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Random Sets-based estimation of soundings density for geotechnical site investigation

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Leonardo Fibonacci (1175 - 1250)

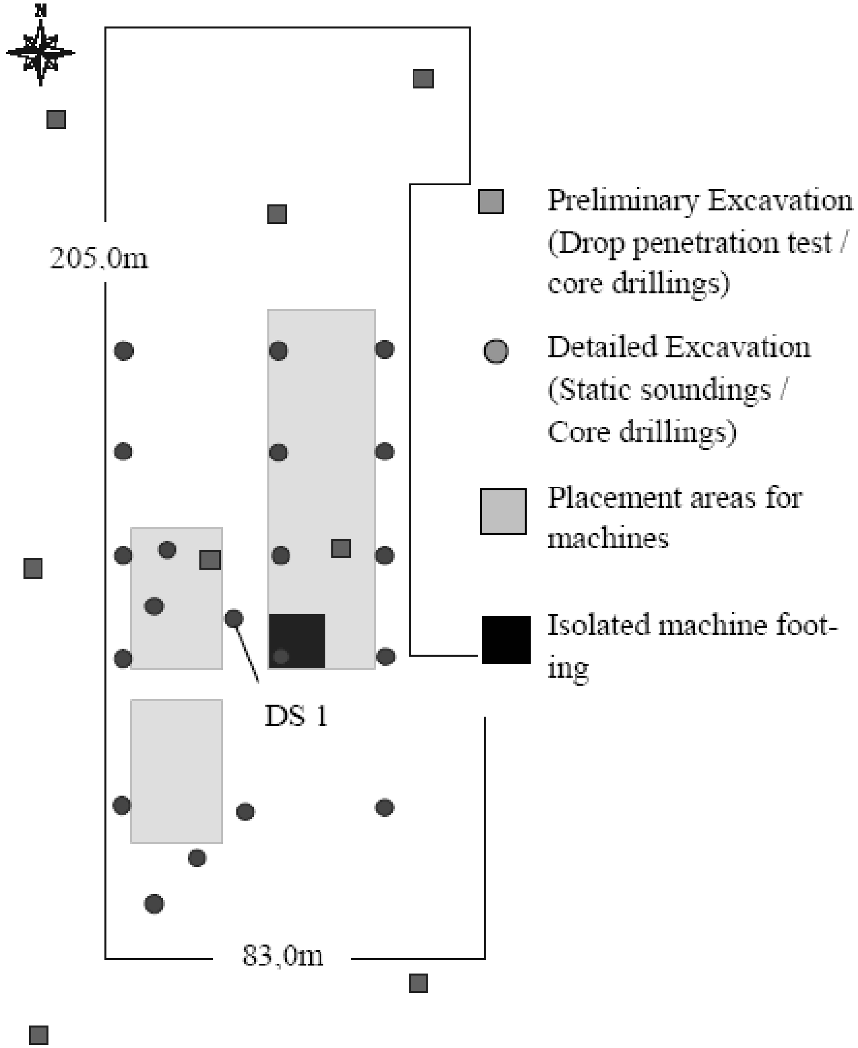
Son éducation s'est faite en grande partie en Afrique du Nord. Son père, Guilielmo Bonacci, vivait à Béjaïa (Bougie, Bgayet, Bugia) où il était le représentant des marchands de la république de Pise

Fibonacci en rapporta à Pise en 1198 les chiffres arabes et la notation algébrique

Introduction

- Geotechnical site investigation is generally conducted in two steps;
- One preliminary stage consisting in collecting available information and executing a limited number of soundings on site, and
- A second step of investigation based on the first stage using more soundings for soil testing. The optimal number of soundings is unknown, it depends on number of factors such as geology of the site, soil variability and the type of project to build...

- There is no specific rule on the optimal number of soundings to execute for geotechnical investigations.
- Previous information on the site is generally given in form of geological and topographic maps and eventual results from adjoining sites.
- The engineer's judgement is important.
- For a geotechnical investigation, and given preliminary information, experts can formulate a subjective probability (degree of belief) related to the density of soundings to carry out.
- For a high variability of soil properties experts will propose with a "high" degree of belief that the density of boreholes should be "important" to complete an efficient investigation. The approach will need certain number of experts to be reliable. The more experts the more reliable will be the result.



Example of soundings distribution for geotechnical investigation
(Schönhardt and Witt 2003)

- **Some of the parameters affecting Geotechnical Investigations**

- Geologic context of the project area (maps, reports, on site visits…)

- Topography of the site (maps, visits…)

- Soil variability (maps, preliminary investigation….)

- Project type, and

- Information from neighbouring areas

GEOLOGY

- The degree of information (knowledge) depends mainly on the scale of geological maps used, and on the on-site engineer's judgement.
- Clayton et al (2005) recommend for geotechnical studies to use geologic maps in the scale 1/2500.
- The spacing of borings depends on the geology of the area and may vary from a site to another. Soundings spacing should be selected to intersect distinct geological characteristics of the project.

SOIL VARIABILITY

- The preliminary step of geotechnical investigation consists in few soundings that permit to have a rough idea about the variability of soil properties. The parameter "Soil Variability" is important for the engineer to decide on how many soundings will be necessary in the second stage of site investigation. The soil variability is related to the number of different soil layers, their orientations and thickness. Average values of soil parameters can be obtained from different points of the site. For important variability of soil properties the density of soundings should be significant.

Parameters affecting the density of soundings on site (Geology, Soil variability, type of Project...)

When High Soil Variability we need Important number of Soundings

IF Geology is Well Known THEN few soundings.

For a regular Site Topography ---- Moderate the number of soundings.

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- Optimal Density of soundings on site?
- A Minimum is recommended

Certain technical documents give a "minimum" number depending only on the surface of the project. (Eurocode 7 FHWA 2002)

How to construct a decision support system to quantify an "optimal" number of soundings on site?

- The degree of belief an engineer could have given preliminary information (soil variability, geology, type of project…) is used to construct the upper and lower probabilities to estimate the number of soundings for geotechnical investigation.
- The calibration is done upon minimal number of soundings per surface recommended by Eurocode7.

- Each engineer can give an interval of values based on his degree of belief. He will support his judgement by available information.
- If “Soil Variability” obtained from preliminary soundings is “Very Important” for instance then he will propose an important number of soundings with a strong degree of belief.

- For Soil Variability we proposed a scale between 1 and 10 representing intervals of “Very Low”, “Low”, “Medium” and “High” Variability.
- Eurocode 7 recommends 1 sounding per 40x40m² as a minimum for an investigation.
- The degree 1 of soil variability corresponds to a “very low” variability. We consider this degree of variability necessitating the minimal number of soundings recommended by Eurocode7.
- The maximum number of soundings recommended by Eurocode7 and some authors (Hunt, 2007) is given by 1 sounding / area of 15x15m².
- Globally the number of soundings per unit area of 40x40m² varies between 1 as a minimum and 6 as maximum, but it is possible to have more soundings if information is lacking.
- Let’s consider the opinions of experts about the density of soundings on site, given soil variability. For certain soil variability degree between [1,10] the expert will give the corresponding number of soundings (with a degree of belief m_{ij}).

Eurocode7 recommends
1 sounding
per 15x15m² as a maximum

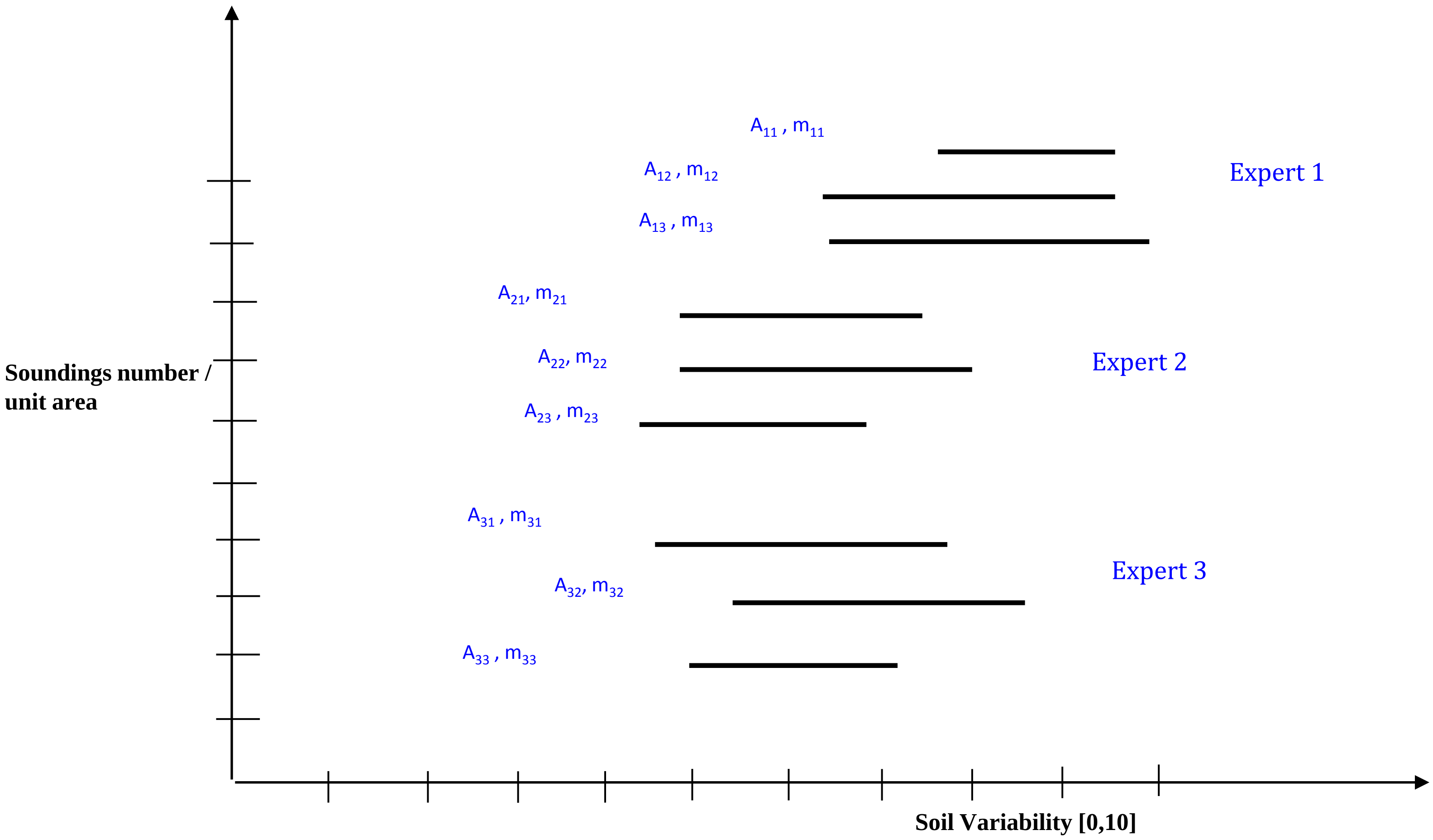
the number of soundings per unit area of 40x40m² varies between a minimum and maximum

Soil Variability (1 - 10)

For certain soil variability between [1,10] the expert will give the corresponding number of soundings (with a degree of belief m_{ij})

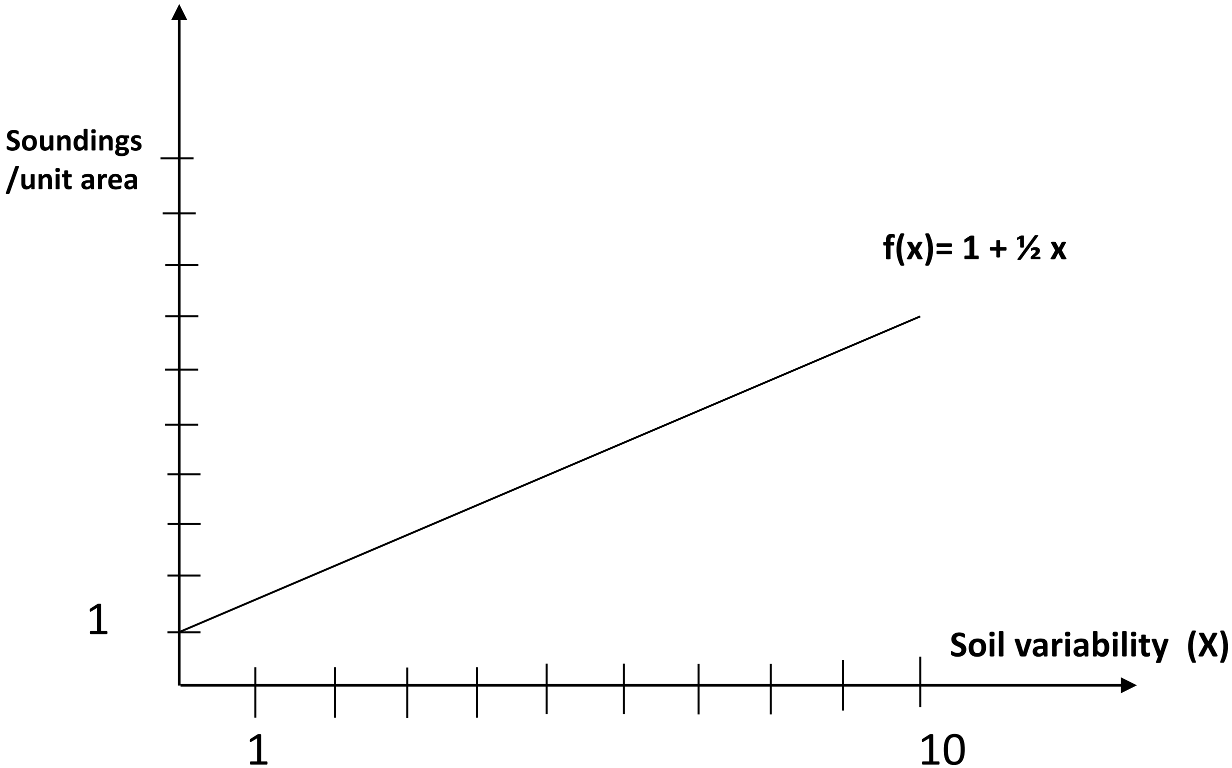
Eurocode7 recommends
1 sounding
per 40x40m² as a minimum

• Optimal Density of soundings on site?


A11 , m11
A12 , m12
A13 , m13
Expert 1
A21, m21
A22, m22
A23 , m23
Expert 2
A31 , m31
A32, m32
A33 , m33
Expert 3
Soundings number / unit area
Soil Variability [0,10]

Point to point approach

- We try first with only one expert 1.
- According to eurocode7 the minimum number of soundings is 1 for an area of $40x40m^2$. This minimum number as explained before could be used for a “Very low” **soil variability** (which is comprised in the interval [0,2] on the scale). If the maximum number of soundings (6 to 7 / unit area $40x40m^2$) corresponds to a “High variability” (10 on the scale) we could consider a linear variation and construct an “objective function” to rely “soil variability” to the number of soundings.



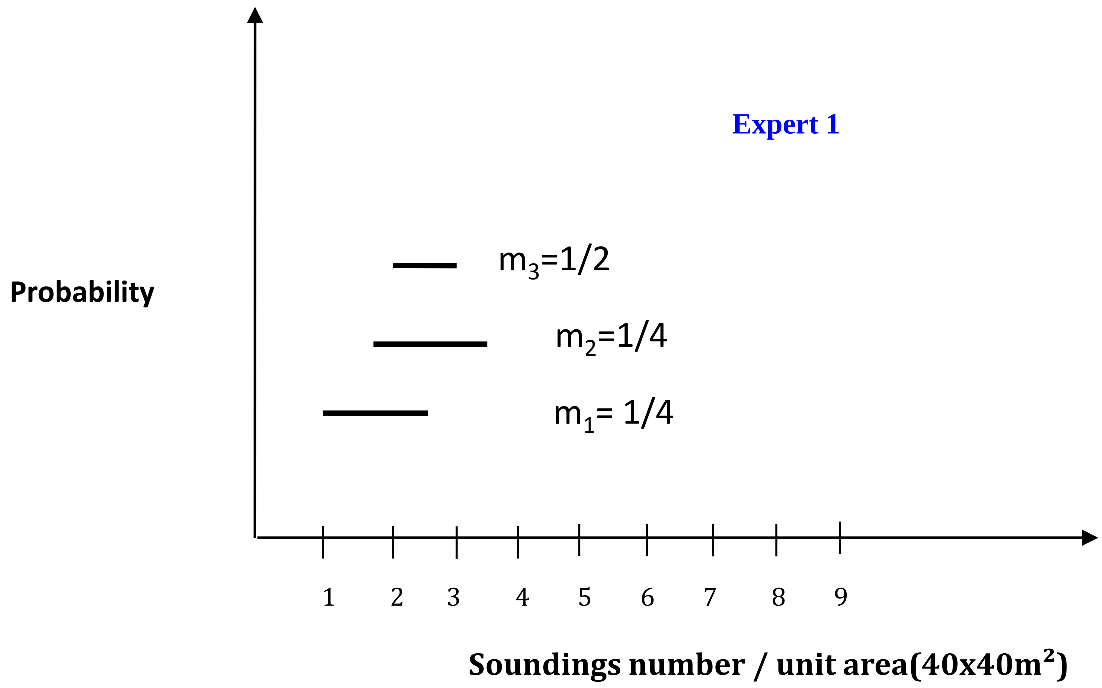
Objective function f(x), point to point approach

The obtained "objective function" permits to calculate the number of soundings based on soil variability

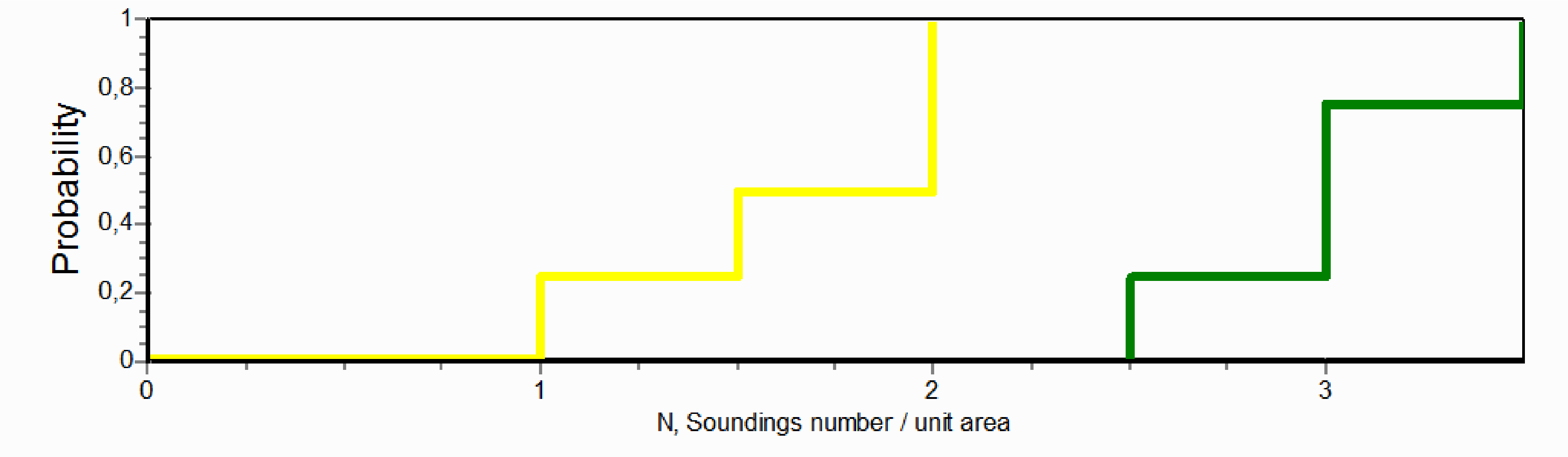
- **Example**:
- Expert 1 gave the following number of soundings upon a "low" **soil variability**, with a degree of belief $\mathbf{m_i}$ for each case.
- Soil variability = [0,3]; n_1=2 ; m_1= ¼
- Soil variability = [1,5]; n_2=3 ; m_2= ¼
- Soil variability = [2,4]; n_3=3 ; m_3= ½

- Using **f(x)** we obtain for the number of soundings / unit area (40x40m^2) as shown in the next fig.:
- Number of soundings [1, 2.5], m_1=1/4 ;
  [1.5, 3.5], m_2=1/4 ,
  [2, 3], m_3=1/2

The obtained random set on the number of soundings for **one** expert (and **one** parameter – Soil Variability)



- The next step is the construction of the upper and lower probabilities,
- Have an estimation of the soundings number on site according to one expert.



The suitable number of soundings per unit area is comprised in the probability box .

Reported to the total area of the project we will obtain the optimal number of soundings for the geotechnical investigation.

Upcoming work;

- Application on real situations
- Considering more than one expert using one parameter (an aggregation is necessary).
- Taking into account different parameters that affect a geotechnical investigation (with several experts).

CONCLUSION

- A random set-based approach is introduced to estimate the number of soundings for geotechnical investigations.
- As a first step we used only one parameter (soil variability) to construct the random sets. For certain soil variability degree between [1,10] the expert will give the corresponding number of soundings (with a degree of belief m_{ij}).
- Using Eurocode7 recommendations for site soundings, we constructed an “objective function” f(x) to rely “soil variability” to the number of soundings.
- This function permits constructing the random set and obtain the number of soundings by unit area for each expert (engineer).
- The proposed system needs to be run with different experts and different parameters (soil variability, geology….) and then aggregate them together to obtain a suitable upper and lower probabilities for estimating the number of soundings on site.

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THANK YOU