of cement increases the concentration of Ca^{2+} ions, which reduces the hydrophilic property of organic molecules [39]. Rekik et al. [26] treated marine sediments at the initial water content (120 %) using 2-15 % of cement with respect to dry weight of sediments. They reported that calcium silicate hydrates are formed around clay-organic aggregates, producing larger clusters, which accelerates the primary consolidation process and reduces the secondary compression. Wang et al. [40] observed

that the addition of 3 to 6 % of cement or lime, increased liquid and plastic limits of marine sediments. And obviously, increasing cement dosage increases the mechanical resistance of treated sediments [26,39,41,42].

2.2.2. Lime

Humic acid in the soil influence the setting of cement, so it is necessary to add lime to cement in the stabilization/solidification treatment process [41]. Four types of reactions can take place during stabilization with lime: (*i*) cationic exchange [43,44], (*ii*) flocculation and particle aggregation [43], (*iii*) lime carbonation [45], and (*iv*) pozzolanic reactions at long term between lime, silica and alumina.

The reaction of lime with water produces calcium hydroxide with high emission of heat according to equation 1 given below:

$$CaO + H_2O \rightarrow Ca(OH)_2 + 1155kJ/kgCaO \quad (1)$$

Using lime fixation method, the quantity of lime to reach high constant pH can be adjusted. Banoune et al. [46] treated two river sediments using lime from 2-15 wt%. They observed that increasing the quantity of lime increases the mechanical resistance and optimal water content W_{SPO} (Standard Proctor Optimum) but decreases optimal dry density γ_{SPO} and plasticity index.

2.2.3. Fly ash

According to the American Concrete Institute (ACI), fly ash is defined as *the finely divided residue resulting from the combustion of ground or powdered coal* [47]. Fly ash develops pozzolanic properties, in presence of moisture and lime or cement. It chemically reacts with calcium hydroxide at ambient temperature to form compounds having hydraulic properties [41]. Fly ash is classified into two classes *i.e. C or F* according to their chemical composition [48]. Class F fly ash is pozzolanic in nature, contains less than 10 % of CaO, and needs a cementation agent. While class C fly ash contains more than 20 % CaO, and doesn't need a cementation agent.

Silitonga [49] investigated the effect of two types of fly ash with different percentages (4-8 dwt%) combined with 2 dwt% of lime and 3 dwt% of cement on marine sediments. Results demonstrated that sediments treated with class F, containing higher percentage of SiO_2 and Al_2O_3, showed higher mechanical resistance than class C fly ash.

2.2.4. Silica fume

Silica fume or micro-silica is a by-product made from the silicon and its alloys production. In 1994, McKennon et al. [50] found that the addition of silica fume on soil treated with lime or Portland cements promotes the creation of calcium silicate hydrate and control the creation of unsuited products such as *Ettringite*. Kalkan [51] reported that the treatment of clayey soils with silica fume decreases the rate of swelling and desiccation cracks. Silitonga [49] has also studied the effect of different additives on fine sediment's mechanical resistance. He observed that the addition of silica fume improves the unconfined compressive strength at both short and long terms.

2.2.5. Sand

Sand is added to dredged sediments as a granular corrector, it improves sediments granular structure and subsequently reduces its porosity. It brings a dilution effect by modifying natural parameters, where the addition of dry sand decreases clay and OM contents, and accelerates natural dewatering that facilitates the implementation of the treated sediments [52].

Table 1 shows the considered input parameters in the present statistical analysis. Additives were expressed by mass percentage of raw dry sediments. However, water content is referred by percentage of total dry mass (dwt %).

3. Method

Within the frame of the present study, a total of 22 different fine sediments (fluvial, marine and dams), treated with various quantities of additives *i.e. cement, lime, sand, fly ash and silica fume*, compacted in cylindrical moulds with height/diameter ratio of 2, constituted the database. This database is issued from 7 references [21,42,46,49,53–55] (see Table 4 in Annex).

The multivariate linear regression is an approach to model a relationship between a scalar dependent variable and one or more explanatory variables. The objective is to estimate UCS_{28} through a linear combination written as follows:

$$UCS = C_1V_1 + C_2V_2 + ... + C_iV_i + ... + C_nV_n + e \quad (2)$$

Assuming there are n parameters, C_i is the coefficient corresponding to parameter i, V_i is the value taken by parameter i, and e is a disturbance term. Three steps are required to conduct this regression, as shown in Figure 1.

3.1. Database acquisition

Input parameters were identified in section 2 *i.e. sediment's properties, water content in mixtures, type and quantity of binders/additives*. Thereafter, 133 tested mixtures results were acquired from the beforementioned references. Each test constituted of input parameters and its corresponding compressive strength UCS_{28}.

3.2. Elimination of correlated parameters

Before performing regression analysis, linearly correlated parameters must be eliminated from input data using a data-mining tool called principal component analysis (PCA). When several parameters are correlated, one parameter should be retained. PCA is a projection method of observations from p-dimensional space (p variables) to a k-dimensional space (where k < p). It allows the full set of variables to be reduced to a subset representing the principal components assuming a linear correlation between the variables. Each parameter is represented in a factor space (axis), and the geometrical representation associates a vector to each parameter. The scalar product of two vectors is the linear correlation coefficient between them. Only parameters having high correlation should be inspected in PCA projection plans.

In these PCA projection plans, two variables follow a linear relationship when their positions are near the unit circle and very close to each other (positive correlation) or near to the unit circle and diametrically opposite (negative correlation). Two variables are independent when their representations are in a quadrature.

3.3. Multivariate linear regression

To obtain an equation with significant parameters, ineffective parameters should be eliminated. In regression analysis, p-value (probability value) indicates whether the relationships between independent and dependant parameters are statistically significant or not. The p-value examines the null hypothesis that a variable does not affect a dependant variable. If the p-value of a parameter is less than the conventional level of significance, 0.05 [56], the null hypothesis is rejected.

Another method to examine the significance of parameters is performed, as shown in equation 3, by investigating the influence of each parameter on predicted UCS_{28}. For a parameter i and at an observation j, the value taken by the parameter (V_{ij}) is multiplied by its corresponding coefficient C_i. The obtained values were normalized by its sum among all the observations. The maximum value (I_i) among tested mixtures is the influence of parameter i on predicted UCS_{28}.

$$I_i = \max(I_{ij}) = \max\left(\frac{C_i \times V_{ij}}{e + \sum_{j=1}^{p} \left|C_i \times V_{ij}\right|} * 100\right) \quad (3)$$

I_{ij}: Influence of parameter *i* on mixture *j* on UCS_{28} (predicted),

$C_{i:}$ Coefficient corresponding to parameter *i*,

V_{ij}: Value taken by parameter *i* for mixture *j*,

e: Disturbance term (see equation 3),

p: Total number of observations.

Parameters with low influence were eliminated, maintaining high adjusted coefficient of determination (adjusted R^2) and low root mean square error (RMSE) between predicted and experimental UCS_{28}.

4. Results and discussion

First principal component analysis (PCA 1) is performed using 17 input parameters (Table 1) and 133 tested mixtures to eliminate correlated parameters. Note that the sum of variability of chosen projection factors should be high to guarantee good projection of initial multi-dimensional data. When the variability represented by the first two factor plans is not very high, complement factor plans to be added to avoid misinterpretation of results.

Table 2 shows correlated parameters, and PCA projections in Figure 2 validate correlations as follows:

- D_{10}, D_{30}, D_{50}, D_{60} and D_{90} in Figure 2(a) and (b);
- LL and PL in Figure 2(a) and (c);
- OM and PL in Figure 2(a) and (c).

The median diameter (D_{50}) is chosen among other diameters since it is the most representative of the particle size distribution. Figure 3 shows the graphical inspection of correlation between OM and PL; LL and PL, where the presence of trends confirms the correlation. Equations 4 and 5 show linear relationships between OM and PL; LL and PL respectively. Likewise Maherzi et al. [57] reported that OM content is correlated with PL of fine sediments. Knowing that PI is equal to LL-PL, and since plasticity index PI is not correlated with any parameter, thus PI is selected as the representative factor for sediments plasticity, that allows to keep OM and eliminate PL and LL.

$$OM = 0.28 \times PL - 2.3 \quad (4)$$

$$LL = 1.13 \times PL + 16.7 \quad (5)$$

Adjusted coefficient of determination R^2, the root mean square error (RMSE) and parameters coefficients and p-values of performed linear regressions, are given in Table 3. The first multivariate linear regression is performed using 133 observations and 10 parameters. Figure 4 shows the normalized coefficients and coefficient's sampling standard deviation of regression 1. For easier use of the model, an equation with least number of parameters must be achieved without decreasing the accuracy of the model, where better model generates higher adjusted R^2 and lower RMSE.

As shown in Table 3, p-values of D_{50}, MBV and S, are much higher than the significance level (0.05), and therefore these parameters should be eliminated. On the other hand, knowing the significant role of lime in sediments treatment (*see section 2.2.2*), L is not eliminated even that its p-value is higher than 0.05. Using equation 3, three parameters are found to have low influence on predicted UCS_{28}: D_{50} (-4.6 %), MBV (-3.8 %) and sand S (-6.9 %). The low influence of D_{50} can be explained by the fact that the investigated D_{50} range is narrow, see Table 1, since only fine sediments were considered. The influence of MBV is negative, yet low. That can be explained by the fact that soil sensitivity to water is better characterized by PI in case of earthworks (see paragraph 2.1.1). When adding sand for sediments treatment, several authors fixed water content with respect to percentage of sediments. Thus, they neglected the decrease of water content with respect to total dry mass (dwt %), that resulted in negative coefficient, yet low, of sand. A parametric study could help to better identify the effect of sand on sediments treatment.

In regression 2, three parameters were eliminated, namely: sand content, MBV and D_{50}. This regression generated approximately same R^2 and RMSE as regression 1 (Table 3) which ensured that the eliminated parameters did not affect model's convergence (equation 6). Figure 5 shows the normalized coefficients and sampling standard deviation of the seven considered parameters. The p-value of L (0.056) is lightly higher than the significance level, then L is considered a significant parameter. Furthermore, p-values of other parameters are much lower, thus null hypothesis is neglected.

$$UCS_{28}(predicted) = 2.05 - 0.02 \times PI - 0.044 \times OM - 0.019 \times W + 0.019 \times L + 0.086 \times SF + 0.14 \times C + 0.043 \times FA \quad (6)$$

With a view to increase the accuracy of the present study, and knowing that sediments were treated with several types and classes of cement (CEM I or CEM II; 32.5MPa or 42.5MPa) and fly

ash classes (C and F), the chemical composition of these additives is used instead of total quantities in the third regression.

Four oxides were chosen to replace the dosages of cement and fly ash (SiO_2, CaO, Al_2O_3 and Fe_2O_3) since it constitutes more than 80% of the composition. Correlation coefficients between cement and fly ash oxides are given in Table 2, and principal component analysis (PCA 2) is given in Figure 6 where the high variability of factor plans F1-F2 is sufficient for results interpretation. Table 2 and Figure 6 show that cement CaO content (C-CaO) is negatively correlated with C-SiO_2 and C-Al_2O_3. Note that C-Fe_2O_3 is excluded since constant parameters should be excluded from multivariate regressions. As well, fly ash CaO content (FA-CaO) is negatively correlated with FA-Fe_2O_3, while FA-Al_2O_3 positively correlated with FA-Fe_2O_3. As a result, percentage of CaO used in sediments treatment, is chosen to represent cement dosage, and percentage of FA-CaO and FA-SiO_2 to represent fly ash dosage.

Results of regression 3 are given in Table 3 and Figure 7, a decrease of adjusted R^2 and increase of RMSE were observed. This result can be explained by the fact that one or two oxides is(are) not sufficient to neither represent fly ash nor cement. Additional parameters such as the fineness, free CaO in fly ash and its reactivity, could better identify the different additives, and therefore obtain better results. Except that this information was not available.

Validation of model

The model obtained from regression 2 is chosen *i.e. equation 6.* This model is validated using observations that were not used in the model's data set, see Table 6 in Annex. To eliminate identical handling effect of experiments originated from the same author, the validation consisted of three types of fine sediments treated with different quantities of additives and water, carried out by two authors. Figure 8 shows UCS_{28}(predicted) *versus* UCS_{28}(experimental) with the calculated error between them in percentage. Developed model shows UCS_{28} prediction with an acceptable accuracy.

5. Evolution of UCS *versus* time

It would be interesting for *in situ* applications, to predict short and long-term resistance of treated sediments. In this section the possibility of modelling the evolution of treated sediments UCS as a function of time UCS(t) is performed using a set of experimental data [46,49,53]. The acquired results represented UCS resistance of treated sediments obtained at 7, 14, 28, 60 and 90 days, see Table 7 in Annex. Equation 7 is used to model the experimental data, in a manner to fulfil the following assumptions:

- A zero-resistance imposed at t=0 (fresh state),

- Increasing exponential function with a calibration parameter (τ) that controls the curvature of the plot in the logarithmic scale,
- The unconfined compressive strength at 28 days is fixed such that: UCS (t=28 days) =$UCS_{28,exp}$, where $UCS_{28,exp}$ is the measured experimental UCS resistance at 28 days.

$$UCS(t) = UCS_{28,\exp} \times \frac{(1 - e^{-\frac{t}{\tau}})}{(1 - e^{-\frac{28}{\tau}})} \quad (7)$$

To find the optimal value of τ, least square error method is used to measure the discrepancy between the experimental data and the suggested numerical model, where the sum of the square errors (SS^2) between the experimental curve and the model is an indicator of the goodness of the fit. Using 87 sets of test data, the optimal value of τ is found to be 8.88. Although UCS_{28} is estimated from the statistical model (equation 6), which gives equation 8:

$$UCS\ (t) = f\left(IP, OM, L, SF, C, FA, W\right) \times g\left(t\right) \quad (8)$$

where,

f (PI, OM, L, SF, C, FA, W) shown in equation 6,

and

$$g(t) = \frac{1 - e^{-\frac{t}{8.88}}}{1 - e^{-\frac{28}{8.88}}} \quad (9)$$

Analysing the ratios UCS_{60}/UCS_{28} and UCS_{90}/UCS_{28}, issued from experimental values, permits to interpret UCS development with time of tested mixtures (Table 7 in Annex). Three types of UCS evolution trends were observed among acquired data set due to different applied treatments. These were plotted in Figure 9, where each type is represented by a tested mixture, fitted using model defined in equation 7:

- Case (1): UCS_{60}/UCS_{28} and UCS_{90}/UCS_{28} tend to 1, which indicates that UCS does not evolve after 28 days and UCS_{28} is the maximum resistance. This mechanical behavior can be linked to treatment with lime and cement.

- Case (2): UCS_{60}/UCS_{28} and UCS_{90}/UCS_{28} higher than 1, which indicates that UCS continue to increase after 28 days even after 90 days [49]. This result mainly occurred with the addition of silica fume or fly ash that develops a pozzolanic activity.
- Case (3): UCS_{60}/UCS_{28} less than 1, which indicates a drop of UCS after 28 days, this kind of result must be due to high organic matter content (Mix N° 130-131-132-133). Further interpretations are needed especially at the level of the microstructure to understand the source of this outcome.

6. Conclusion

Valorisation (recycling) of sediments has shown some limitations and difficulties coming from scientific, socio-economic, regulatory and technical considerations. From a geotechnical point of view, fine dredged sediments are regarded as compressible or soft soils.

In the present study, a quantitative evaluation of treated sediment's mechanical resistance is given. Organic matter content and liquid limit of fine sediments were found to be correlated with plastic limit. A statistical model is developed to estimate the mechanical resistance of treated sediments as a function of physical properties of raw sediments, type and quantity of additives. Plasticity index and OM content were identified as the most significant factors among the physical properties of raw sediments. The present study confirmed that cement imposes the best curing effect, whereas silica fume and lime showed lower effect. As reported by several authors, higher water content requires more additives to solidify/stabilize sediments, which is confirmed by the high negative coefficient of water content (W). The obtained model is validated using three different sediments with different treatments, this model ensured UCS prediction with acceptable accuracy. Nevertheless, further studies could improve accuracy by considering other parameters such as salinity of sediments, specific area of the sediment's grains, mineralogy and quantity of calcium carbonates, that was not possible herein due to data limitations.

As well, empirical modelling of the mechanical strength development as function of curing time is studied herein. The obtained exponential model showed varied accuracies depending on implemented treatments. Three types of resistance development were identified. Sediments treated with hydraulic binders showed maximum resistance approximately at 28 days, while the addition of silica fume or fly ash extended this period for 90 days or even more due to pozzolanic activity. Further studies are also needed to analyse and consider the resistance drop found in some cases, whereas it could be investigated using experiments at microstructural scale.

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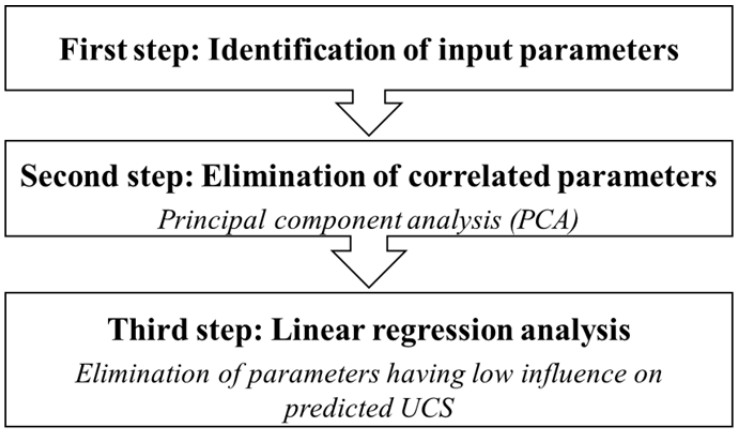
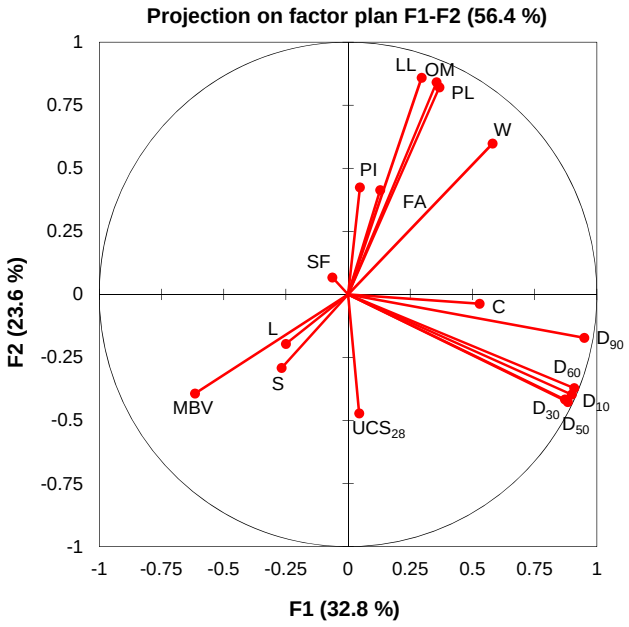
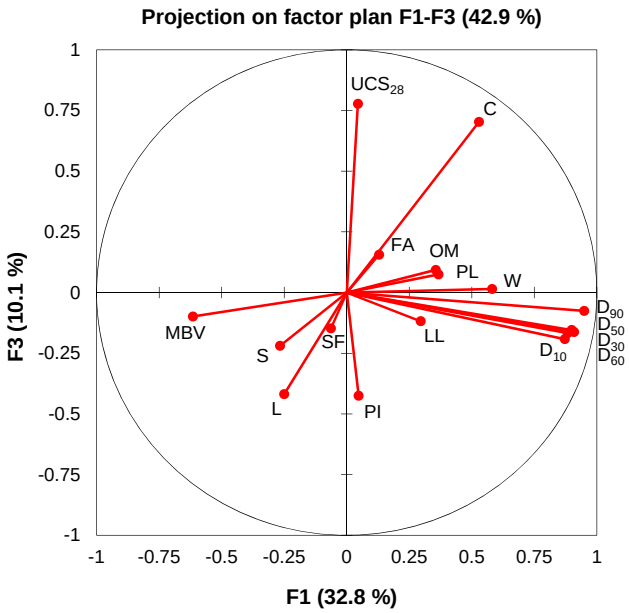


Figure 1. Followed steps to perform multivariate regression analysis



(a)



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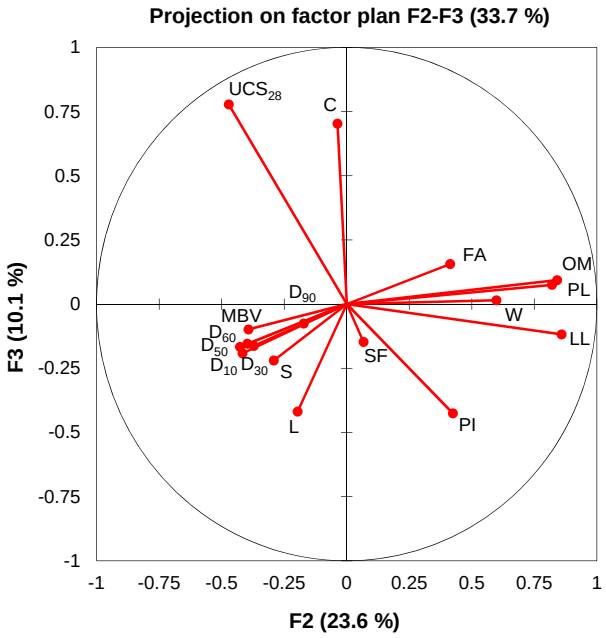
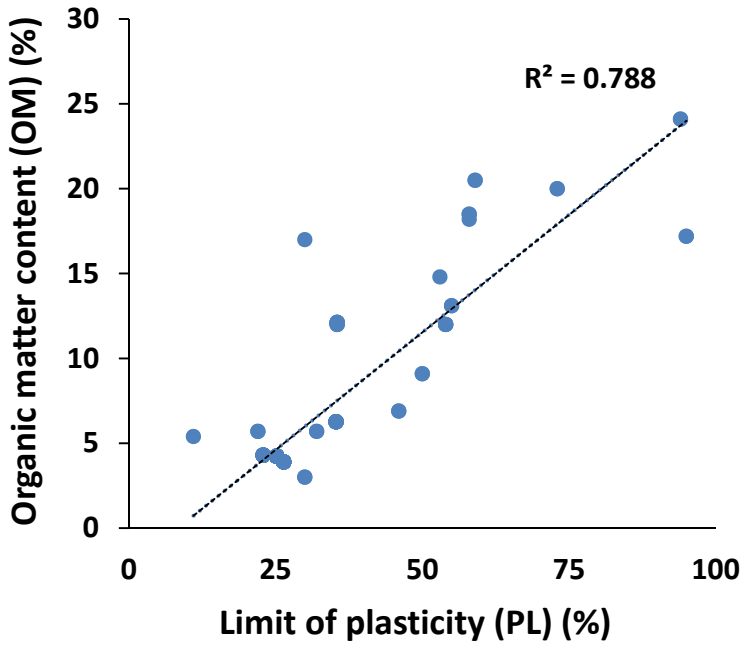
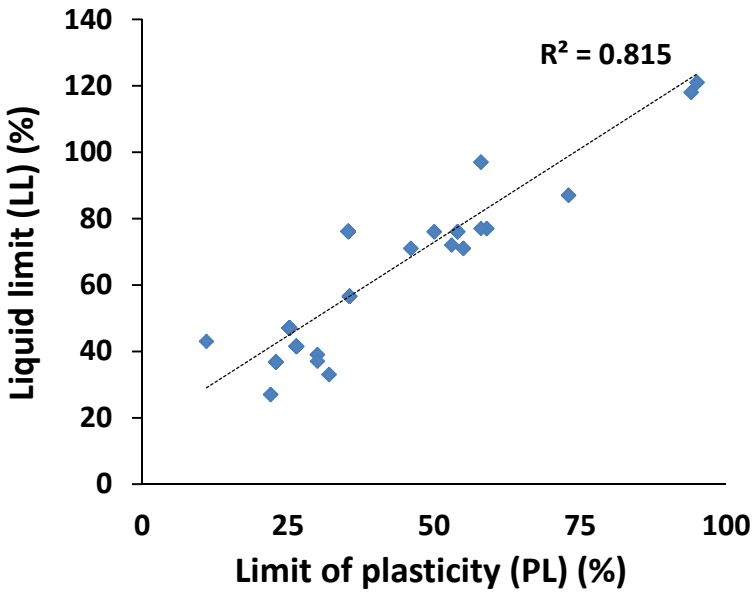


(c)

Figure 2. PCA projections (a) factor plan 1-2; (b) factor plan 1-3; (c) factor plan 2-3



(a)



(b)

Figure 3. Correlations between: a) PL and OM; b) PL and LL

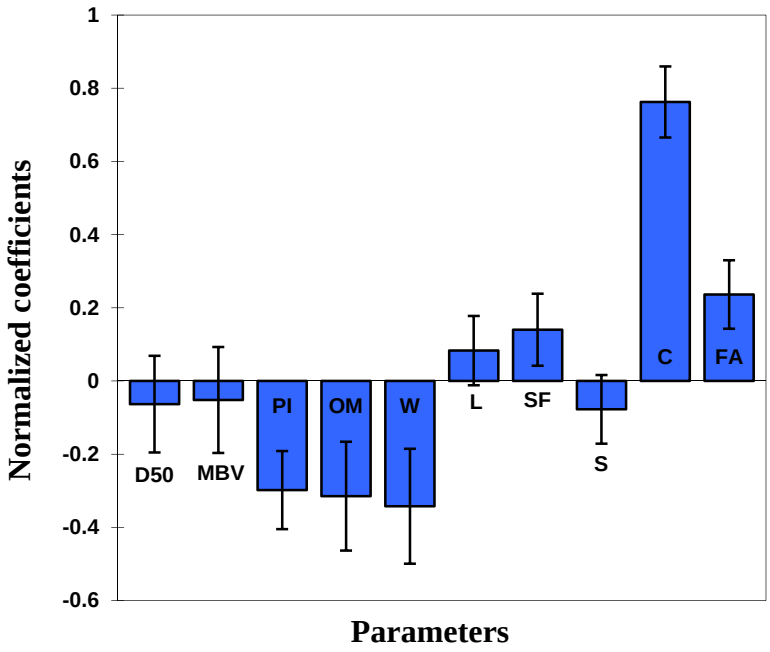


Figure 4. Normalized coefficients of regression 1 (with 95% interval of confidence)

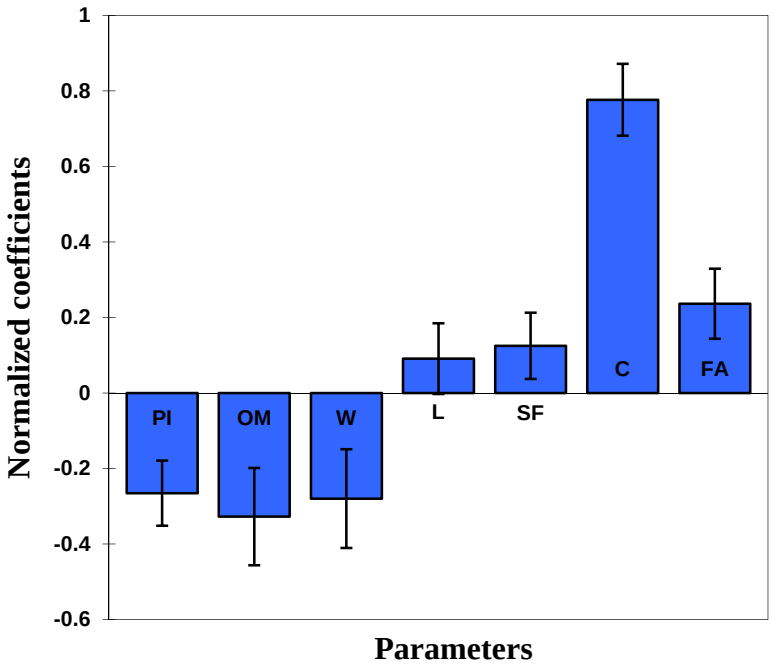


Figure 5. Normalized coefficients of regression 2 (with 95% interval of confidence)

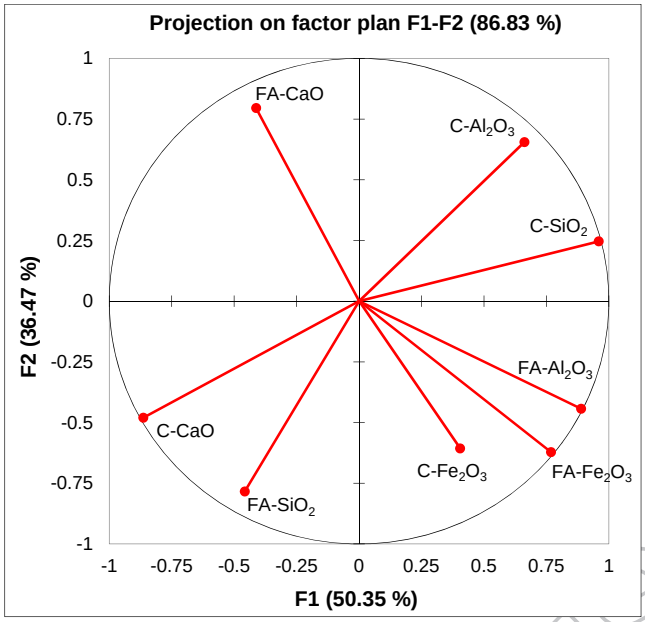


Figure 6. Cement and lime oxides PCA projection, factor plan 1-2

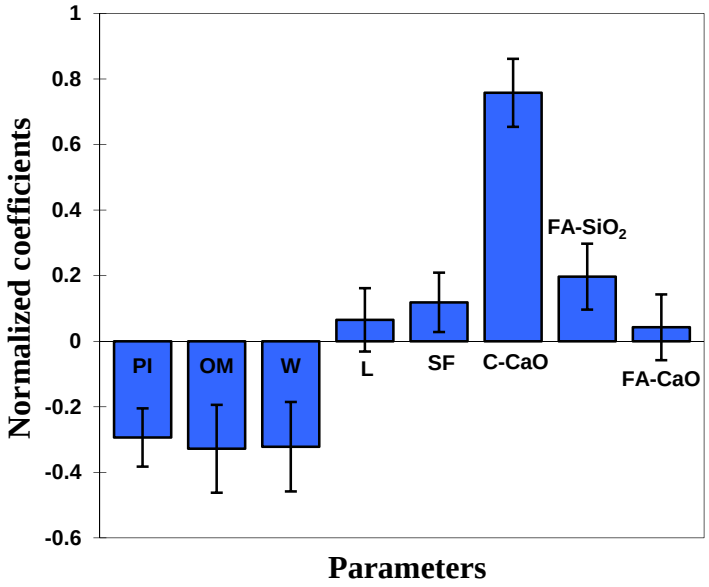


Figure 7. Normalized coefficients of regression 3 (with 95% interval of confidence)

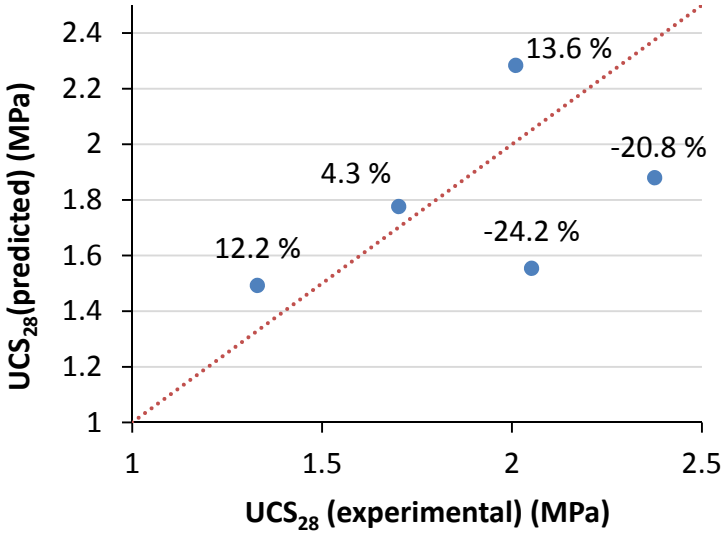


Figure 8. Validation of equation 6; UCS_{28} (predicted) *vs* UCS_{28} (experimental)

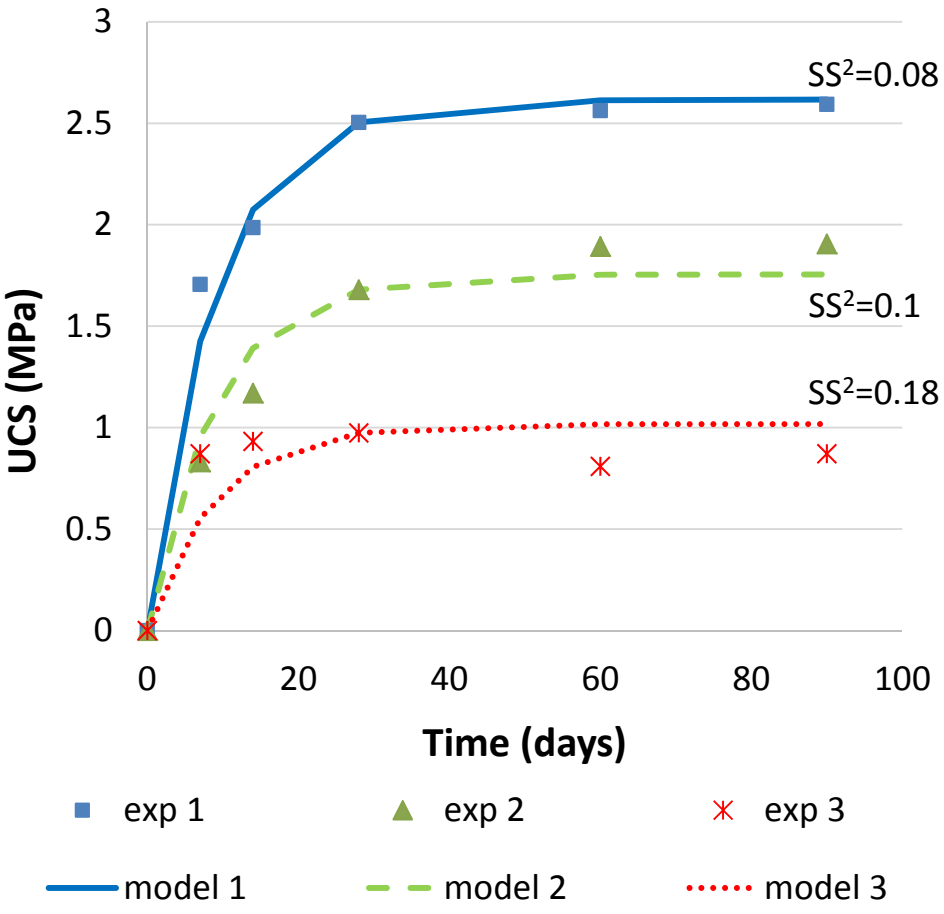


Figure 9. Modelisation of UCS development of treated sediments over time

Table 1. Input parameters

	Parameter	Symbol	Range
Properties of raw sediments	Grain size distribution	D_{10}, D_{30}, D_{50}, D_{60}, D_{90}	D_{50}:7.3-86.7 µm
	Methylene blue value	MBV	
	Organic matter	OM	0.7-4.3 g/100g
	Atterberg limits	PI, LL, PL	3-24.1 % PI: 1-40.8
Treatment	Water	W	
	Lime	L	10.9-45.9 dwt%
	Fly ash	FA	0-17.6 %
	Cement	C	0-10 %
	Silica fume	SF	0-17.6 %
	Sand	S	0-10 %
			0-34.2 %
Mechanical resistance	Experimental UCS (28 days)	UCS_{28}	0.28-4.12 MPa

Table 2. Correlated parameters

	Correlated parameters	Correlation coefficients
PCA 1	**D_{10} : D_{30}**	0.865
	D_{30} : D_{50}	0.889
	D_{50} : D_{60}	0.977
	D_{60} : D_{90}	0.738
	PL : OM	0.888
	PL : LL	0.907
PCA 2	**C-CaO : C-SiO_2**	-0.939
	C-CaO : C-Al_2O_3	-0.938
	FA-CaO : FA-Fe_2O_3	-0.876
	FA- Al_2O_3 : FA-Fe_2O_3	0.946

Table 3. Results of the 3 performed regressions

Regression	1		2		3	
Adjusted R^2	0.765		0.764		0.751	
RMSE	0.316		0.317		0.326	
	Coefficients	p-values	Coefficients	p-values	Coefficients	p-values
Constant	2.39	<0.0001	2.05	<0.0001	2.16	<0.0001
D_{50}	- 0.003	0.344				
MBV	- 0.031	0.481				
PI	- 0.023	<0.0001	- 0.02	<0.0001	- 0.023	<0.0001
OM	- 0.042	<0.0001	- 0.044	<0.0001	- 0.044	<0.0001
W	- 0.024	<0.0001	- 0.019	<0.0001	- 0.022	<0.0001
L	0.017	0.085	0.019	0.056	0.013	0.185
SF	0.097	0.006	0.086	0.0065	0.082	0.011
S	- 0.007	0.105				
C	0.138	<0.0001	0.14	<0.0001		
FA	0.043	<0.0001	0.043	<0.0001		
C-CaO					0.255	<0.0001
FA-SiO_2					0.088	0
FA-CaO					0.024	0.402

Annex

Table 4. Used database in regressions 1, 2 and 3

Origin of sediments	Mix N°	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
Lake of Serre-Ponçon (France)	1	2.6	10.8	21.1	30.2	82.6	0.7	30	9	21	3	30	3.2	0	0	3.2	0	1.21
	2	2.6	10.8	21.1	30.2	82.6	0.7	30	9	21	3	30	0	0	0	6.4	0	1.28
Water reservoir of Garonne (France)	3	6.4	18.9	37.7	53.8	189.4	1.4	76	50	26	9.1	30	3.2	0	0	3.2	0	1.06
	4	6.4	18.9	37.7	53.8	189.4	1.4	76	50	26	9.1	30	0	0	0	6.4	0	1.17
Marckolsheim (France)	5	3.4	12.2	24.4	37.3	135.7	2.4	71	46	25	6.9	30	0	0	0	6.4	0	1.8
	6	3.4	12.2	24.4	37.3	135.7	2.4	71	46	25	6.9	30	3.2	0	0	3.2	0	1.88
East port of Dunkirk harbour (France)	7	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	21.6	0	0	0	0	0	0.54
	8	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	23.3	3.1	0	0	0	0	0.77
	9	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	23.8	6.4	0	0	0	0	0.54
	10	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	23.9	9.9	0	0	0	0	0.63
	11	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.9	0	0	0	3.1	0	0.91
	12	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.7	0	0	0	6.4	0	1.66
	13	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.4	0	0	0	9.9	0	2.26
	14	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	21.9	3.2	0	0	0	3.2	0.98
	15	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.8	3.3	0	0	0	6.6	0.9
	16	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	22.3	6.6	0	0	0	3.3	0.88
	17	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.4	0	0	0	6.6	3.3	1.49
	18	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.7	0	0	0	3.2	3.2	0.68
	19	1.3	3.5	7.3	10.7	67.6	3.1	76.1	35.3	40.8	6.3	20.8	0	0	0	3.3	6.6	0.68
(Algeria)	20	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	11.7	2.7	0	34.2	0	0	0.78
	21	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.3	2.4	0	18.1	0	0	0.73

See Table 1 for notations

Annex

See Table 1 for notations

Origin of sediments	Mix N°	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}	Reference
Soummam river (Algeria)	22	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.2	0	0	0	0	0	0.98	21
	23	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.3	2	0	0	0	0	1.16	
	24	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.8	4.2	0	0	0	0	1.2	
	25	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.1	6.4	0	0	0	0	1.29	
	26	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.5	8.7	0	0	0	0	1.32	
	27	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.9	11.1	0	0	0	0	1.37	
	28	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	15.2	13.6	0	0	0	0	1.46	42
	29	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	15.8	17.6	0	0	0	0	1.57	
	30	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.5	0	0	0	2	0	2.07	
	31	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	13.8	0	0	0	4.2	0	2.36	
	32	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.2	0	0	0	6.4	0	2.42	
	33	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.5	0	0	0	8.7	0	2.49	
	34	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	15	0	0	0	11.1	0	2.55	
	35	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	15.2	0	0	0	13.6	0	2.63	
	36	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	16	0	0	0	17.6	0	2.95	
	37	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.9	2.2	0	5.4	0	0	0.91	
	38	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	14.1	2.3	0	11.4	0	0	0.86	
	39	2	12.1	32.2	42.4	82.7	4	41.5	26.4	15.1	3.9	12.5	2.6	0	25.6	0	0	0.77	
(Algeria)	40	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	16	0	0	0	0	0	1.25	
	41	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.2	2	0	0	0	0	1.28	46
	42	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.4	4.2	0	0	0	0	1.4	

Annex

Reference
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See Table 1 for notations

Mix N°	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
43	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.6	6.4	0	0	0	0	1.48
44	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.8	8.7	0	0	0	0	1.5
45	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.1	11.1	0	0	0	0	1.55
46	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.3	13.6	0	0	0	0	1.58
47	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.5	17.6	0	0	0	0	1.72
48	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.3	0	0	0	2	0	2.12
49	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.6	0	0	0	4.2	0	2.5
50	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.8	0	0	0	6.4	0	2.67
51	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13	0	0	0	8.7	0	2.74
52	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.4	0	0	0	11.1	0	2.83
53	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.7	0	0	0	13.6	0	3.28
54	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	14.1	0	0	0	17.6	0	4.12
55	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	14	2.2	0	5.4	0	0	1.9
56	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	13.2	2.3	0	11.4	0	0	1.84
57	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	12.5	2.4	0	18.1	0	0	1.61
58	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	11.7	2.6	0	25.6	0	0	1.51
59	7	22	36.4	46.5	108	2.6	36.8	22.9	13.9	4.3	11	2.7	0	34.2	0	0	1.46
60	2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	21.1	0	0	0	0	0	1.18
61	2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.6	3.2	0	0	2.1	0	1.53
62	2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	24	3.2	1.1	0	2.1	0	1.53
63	2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	21.6	3.3	0	5.6	2.2	0	1.83

Annex

D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	20.3	3.4	1.1	5.6	2.2	0	1.83
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	18.3	3.5	0	11.8	2.4	0	1.68
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.5	3.6	1.2	11.9	2.4	0	1.83
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	15.4	3.8	0	18.8	2.5	0	1.59
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.8	3.8	1.3	19	2.5	0	1.78
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	24	3.2	1.1	0	2.1	0	1.33
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	24	3.2	1.1	0	2.1	0	1.33
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.7	3.4	1.1*	5.6	2.2	0	1.18
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.7	3.4	1.1**	5.6	2.2	0	1.19
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.3	3.8	1.3*	19	2.5	0	1.52
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.3	3.8	1.3**	19	2.5	0	1.42
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.6	3.2	0	0	2.1	4.2	1.76
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.6	3.2	0	0	2.1	8.4	1.83
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.6	3.2	0	0	2.1	4.2	1.55
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.6	3.2	0	0	2.1	8.4	1.91
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.8	3.3	0	5.6	2.2	4.4	1.95
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.8	3.3	0	5.6	2.2	8.9	2.2
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.8	3.3	0	5.6	2.2	4.4	1.88
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.8	3.3	0	5.6	2.2	8.9	1.97
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.6	3.8	0	18.8	2.5	5	2.11
2	5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.6	3.8	0	18.8	2.5	10	2.23

See Table 1 for notations

Reference	Origin of sediments
46	(Algeria)

Annex

Mix N°	Origin of sediments	Reference
64	Port-en-Bassin Harbour (France)	49
65		
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D_{30}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.6	3.8	0	18.8	2.5	5	2.17
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.6	3.8	0	18.8	2.5	10	2
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23.5	3.3	0	0	5.4	0	1.72
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	24.4	3.3	1.1	0	5.5	0	1.97
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	23	3.4	0	5.7	5.7	0	1.86
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	20.5	3.5	1.2	5.8	5.8	0	1.92
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	16.8	3.7	0	12.2	6.1	0	1.71
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.1	3.7	1.2	12.3	6.2	0	1.81
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	25	3.9	0	19.5	6.5	0	1.74
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	26.2	3.9	1.3	19.7	6.6	0	1.84
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	22	3.2	0	0	2.1	0	1.36
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	22.8	3.2	1.1	0	2.1	0	1.4
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	20.6	3.3	0	5.6	2.2	0	1.39
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	19.7	3.4	1.1	5.6	2.2	0	1.4
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.5	3.5	0	11.8	2.4	0	1.1
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	18.2	3.6	1.2	11.9	2.4	0	1.04
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	18.3	3.8	0	18.8	2.5	0	1.2
5.7	12.1	17.4	78.4	4.3	47	25.2	21.8	4.2	17.3	3.8	1.3	19	2.5	0	1.28
8.6	16	22.1	88		76	54	22	12	33.9	3	0	0	5	10	1.41
8.6	16	22.1	88		76	54	22	12	34.8	0	0	10	5	0	1.25
8.6	16	22.1	88		76	54	22	12	34.8	0	0	10	5	0	0.97

* Silica Fume 2 ** Silica Fume 3 (3 different Silica Fume were used in this reference, that slightly differs in SiO_2 content)

See Table 1 for notations

Annex

Reference	Origin of sediments	Mix N°	D_{10}	D_{50}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
49	Harbour (France)	85	2	16	22.1	88		76	54	22	12	34.3	1.5	0	0	5	10	0.93
		86	2	14	25.1	257		37	30	7	17	27.5	2	0	0	7	0	2.01
		87	2	40	62.7	282		27	22	5	5.7	27.5	2	0	0	7	0	1.87
		88	2	40	62.7	282		27	22	5	5.7	25.2	2	0	0	7	10	3.2
		89	2	19	28.9	257		33	32	1	5.7	45.9	2	0	0	7	0	2.43
		90	2	19	28.9	257		33	32	1	5.7	42	2	0	0	7	10	2.3
		91	2	23	28.9	177		121	95	26	17.2	27.5	2	0	0	7	0	1.76
		92	2	23	28.9	177		121	95	26	17.2	25.2	2	0	0	7	10	1.98
		93	2	21	37.8	213		77	58	19	18.2	45.5	0	10	0	0	0	1.05
		94	2	86.7	5	494		77	59	18	20.5	27.5	2	0	0	7	0	1.45
		95	2	86.7	5	494		77	59	18	20.5	25.2	2	0	0	7	10	1.45
		96	2	36	56.3	257		71	55	16	13.1	45.9	2	0	0	7	0	1.44
		97	2	36	56.3	257		71	55	16	13.1	42	2	0	0	7	10	1.91
		98	2	17	31.8	257		118	94	24	24.1	45.9	2	0	0	7	0	0.3
		99	2	17	31.8	257		118	94	24	24.1	42	2	0	0	7	10	0.85
		100	2	23	32.1	122		87	73	14	20	45.9	2	0	0	7	0	1.29
		101	2	23	32.1	122		87	73	14	20	42	2	0	0	7	10	1.48
		102	2	21	30.5	101		72	53	19	14.8	45.9	2	0	0	7	0	0.72
53	(France)	103	3.4	25	36.2	177		97	58	39	18.5	45.9	2	0	0	7	0	0.91
		104	3.4															
		105	3.4															

See Table 1 for notations

Annex

Reference	Origin of sediments	Mix N°	D_{10}	D_{30}	D_{60}	D_{90}	MBV	LL	PL	PI	OM	W	L	SF	S	C	FA	UCS_{28}
	harbour (France)	106	3.4	8.6	78.7	223		43	11	32	5.4	39.2	0	0	0	2	0	0.9
		107	1.3	4.6	36.2	177		97	58	39	18.5	42	2	0	0	7	10	1.5
	(France)	108	3.2	13.7	59.6	165.9		56.5	35.4	21.1	12.1	33.8	0	0	0	0	0	0.29
		109	3.2	13.7	59.6	165.9		56.5	35.4	21.1	12.1	35.3	0	0	0	0.5	9.4	0.5
	(France)	110	1.4	7.5	59.6	165.9		56.5	35.4	21.1	12.1	34.7	0	0	0	0	9.9	0.55
		111	1.4	7.5	59.6	165.9		56.5	35.4	21.1	12.1	36	2.2	0	0	0	7.7	0.55
	(France)	112	1.4	7.6	59.6	167.7		56.6	35.5	21.1	12	33.6	0	0	0	0	0	0.29
		113	1.4	7.6	59.6	167.7		56.6	35.5	21.1	12	35.2	0	0	0	0.5	9.4	0.54
	(France)	114	0.6	4.8	59.6	167.7		56.6	35.5	21.1	12	36.4	2.2	0	0	0	7.7	0.56
	harbour (France)	115	3.5	25.9														
		116	3.5	25.9														
	(France)	117	2.2	13.3														
		118	2.2	13.3														
	Marseilles (France)	119	1.5	6.5														
		120	1.5	6.5														
	(France)	121	2.4	8.5														
		122	2.4	8.5														
	(France)	123	3.2	9.8														
		124	2.2	9.6														

DD: Dehydrated and Desanded (Degritted) sediments

See Table 1 for notations

Annex

Reference	Origin of sediments	Mix N°	D_{10}	D_{30}	D_{50}
53	Nantes Estuary (France)	125	3.7	30.9	61
	(France)	126	2.2	9.6	25
54	Dunkirk harbour (France)	127	5.1	16.6	33.2
		128	5.1	16.6	33.2
		129	5.1	16.6	33.2
		130	5.1	16.6	33.2
55	Dunkirk harbour (France)	131	5.3	16.7	33.6
		132	5.3	16.7	33.6
		133	5.3	16.7	33.6

DD: Dehydrated and Desanded (Degritted) sediments

Table 5. Percentage of oxides in used Cement and Fly ash

Reference	C-CaO	C-SiO_2	C-Al_2O_3	C-Fe_2O_3	FA-CaO	FA- SiO_2	FA-Al_2O_3	FA-Fe_2O_3
21	56.8	20.2	6.9	3.9	-	-	-	-
42	63.3	21.4	3.3	4	8.5	50	29	8.5
46	56.8	20.2	6.9	3.9	-	-	-	-
49	56.8	20.2	6.9	3.9	8.5	47.4	21.6	7.1
					35.3	20.4	11.7	1.9
53	56.8	20.2	6.9	3.9	8.5	47.4	21.6	7.1
54	76.9	11.7	2.4	3.9	17.7	63.2	9.3	3.3
55	76.9	11.7	2.4	3.9	17.7	63.2	9.3	3.3

Table 6. Database used for validation of model

Reference	Origin of sediment	Mix N°	PI	OM	W	L	SF	C	FA	UCS_{28}
21	La Durance river (France)	1	46	3.6	30	3.2	0	3.2	0	1.33
		2	46	3.6	30	0	0	6.4	0	2.38

See Table 1 for notations

Annex

53	Arsenal de Toulon harbour- DD (France)	3	6	6.5	45.9	2	0	7	0	1.7
		4	6	6.5	42	2	0	7	10	2.01
	Arcachon harbour 2 (France)	5	29	10	33.9	3	0	5	10	2.05

DD: Dehydrated-Desanded (Degritted)

Table 7. Evolution of UCS as function of time database

Mix N°	**UCS_7**	**UCS_{14}**	**UCS_{28}**	**UCS_{60}**	**UCS_{90}**	**UCS_{60}/ UCS_{28}**	**UCS_{90}/ UCS_{28}**
20	0.42	0.52	0.78	0.77	0.79	0.98	1.01
21	0.5	0.59	0.73	0.84	0.87	1.16	1.19
22	0.65	0.82	0.98	1.05	1.06	1.06	1.08
23	0.76	0.9	1.16	1.19	1.2	1.02	1.03
24	0.8	0.95	1.2	1.26	1.26	1.05	1.06
25	0.87	1.08	1.29	1.3	1.31	1.01	1.02
26	0.89	1.2	1.32	1.33	1.34	1.01	1.02
27	0.95	1.29	1.37	1.37	1.37	1	1
28	1.01	1.36	1.46	1.47	1.47	1.01	1.01
29	1.07	1.46	1.57	1.58	1.6	1.01	1.02
30	1.15	1.63	2.07	2.13	2.15	1.03	1.04
31	1.46	1.92	2.36	2.43	2.43	1.03	1.03
32	1.66	2.04	2.42	2.43	2.43	1	1
33	1.93	2.13	2.49	2.55	2.53	1.02	1.02
34	2.06	2.32	2.55	2.55	2.57	1	1.01
35	2.18	2.4	2.63	2.65	2.66	1.01	1.01
36	2.42	2.66	2.95	2.99	2.99	1.01	1.01
37	0.59	0.67	0.91	0.96	0.97	1.05	1.06
38	0.54	0.62	0.86	0.85	0.86	0.99	1
39	0.45	0.55	0.77	0.84	0.86	1.1	1.12
40	0.44	0.89	1.25	1.26	1.27	1.01	1.01
41	0.65	0.98	1.28	1.3	1.32	1.01	1.03

See Table 1 for notations

Annex

42	0.7	1.03	1.4	1.49	1.5	1.06	1.07
43	0.72	1.11	1.48	1.52	1.53	1.03	1.03
44	0.9	1.19	1.5	1.52	1.53	1.02	1.02
45	0.95	1.21	1.55	1.56	1.56	1	1

Mix N°	**UCS_7**	**UCS_{14}**	**UCS_{28}**	**UCS_{60}**	**UCS_{90}**	**UCS_{60}/ UCS_{28}**	**UCS_{90}/ UCS_{28}**
46	1.07	1.28	1.58	1.61	1.63	1.02	1.03
47	1.16	1.37	1.72	1.76	1.8	1.02	1.05
48	1.14	1.56	2.12	2.14	2.17	1.01	1.03
49	1.71	1.99	2.5	2.56	2.59	1.02	1.04
50	1.96	2.21	2.67	2.7	2.71	1.01	1.02
51	2.09	2.37	2.74	2.77	2.78	1.01	1.01
52	2.31	2.56	2.83	2.91	2.92	1.03	1.03
53	2.69	3.12	3.28	3.34	3.35	1.02	1.02
54	3.24	3.57	4.12	4.15	4.15	1.01	1.01
55	1.33	1.63	1.9	1.94	1.94	1.02	1.02
56	1.12	1.57	1.84	1.92	1.93	1.04	1.05
57	0.92	1.36	1.61	1.62	1.63	1.01	1.01
58	0.61	1.21	1.51	1.59	1.58	1.05	1.05
59	0.6	1.18	1.46	1.5	1.52	1.03	1.04
60	0.53	0.98	1.18	1.24	1.31	1.05	1.11
61	0.69	0.82	1.53	1.62	1.64	1.06	1.07
62	0.62	0.88	1.53	1.52	1.58	0.99	1.03
63	0.85	1.23	1.83	1.9	1.92	1.04	1.05
64	0.83	1.69	1.83	1.85	1.9	1.01	1.04
65	0.83	1.17	1.68	1.89	1.91	1.13	1.13
66	0.85	1.23	1.83	1.9	1.92	1.04	1.05
67	0.82	1.13	1.59	1.61	1.73	1.01	1.09
68	0.75	1.19	1.78	1.83	1.7	1.03	0.96
69	0.82	0.89	1.33	1.73	1.92	1.3	1.44
70	0.7	0.87	1.33	1.93	1.83	1.46	1.38
71	0.73	0.87	1.18	1.52	1.73	1.29	1.47
72	0.67	0.81	1.19	1.52	1.63	1.28	1.37

See Table 1 for notations

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73	0.84	0.92	1.52	1.91	1.95	1.26	1.28
74	0.73	0.88	1.42	1.7	1.73	1.2	1.22
75	0.73	1.32	1.76	1.85	1.85	1.05	1.05
76	0.77	1.4	1.83	2.02	2.02	1.11	1.11
77	0.75	1.28	1.55	1.87	1.87	1.21	1.2
78	0.86	1.67	1.91	2.02	2.03	1.06	1.06
79	0.72	1.64	1.95	2.34	2.74	1.2	1.41
80	1.03	1.72	2.2	2.49	3.1	1.13	1.41
81	0.78	1.64	1.88	2.33	2.67	1.24	1.42
82	0.89	1.7	1.97	2.51	2.81	1.28	1.43
83	0.85	1.71	2.11	2.39	2.45	1.13	1.16
84	0.98	1.85	2.23	2.66	2.72	1.19	1.22
85	0.89	1.79	2.17	2.29	2.37	1.06	1.09
86	0.82	1.93	2	2.48	2.5	1.24	1.25
87	0.9	1.38	1.72	1.89	1.91	1.1	1.11
88	0.92	1.48	1.97	2.09	2.12	1.06	1.08
89	0.99	1.55	1.86	1.98	2.02	1.06	1.08
90	1.06	1.75	1.92	2.01	2.11	1.05	1.1
91	0.9	1.48	1.71	1.92	1.93	1.12	1.13
92	0.9	1.42	1.81	1.95	2	1.08	1.1
93	0.93	1.5	1.74	1.81	1.83	1.04	1.05
94	0.88	1.76	1.84	1.86	1.89	1.01	1.03
95	0.83	0.98	1.36	1.84	1.91	1.35	1.4
96	0.78	1.18	1.4	1.81	1.86	1.29	1.33
97	0.76	1.08	1.39	1.59	1.59	1.14	1.14
98	0.8	1.1	1.4	1.6	1.68	1.14	1.2
99	0.67	0.83	1.1	1.38	1.4	1.25	1.27
100	0.7	0.87	1.04	1.4	1.46	1.35	1.4
101	0.7	0.9	1.2	1.59	1.6	1.33	1.33
102	0.76	0.97	1.28	1.52	1.58	1.19	1.23
103	1.25	1.46	1.41	1.28	1.37	0.9	0.97
104	1	1.22	1.25	1.15	1.21	0.93	0.97

See Table 1 for notations

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105	0.87	0.93	0.97	0.81	0.87	0.83	0.89
106	1.12	1.04	0.93	0.89	0.94	0.95	1.01

See Table 4 for sediment type, and applied treatment details according to Mix N°

See Table 1 for notations