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RESEARCH ARTICLE

OPTIMIZING CONSOLIDATION COSTS OF COMPACTIBLE SOIL: AS APPLIED ON THE CONSTRUCTION PROJECT OF THE SECOND WOURI BRIDGE IN CAMEROON

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ABSTRACT

The construction of infrastructure on compactible soil such as estuaries which feature very thick compactible alluvial deposits entails the mastery of the magnitude of compaction over time according to the importance of load applied. The Douala basin, especially the port area is made up of sandy and sandy argilous sedimentary soil with imbrications of loam layers, which make them highly compactible.This feature constitutes an instability factor for buildings constructed in this area, which calls for special precautions that may lead to considerable overcosts relating to earthworks (backfills carried out to reclaim land over the river) and special equipment (vertical drains, pillars, drilled micro-pillars). This article deals with the optimization of costs relating to the putting in place of drainage materials in the form of vertical drains as part of the construction project of the 2ndWouribridge in Douala, Cameroon. After a mathematical modeling of the optimization problem, followed by its solution using the simplex method, a gain of*72 829 690 frs CFA* for the building of the foundation, *13 620 165 frs CFA* for putting in place vertical drains and*6 750 567 frs CFA* for the putting in place of the draining layer.

INTRODUCTION

Construction works on compactible soil (saturated argilous) entail many hurdles, such as important compaction of infrastructure, instability of foundations and infrastructure built on highly compactible (low-resistant) saturated argilous soil. Areas with compactible soil can be treated using several technical solutions. The solution most commonly used for construction works is that of deep foundations. Emmanuel Kemongne (2007) showed that the method for stabilizing compactions through the progressive unidirectional loading could help to reduce between 20 to 50% the cost of the foundation of heavy infrastructure in the Douala area. This study further states that four years following the commissioning of the infrastructure, no damage was reported. However, this stabilization method is only efficient when the loading and consolidation periods are incompatible with the project's deadline.

Concerning the project for the construction of the second bridge on the WouriRiver where the consolidation period is still compatible with the provisional planning of works, pre-filling with vertical drains followed by compaction with equipment in order to accelerate compactible soil compaction and consolidation through a network of vertical drains was the method used.This treatment technique implies the use of borrowed materials (***2/3***of sand and***1/3***of pozzolanfor example). Conversely, using over thick material impacts the supply cost of materials, the cost of using equipment and the cost in manpower. Also, the deepness of drains depends on soil lithology.

Results of pressiometric tests (FP1, SPTFP1) on site (at the right side of C0 abutment) are summarized in Figure 1

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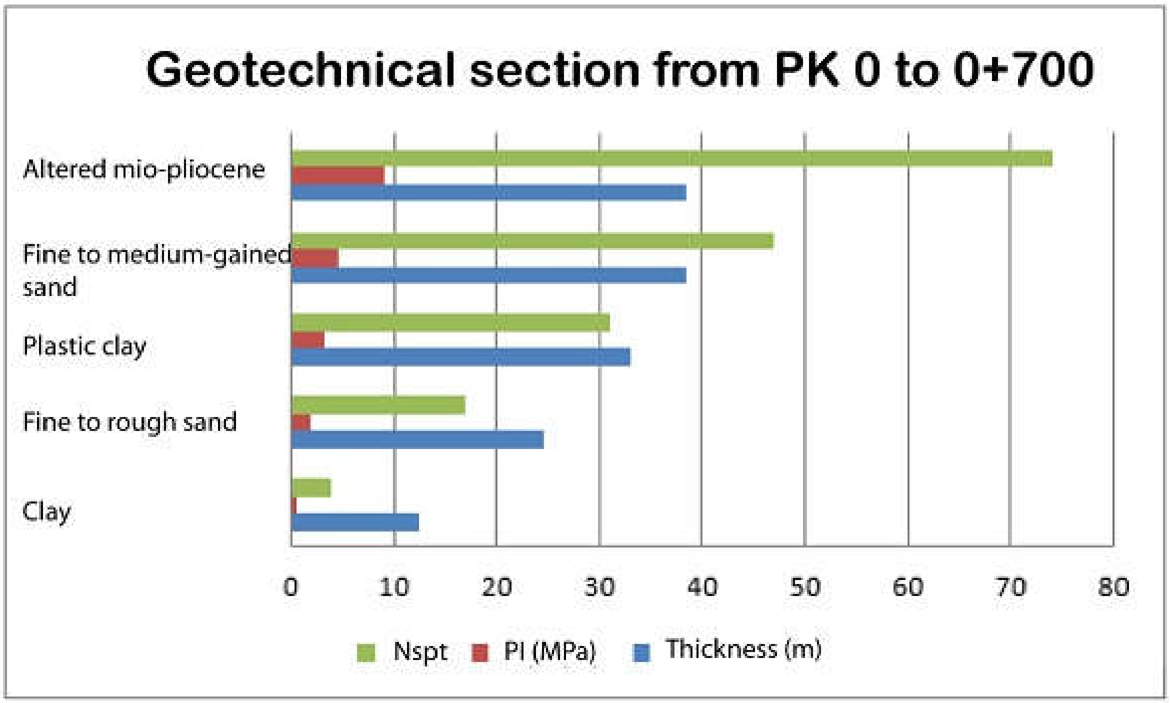

Figure 1 Geotechnical section fromPK 0 to 0+700

As part of soil consolidation works using vertical drains, the evaluation of optimum depth of drains during their construction, as well as the evaluation of necessary backfill optimum thickness is two important parameters. The consolidation phase using vertical drains in this area comprise of the basement of the platform, the construction of vertical drains and the putting in place of the draining layers (Figure 2).

The mandrelis inserted into the ground trough chains operated by hydraulic engines. The required construction depth is 20 m. Then, the drain is cut using a cutter in such a way as to leave a free height of about 25 cm above ground level (Figure 3).

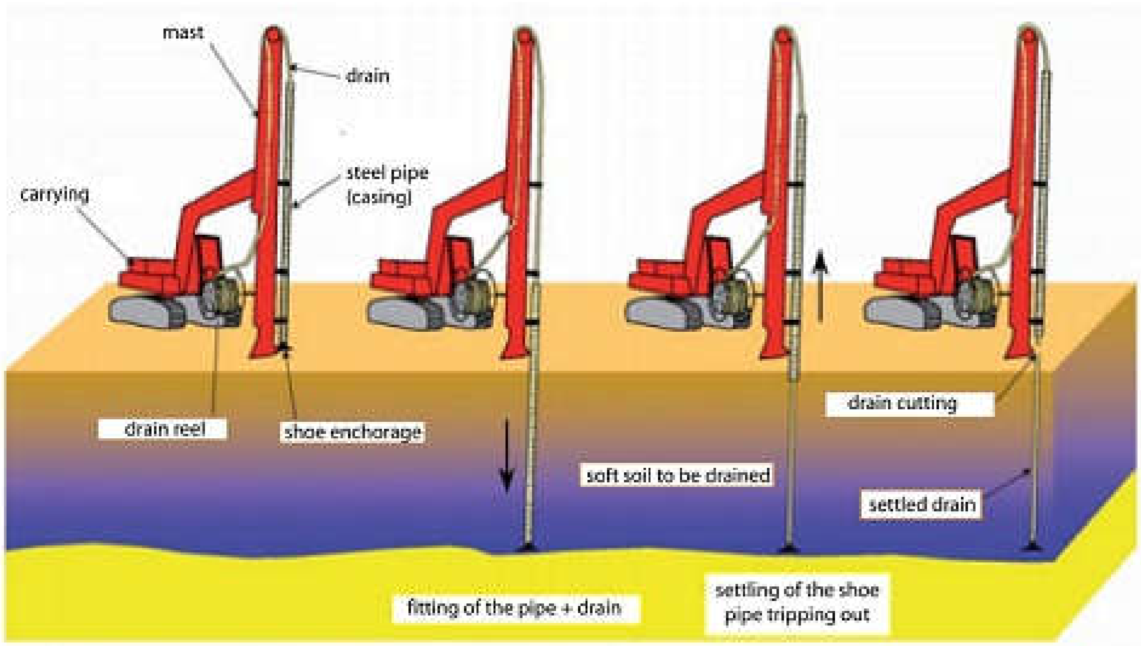

Figure 2 Operating model for the construction of a drain

Figure 3 Some vertical drains put in place

Problem Modelling

The*Ishikawa diagram (Fig 4)* shows parameters that could impact the construction cost of vertical drains.

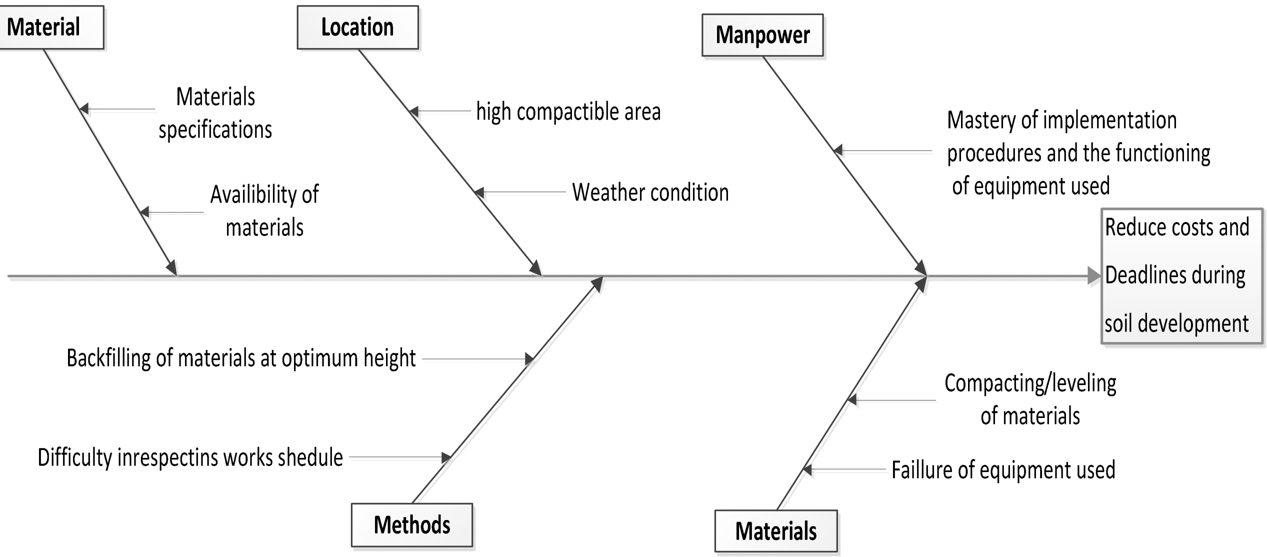

Figure 4 *Ishikawa Diagram*

To better understand the problem, the utility function shall be expressed as follows:

$$f\left(u\right)=\sum_{i=1}^{6}\alpha_i a_i$$

Whereby f(u) is the utility function, α_i i coefficient associated to activityi;
Following a survey carried out among professionals, the weight values of α_i were estimated.

- a_1 = Backfilling of materials at optimum height ; α_1 = *0,35*
- a_2 = Respect of work schedules ; α_2 = *0,1*
- a_3 = Availability of materials ; α_3 = *0,06*
- a_4= Failure in equipment used ; α_4 = *0,04*
- a_5 = Features of materials; α_5 = *0,25*
- a_6 = Compacting/leveling of materials; α_6= *0,2*

This Pareto diagram shows that the main aspects we should focus on to reduce costs and deadlines during the upgrading of compactable soil are as follows:

- *Backfilling of materials at optimum height*
- *Features of materials put in place*
- *Compacting/leveling of materials (use of equipment)*

Definition of the objective function

Cost = cost for the construction of the platform foundation +cost for the construction of vertical drains + cost for the construction of the draining layer

The cost of materials, the cost for the purchase of the material, the cost of labour and the overall cost for the construction of the foundation are expressed in ***annex 1.***

The cost of materials, the cost for the purchase of the material, the cost of labour and the overall cost for the construction of drains are shown in***annex 2***.

The average daily drain production is***129 drains/day***.

The cost of materials, the cost for the purchase of the material, the cost of labour and the overall cost for the putting in place of the draining layer is shown in***annex*** 3.

That is:

xthe height of the supporting ground (m);
ythe height of the prefabricated vertical drains (m);
zthe height of the draining layer (m);
Thus, the objective function shall be expressed as follows:

Min f(x, y, z) = 56 556 011.5 x+ 1 129 701.6 y+79 864 066 z
The resulting expression of soil consolidation time is thus as follows:

Working time [t] in (hrs) ***=101.2 x + 0.5 y + 91.1 z***
The objective function obtained is:

Min f(x, y, z) = 56 556 011.5 x+ 1 129 701.6 y + 79 864 066 z

Constraints defining the formulation of the optimization problem stems from the numerous information gathered from special technical specifications (CCTP), fascicles relating to the secondary access project, the Technical Refill Guide as well as the Technical Guide for the refill of trenches.

According to procedure *VRD/SOG/PES/EXE/1185/B*, vertical drains should be built under the buttress of standard section***PK2+500 to PK2+680***and under the entry ramp***PT12 to PT21***. The total number of drains to be constructed is***2011.***The draining network is a mesh of***2.5 x 2.5 m***^{2}made up of flat drains built at a depth of***20m*** or until refusal when the clay layer comes before.

The platform should be made of *Wouri sand layers*of a total thickness varying between*1m30 and 1m80*, thus avoiding preliminary drilling while providing the required carrying capacity.

For vertical drains to function perfectly, a draining surface comprising a pozzolan layer of at least *50 cm*shall be built on the working platform.

Knowing the total height of the roadway (from the**red line** to underlying soil), as well as the thickness of the various layers of the roadway, it would be possible to determine the theoretical height of the platform (Figure 5).

Information ondifferences*TN-transverse profiles project P5 toP10is* presented in annex 4.

In the subsequent analyses, we shall work with TN difference and transverse profile project***P6*** (***TN Difference andProject ≈ 2.99 m)***which is the most closer to the average value of***1.854 m.*** From the roadway structure sketch and the cross sectionof the access ramp, one can notice that: the*roadway surface* is made of*BB*with theoretical thickness $\boldsymbol{e_1 = 0.07}$ ***m***; the*binder course*is made up of*GB*with theoretical thickness $\boldsymbol{e_2 = 0.16}$ ***m***; the*road base* is made up of*GC*with a theoretical thickness $\boldsymbol{e_3 = 0.25}$ ***m***; la the *subbase course* is made up of pozzolan with theoretical thickness$\boldsymbol{e_4 = 0.5}$ ***m***.

TN Difference and project = Thickness of roadway layers + Thickness of the working platform (ep), Thereby:*TN Differenceand project* $= (e_1 + e_2 + e_3 + e_4) + x + z$ *because* $e_p = x + z$
Considering that:***TNDifferenceand project = (TN Difference and project)***$_{aver}$,we have:
$x + z = (\text{TN Difference and project})_{aver} - (0.07 + 0.16 + e_3 + e_4)$ ***(19)***
Or $(e_{3\ theoretical} - 0.02) \leq e_3 \leq e_{3\ theoretical} \Longrightarrow 0.23 \leq e_3 \leq 0.25$ ***(20)***

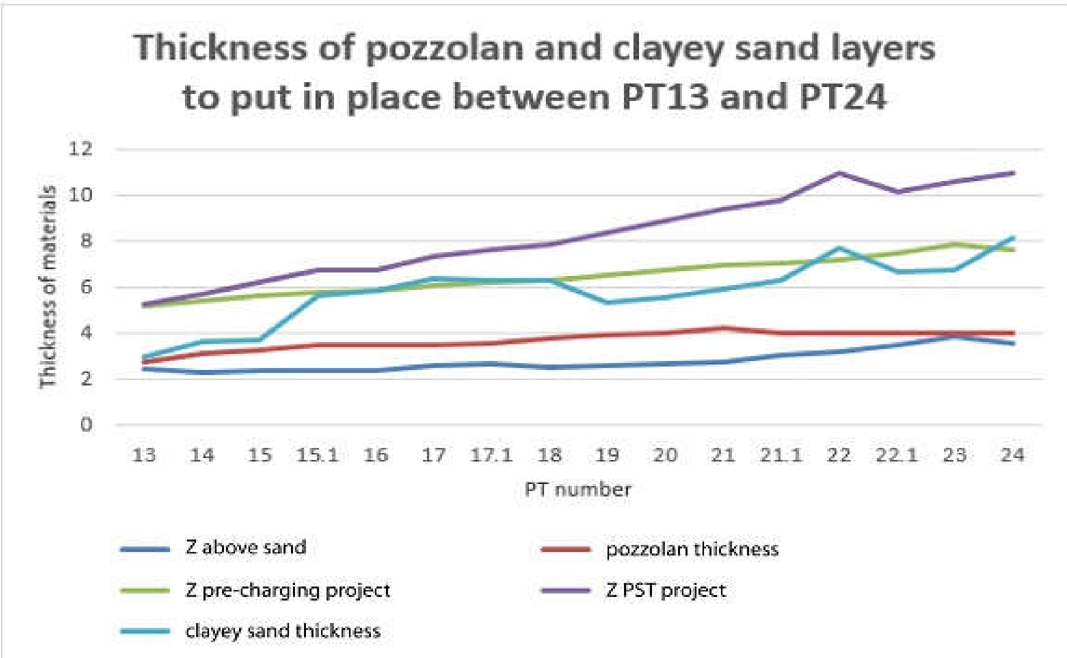

Figure 5 Thickness of pozzolan and clayey sand layers to be put in place between PT 13 and PT 24

and $(e_{4\ theoretical} - 0.02) \leq e_4 \leq e_{4\ theoretical} \Longrightarrow 0.47 \leq e_4 \leq 0.50$ **(21)**

(20)+ **(21)**$\Longrightarrow 0.7 \leq e_3 + e_4 \leq 0.75$

$\Longrightarrow 0.07 + 0.16 + 0.7 \leq 0.07 + 0.16 + e_3 + e_4 \leq 0.07 + 0.16 + 0.75$

$\Longrightarrow 0.93 \leq 0.07 + 0.16 + e_3 + e_4 \leq 0.98$

$\Longrightarrow 2.99 - 0.93 \geq (TN\ Difference\ and\ Project)_{aver} - (0.07 + 0.16 + e_3 + e_4) \geq 2.99 - 0.98$

$\Longrightarrow 2.06 \geq (TN\ Difference\ and\ Project)_{aver} - (0.07 + 0.16 + e_3 + e_4) \geq 2.01$ **(22)**

(19)in***(22)***$\Longrightarrow$: $2.06 \geq x + z \geq 2.01$ ***(C1)***

According to*fascicle E3 Earthworks – subformation level*and the*procedure for the construction of vertical drains,* $z \geq 0.5$ **(C2)**

According to the*TechnicalGuide for the backfill and trenches,* $D_{max} \leq 2/3\ z$. also, according to *Fascicle E3 Earthworks,*$D_{max} \leq ½\ x$.Supposing that$D_{max} = 50$ ***mm***, we find that: $2\ D_{max} \leq ½\ x + 2/3\ z \Longleftrightarrow 0,1 \leq ½\ x + 2/3\ z$ ***(C3)***

According to the*procedure for the construction of vertical drains*, we were able to deduct the following constraints: $z \geq 0.5$; $1.30 \leq x \leq 1.80$; $y \geq 20$;

The maximum depth attained by drains is of about 25 m. Thereby: $y \leq 25$;

According to the *provisional plan for the execution of the additional project*, the construction of drains should be done in*7* ***days***and the duration for the construction of the platform on the North access way should be ***9 months***. Consequently, the following constraints are derived from relations between the necessary time for the construction of drains (respectively for the construction of the platform) and the duration earmarked for each sub-structure (expressed in hours): $0.5\ y \leq 56$ ***and*** $101.2\ x + 0.5\ y + 91.1z \leq 1\ 728$***(C4)***

It should be recalled that the platform should be made up of *Wouri sand* layers of a total height between*1m30 and 1m80 :* $1.30 \leq x \leq 1.8$***(C5)***

Inequations$y \leq 25$ ***and*** $x \leq 1,80$are summarized as: $x + y \leq 26.8$ ***(C6)***

Inequations$y \geq 20, x \geq 1.30$ ***and*** $z \geq 0.5$***are*** summarized as : $x + y + z \geq 21.8$; ***(C7)***

Thereby the optimization problem:

Minimising $f(x, y, z) = 56\ 556\ 011.5\,x + 1\ 129\ 701.6\,y + 79\ 864\ 066\,z$

underconstraints : $x + z \leq 2.06$;

$x + z \geq 2.01$;

$0.1 \leq ½\,x + 2/3\,z$;

$101.2\,x + 0.5\,y + 91.1z \leq 1\ 728$;

$x + y \leq 26.8$;

$x + y + z \geq 21,8$;

$z \geq 0,5$;

Solving The Optimization Problem

The objective function is a minimizing or maximizing type, depending on n variables ($x_1, x_2,\ldots,x_n$). Theseare satisfactory to constraints if they are within or at the periphery of an associated hyper-volume limited by its constraints. To solve a linear programming problem, we could use the graphical method, the big M method, the 2-phases method or the simplex method. The latter is the main tool used to solve linear programmingproblems. It is an iterative algebraic method that helps to find the exact solution to a linear programmingproblem through a limited number of phases.

A general linear programming problem may be expressed as follows: finding n variables valuesx_j, $j = 1, 2, \ldots, n$that are satisfactory to m inequations or linear equations (constraints) in the form of:

$$a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \begin{Bmatrix} \leq \\ = \\ \geq \end{Bmatrix} b_i,\ i = 1.2,\ldots,m$$

To solve this problem, we shall use the ***duality theorem***. Let be the initial linear program, referred to as *primal,*a second linear program, referred to as *dual*program (equivalent and obtained by introducing difference values).The theorem stipulates that: « For any solution relating to the primal and any solution relating to the dual, z, the objective of the primal, shall be lower or equal to w, the objective of the dual. If the primal has anoptimal solution$x_1^*, \ldots, x_n^*$then the dual shall have anoptimal solution $y_1^*, \ldots, y_n^*$and for these solutions, the primal's objective shall be equal to the dual's objective»:

$$\sum_{j=1}^{n} c_j x_j = \sum_{i=1}^{m} b_i y_i$$

Minimizing $f(x, y, z) = 56\ 556\ 011.5\,x + 1\ 129\ 701.6y + 79\ 864\ 066\,z$

Sub-constraints: $(-x) + (-z) \geq (-2,06)$ $x + z \geq 2,01$

$½\,x + 2/3\,z \geq 0,1$

$(-101,2\,x) + (-0,5\,y) + (-91,1z) \geq (-1\ 728)$

$(-x) + (-y) \geq (-26,8)$

$x + y + z \geq 21,8$

$z \geq 0,5$

$x, y, z \geq 0$

The minimizing function dual's is therefore:

Maximizing $g = -2.06\,s_1 + 2.01\,s_2 + 0.1\,s_3 - 1728\,s_4 - 26.8\,s_5 + 21.8\,s_6 + 0.5\,s_7$

Constraints: $-s_1 + s_2 + 0.5\,s_3 - 101.2\,s_4 - s_5 + s_6 \leq 56\ 556\ 011.5$ $-0.5\,s_4 - s_5 + s_6 \leq 1\ 129\ 701.6$ $-s_1 + s_2 + 0.67\,s_3 - 65.6\,s_4 - s_5 + s_6 + s_7 \leq 79\ 864\ 066$ $s_1, s_2, s_3, s_4, s_5, s_6, s_7 \geq 0$

Let's introduce the following three difference variables u, v, w,we thus obtain an equivalent formulation of the problem:

Maximizing $g = -2.06\,s_1 + 2.01\,s_2 + 0.1\,s_3 - 1728\,s_4 - 26.8\,s_5 + 21.8\,s_6 + 0.5\,s_7$

Constraints:$-s_1 + s_2 + 0.5\,s_3 - 65.6\,s_4 - s_5 + s_6 + u = 6\ 556\ 011.5$ $-0.5\,s_4 - s_5 + s_6 + v = 1\ 129\ 701.6$ $-s_1 + s_2 + 0.67\,s_3 - 65.6\,s_4 - s5 + s_6 + s_7 + w = 79\ 864\ 066$

This formulation makes it easy to express difference variables as affine functions of decision values:

$$u = 56\,556\,011.5 + s_1 - s_2 - ½\, s_3 + 101.2\, s_4 + s_5 - s_6$$
$$v = 1\,129\,701.6 + 0.5\, s_4 + s_5 - s_6$$
$$w = 79\,864\,066 + s_1 - s_2 - 0.67\, s_3 + 65.6\, s_4 + s_5 - s_6 - s_7$$
$$g = -2.06\, s_1 + 2.01\, s_2 + 0.1\, s_3 - 1728\, s_4 - 26.8\, s_5 + 21.8\, s_6 + 0.5\, s_7$$

Dictionary 1

Variables u, v andw are base variables and s_1, s_2, s_3, s_4, s_5, s_6, s_7 are out-of-base variables. The basic solution, associated to a dictionary, is obtained by attributing value 0 to all out-of-base variables. The basic solution corresponding to Dictionary 1 shall be therefore$s_1 = s_2 = s_3 = s_4 = s_5 = s_6 = s_7 = 0$, giving:$u = 56\,556\,011.5$; $v = 1\,129\,701.6$; $w = 79\,864\,066$; $g = 0$.

Let's consider an out-of-base value whose coefficient in the last line of the dictionary is positive. Let's choose for instance s_6 as the base's entryvariable. $s_6$is increased as from 0, the other out-of-base values remaining null. Constraints on the increase of $s_6$are as follows:

$$u \geq 0 \Longrightarrow 56\,556\,011.5 - s_6 \geq 0 \Longrightarrow s_6 \leq 56\,556\,011.5$$
$$v \geq 0 \Longrightarrow 1\,129\,701.6 - s_6 \geq 0 \Longrightarrow s_6 \leq 1\,129\,701.6$$
$$w \geq 0 \Longrightarrow 79\,864\,066 - s_6 \geq 0 \Longrightarrow s_6 \leq 79\,864\,066$$

The most restrictive among these constraints is$s_6 \leq 1\,129\,701.615$. Thereby, the exit value of the base is v. Let's change dictionaries by swapping the roles of $s_6$and v. We shall use the second equation of dictionary 1 to express $s_6$as depending on s_4, s_5, v:

$s_6 = 1\,129\,701.615 + 0.5\, s_4 + s_5 - v$.
Let's then replace s_6 with this expression in the other equations of the dictionary:

$$u = 55\,426\,309.9 + s_1 - s_2 - 0.5\, s_3 + 100.7 s_4 + v$$
$$s_6 = 1\,129\,701.615 + 0.5\, s_4 + s_5 - v$$
$$w = 78\,734\,364.4 + s_1 - s_2 - 0.67\, s_3 + 90.6\, s_4 - 1.67\, s_5 - s_7 + v$$
$$g = -2.06\, s_1 + 2.01\, s_2 + 0.1\, s_3 - 1717.1\, s_4 - 5\, s_5 + 0.5\, s_7 - 21.8\, v + 24\,627\,495.2$$

Dictionary 2

Let's decide to bring in s_2 into the base; we obtain the following limits on the increase of s_2:

$$u \geq 0 \Longrightarrow 55\,426\,309.9 - s_2 \geq 0 \Longrightarrow s_2 \leq 55\,426\,309.9$$
$$w \geq 0 \Longrightarrow 78\,734\,364.4 - s_2 \geq 0 \Longrightarrow s_2 \leq 78\,734\,364.4$$

The most restrictive of these constraints is$s_2 \leq 55\,426\,309.9$. Therefore, the exit variable of the base is u. The first equation of dictionary 2 is used to express $s_2$against u, s_1, s_4, v:

$$s_2 = 55\,426\,309.9 + s_1 - u - ½\, s_3 + 100.7\, s_4 + v.$$

$s_2$is then replaced by this expression in the other equations of the dictionary:

$$s_2 = 55\,426\,309.9 + s_1 - u - 0.5\, s_3 + 100.7\, s_4 + v$$
$$s_6 = 1\,129\,701.6 + 0.5\, s_4 + s_5 - v$$
$$w = 23\,308\,054.5 + 0.67\, s_3 - 10.1\, s_4 - 1.67\, s_5 - s_7 + u$$
$$g = -0.05\, s_1 - 0.905\, s_3 - 1514.7\, s_4 - 5\, s_5 + 0.5\, s_7 - 19.79\, v - 2.01\, u + 136\,034\,378.1$$

Dictionnaire 3

We then decide to include s_7 into the base; the following limits are obtained on the increase ofs_7:$w \geq 0 \Longrightarrow 23\,308\,054.485 - s_7 \geq 0 \Longrightarrow s_7 \leq 23\,308\,054.5$

Thereby the exit value of the base shall be w. The third equation of dictionary 3 is used to express $s_7$against w, u, s_3, s_4:$s_7 = 23\,308\,054.485 + 1/3\, s_3 + 25{,}5\, s_4 - 5/3\, s_5 - w + u$.

Then, s_7 is replaced by this expression in the other equations of the dictionary:

$$s_2 = 55\,426\,309.9 + s_1 - u - 0.5\, s_3 + 100.7\, s_4 + v$$
$$s_6 = 1\,129\,701.6 + 0.5\, s_4 + s_5 - v$$
$$s_7 = 23\,308\,054.\,5 + 0.67\, s_3 - 10.1\, s_4 - 1.67\, s_5 - w + u$$
$$g = -0.05\, s_1 + 0.045\, s_3 - 1519.8\, s_4 - 6.67\, s_5 + 0.5\, w - 19.79\, v - 1.51$$

Dictionary4

According to the duality principle, the optimal solution of primalf^* is equal to the optimal solution of dual **g**,therefore,$f^* = 147\,688\,405.35$. In addition, the optimal values of variables x, y and z of primal (x^*, y^*, z^*) equate coefficients associated with base variables of dictionary 1. Therefore: $x = 1.51$; $y = 19.79$; $z = 0.5$.
Inconclusion:

$$f^* = 147\,688\,405.3$$
$$x^* = 1.51\ ;\ y^* = 19.79\ ;\ z^* = 0.5$$

Digital authenticationwithMatlab

Results obtained by using the Matlab software are presented in***Annex 7.***

Cost Analysis of Soil Consolidation Through Vertical Drains

Real costs for soil consolidation with vertical drains: the case of the North Access Ramp from PT 12 to PT 21.1

According to the ***draftsurvey statement of ContractNo. 000428/M/MINMAP/CCPM-AI/2015*** for additional works of the project for the construction of the 2nd bridge on the Wouri River, the real overall cost for soil consolidation with vertical drains from PT 12 to PT 21.1 is (C_{TE}): C_{TR} = 158 229 267 + 35 976 960 + 46 682 600 = CFAF240 888 827

$$C_{TE} = \text{CFAF } 240\,888\,827$$

Optimal costs for soil consolidation with vertical drains: case of the North Access Ramp from PT12 to PT21.1

Solving the problem manually gave us the following optimum values:

$x^* = 1.51$; $y^* = 19.79$; $z^* = 0.5$

Therefore, the optimal cost for soil consolidation using vertical drains from PT 12 to PT 21.1 (C_{TO}) is: C_{TO}= *85 399 577.4* + *22 356 794.96* + *39 932 033* = CFAF147 688 405.4

$$C_{TO} = \text{CFAF}147\,688\,405.4$$

Based on the model built earlier and supposing that the thickness of the drainage layer z_1 = 1 m, the cost for the putting

in place of the drainage layer will be*CFAF79 864 066.* In addition, supposing that the length of drains is y_1 = 20 m, the cost for the construction of drains will beCFAF 22 594 032.3. Consequently the overall cost for soil consolidation with vertical drains from PT 12 to PT 21.1 (C_{T1}) is as follows:
C_{T1} = *85 399 577.4* + 22 594 032.3 + 79 *864 066* = CFAF187 857 675.7.

C_{T1} = CFAF 187 857 675.7

Interpretation of results

The optimization of the use of materials has a double impact, in terms of financial resources and time. We have:

An optimal financial gain = CTE- C_{TO}

⇨Financial gain = 240 888 827 - 147 688 405.4

⇨ ***Optimum financial gain = CFAF 93 200 421.6***

Estimated financial gain = C_{TE} - C_{T1}

⇨Estimated financial gain= 240 888 827 - 187 857 675.7

⇨ ***Estimated gain= CFAF 53 031 151.3 CFA***

2* (91.1*0.5) = 91.1 hrs

t_{opt}= 252.8 hrs

The following information is given by the engineering submission for optimal access ramps:

- Construction of the platform foundation: *20 days*that is*160 hrs* ;
- Installation of the drainage layer of 1m thickness for vertical drains: *30 days*that's is*240 h* ;

According to the history on the production of drains, about 129 drains are put in place daily, whereas 1296 should be constructed, which makes*10 days,*that is*80 hrs.*
Effective working time: t_E= *160 + 240 + 80 = 480 hrs*

From the interpretation of results, there is a reduction in cost of CFAF93 200 421.6 and in deadlines (of 128 hrs).

CONCLUSION

The aim of this study was to optimize the cost of the use of materials during soil consolidation with vertical drains as treatment techniques peculiar to the Wouri working site.

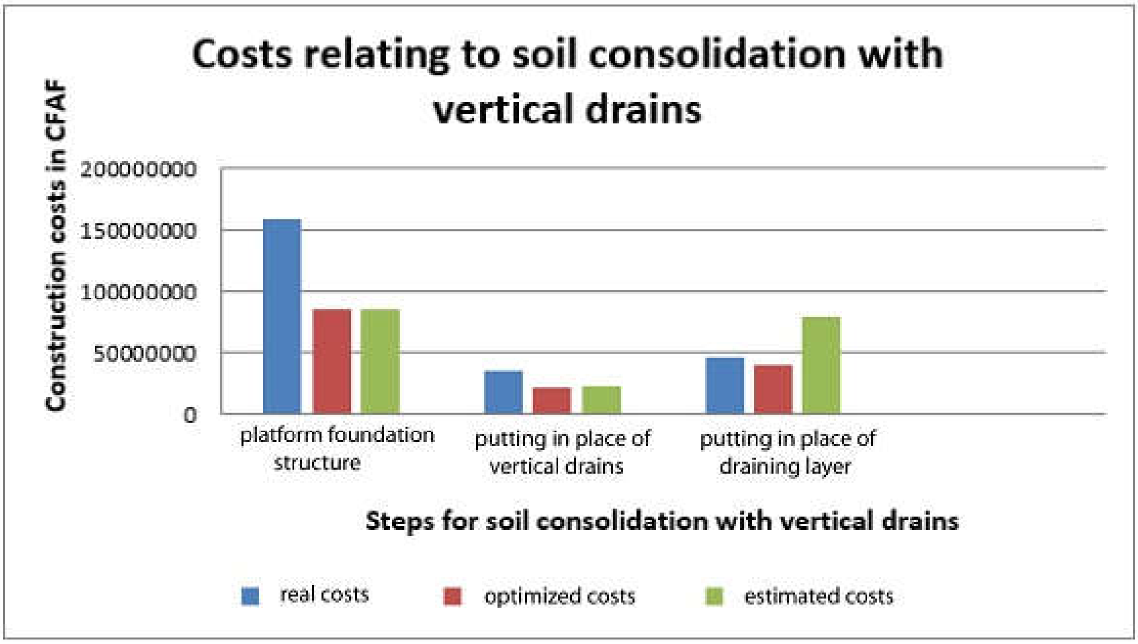

Figure 6 Overview of various costs relating to soil consolidation with vertical drains

➔ **Gain in time**

Working time [t] in (h) =*101.2 x + 0.5 y + 91.1 z*
By replacing x, y and z by x^*, $y^*$and z^*, we obtain the optimal working time t_{opt}:
$t_{opt} = 101.2\, x^* + 0.5\, y^* + 91.1\, z^*$
$x^* = 1.51$; $y^* = 19.8$; $z^* = 0.5$
Optimal time for the construction of the basement of the working platform: ***151.8hrs***
Optimal time for the construction of vertical drains: ***10 hrs***
Optimal time for the installation of the drainage layer of 1m thickness:

This technique includes the construction of the foundation of the working platform, the putting in place of vertical drains, the installation of the drainage layer. Within the optimization perspective, for each step, we carried out an evaluation of the cost of construction machines, the cost of procuring materials and the cost of labour. These enabled us to draw a mathematical design of a linear system including a function-cost to minimize under constraints provided by technical specifications contained in the*procedures for the execution of vertical drains*, the*GTR*and the*CCTP*.

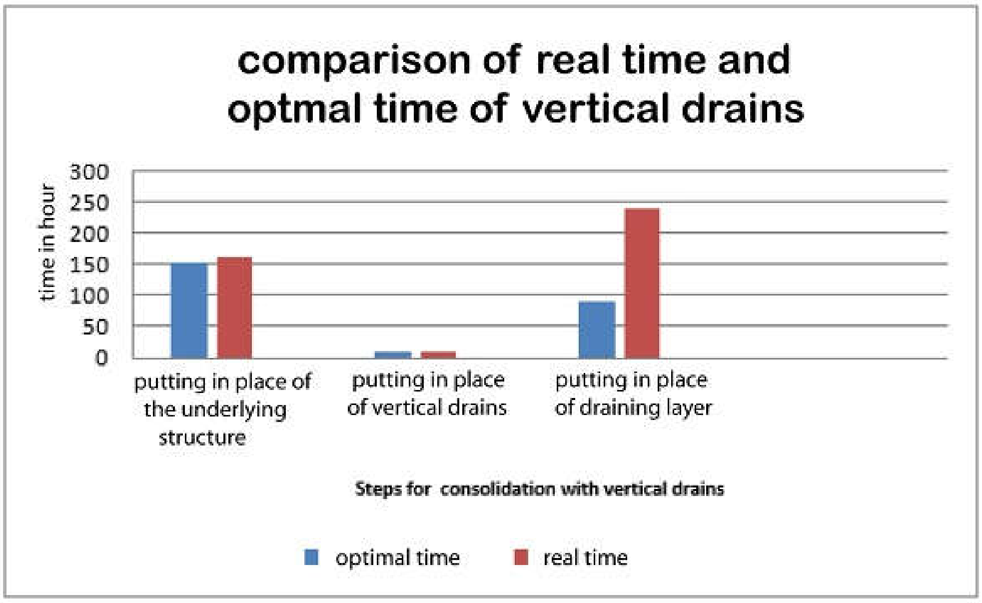

Figure 7 Comparing optimal and real time for the construction of vertical drains

The solution to the design problem was found using the simplex method. Consequently, we obtained a financial gain of54% for the foundation of the platform, 62% for putting the drains in place and85.5% for the drainage layer.

Due to the fact that soil consolidation using vertical drains entails the follow-upofsoil settlement using instruments, we presented results provided by compaction masses, inclinometers and piezometers.

By way of perspectives, we would suggest that a thorough interpretation of curves resulting from the follow-up of settlements be done for a better assessment of the time and quality of soil settlement.Consequently, we would insist on the convergence of results provided by each instrument.

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