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‘’ BIBLIOGRAPHIC REVIEW ON SOIL-STRUCTURE INTERACTIONS OF PYLONS’’

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Abstract

The aim of our study was to find the ideal method for studying the soil-structure interactions (SSI) of guyed towers or masts. The main difficulty was finding behavioral laws and models capable of integrating the 22 parameters that had been identified.

To do this, we reviewed the literature from the last 20 years. We grouped the various models into tables and graphs. There is no single excellent method for calculating the structure of soil-structure interactions (SSI). However, we found that there are three main methods:

-  The sub-structure method integrates 47% of 22 parameters.
-  The direct method (Global) integrates 47% of 22 parameters.
-  The hybrid method integrates 53% of 22 parameters.

The most widely used method is hybrid because it combines the advantages of the other two, such as sophisticated 3D modeling, probabilistic approaches, and new in-situ testing technologies (triaxial and cyclic loading tests).

But our results are limited because they are a function of the works that have been available to us over the last 20 years. They are not fixed; they evolve over time and space.

Keywords: Model, Parameter, Interaction, Soil-structure, Pylons

1. Introduction

The soil-structure interaction of pylons refers to all the phenomena that occur between a structure (such as a power line pylon, telecommunications tower, or mast) and the soil that supports it. This interaction is crucial for ensuring the stability and durability of the structure under various stresses (static, dynamic, seismic loads, etc.). Proper modeling of this interaction is essential to guarantee the stability and longevity of pylons.

The aim of our study was to find an outstanding method for studying the soil-structure interactions (SSI) of guyed towers or masts. The main challenge was to derive behavioral laws with a greater number of parameters.

To achieve our goal, we have summarized the literature review and methods from the past 20 years. A statistical analysis has been conducted, and the results are presented in various tables and graphs.

2. Methodology

According to Demolon Albert (1934), soil is a living part of the geosphere, naturally formed at the surface. It has a loose structure of variable thickness and results from the transformation of the underlying bedrock under the influence of various physical, chemical, and biological processes.

The structure is the framework of a building. It is an assembly of load-bearing structural elements that distributes the applied forces throughout the entire structure for balance reasons.

The tower is a self-supporting steel lattice structure with a rectangular or triangular cross-section. The guyed mast tower is a steel lattice structure with a rectangular or triangular cross-section, or a cylindrical steel structure, stabilized at different levels along its height by guy wires anchored to the ground.

2-1 Evolution historique des interactions sol-structure de 1848 à 2007.

The study of soil-structure interactions dates back to the 19th century and has progressively evolved and matured into the second half of the 20th century as follows:

Table 1: Evolution of soil-structure interaction modelling

N°	Author (s)	Objet	Date
1	William Thomson	"First fundamental solution: harmonic analysis (displacements). (Lord Kelvin)"	1848
2	George Gabriel Stokes	Solution for point forces varying with time in an infinite medium. This resolution is the foundation of the boundary element method.	1849
3	Gabriel Lamé, B. Paul Emile Clapeyron	"Effect of loads on an infinite or semi-infinite elastic body (half-space). The authors mathematicians and engineers were in the early 19th century.	1820 to 1831
4	Joseph Valentin Boussinesq	Loading of a semi-infinite elastic space (closed form) for a disk on the ground.	1878
5	Friedrich Engesser	Study of the stability and load-bearing capacity of foundations. He worked on soil mechanics theory.	1893
6	Karl Von Terzaghi	Founder of soil mechanics. He studied theories and their evolution in response to geotechnical realities.	1930
7	Sezawa,K.,and Kanai,K.	Study of a cylindrical pile with a tip in a homogeneous soil mass.	1935

8	Dr Eric Reissner	Official publication of the soil-structure interaction theory. A simplified method without computers and using the mass-spring system.	1936
8	Dr Erich Reissner et Sagoci	First closed-form solution (formula) for mixed boundary value problems. He also addressed the issue of an excited semi-infinite elastic space.	1944
9	Quinlan	Dynamics of loaded plates on semi-infinite spaces and infinite depth strata.	1953
10	Sung, T.Y.	Dynamics of loaded plates on semi-infinite spaces and infinite depth strata.	1953
11	Bycroft, G.N.	Dynamics of loaded plates on semi-infinite spaces and infinite depth strata.	1956
12	Warburton, G.B.	Dynamics of loaded plates on semi-infinite spaces and infinite depth strata.	1957
13	Pierre Yves Bard	Deformation mode (rotation, bending, translation) of soils based on their nature. The foundation is the analysis of soil deformation..	1957
14	Housner, G.W.	Deformation mode (rotation, bending, translation) of soils based on their nature. The foundation is the analysis of soil deformation.	1957
15	R. A Parmelee	Dynamics of loaded plates on semi-infinite spaces and infinite depth strata.	1967
16	Roscoe and al ; Schofield et Wroth	Elastic-plastic behavior laws of clays. Soil Mechanics Group of the University of Cambridge.	1958 et 1968
17	Barkan, D.D.	Publication of the foundations. However, the book is no longer relevant.	1962
18	Thomson, W.T., and Koberi, T.	Dynamics of charged plates on semi-infinite spaces and infinite-depth strata.	1963
19	Awojobi and Grootenhuis.P	Dynamics of charged plates on semi-infinite spaces and infinite depth strata.	1965
20	Iwan	Rheological model for the soil. This model is based on the plastic behavior of the soil.	1967
21	Gladwell, G.M.L.	Dynamics of charged plates on semi-infinite spaces and infinite depth strata.	1968

22	Mauricio A. Sarrazin, et al	Study of the behavior of shallow foundations. They used Maurice Parmelee's 1960 model	1972
23	Rice Éminent professeur	Response of a structure subjected to dynamic loads. It modeled the ISS system using a spring-damper system.	1975/ 1977
24	WOLF J. P	He worked on a simplified method that replaces the actual contact surface with an equivalent circular disk. Here, the center should coincide with the center of gravity on the actual contact surface.	1985 et 1988
25	R. Nova* and L. Montrasio*	Macro-element study of foundation settlement on a frictional soil subjected to the action of an inclined and eccentric load. They performed a nonlinear analysis of ISS in the irreversible behavior of the soil beneath the foundations.	1991
26	Pierre Yves Bard and al	Deformation mode (rotation, bending, translation) of soils based on their nature, natural vibration period, and damping rate.	1992
27	Crème and al.	Macro-element method for the analysis of soil-structure dynamic interaction. $U_{tot} = U_{el} + U_{pl} + U_{decol}$. Non-linear study, with plasticity coupled to delamination.	2001
28	Chatzigogos and al.	They formulated macroelement models (plasticity and detachment) based on Cremer's work. They discovered a new macroelement structure.	2007

2-2 Direct or global method

This method consists of directly modeling the structure (tower, foundation) and the soil simultaneously as a coupled system. The modeling is carried out without resorting to decoupling simplifications between the structure, the foundation, and the supporting soil. Modeling is performed using the Finite Element Method (FEM) or the Finite Difference Method. This method consists of directly modeling the structure (tower, foundation) and the soil simultaneously as a coupled system. The modeling is carried out without resorting to decoupling simplifications between the structure, the foundation, and the supporting soil. Modeling is performed using the Finite Element Method (FEM) or the Finite Difference Method.

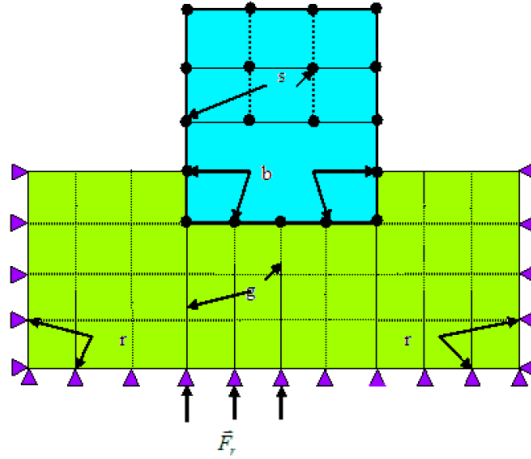


Diagram 1: Soil-structure system

$$\text{The equation of motion is: } \bar{M} \cdot \ddot{u} + \bar{C} \cdot \dot{u} + \bar{K} \cdot u = P = -\bar{M} \bar{I} a \quad (\text{Éq. 1})$$

Where \bar{u} : displacement vector. the acceleration : a . \bar{I} : A vector containing 1. P : Applied load vector. \bar{M} , \bar{C} , et \bar{K} The mass, damping, and stiffness matrices of the system.

2-3 Substructure method or superposition principle

This is a fundamental approach to the analysis of soil-structure interactions in pylons. The aim here is to simplify the complex study by breaking it down into several subsystems (soil, foundation, and structure) that are easier to analyze.

Using Fourier transforms in the frequency domain, we have:

$$U = \sum \tilde{U} (\bar{w}_n)^{i\bar{w}_n t} \quad (\text{Éq. 2})$$

Analytical models (structure and soil) provide the following equations :

$$\text{For the structure, we have : } -w^2 \begin{bmatrix} m_B & 0 \\ 0 & m_{FB} \end{bmatrix} \begin{bmatrix} \tilde{U}_B \\ \tilde{U}_F \end{bmatrix} + \begin{bmatrix} K_{BB} & K_{FB} \\ K_{FB} & K_{FF} \end{bmatrix} \begin{bmatrix} \tilde{U}_B \\ \tilde{U}_F \end{bmatrix} = \begin{bmatrix} 0 \\ \tilde{P}_F \end{bmatrix} \quad (\text{Éq. 3})$$

$$\text{For the floor, we have: } -w^2 \begin{bmatrix} M_{FS} & 0 \\ 0 & M_S \end{bmatrix} \begin{bmatrix} \tilde{U}_F \\ \tilde{U}_S \end{bmatrix} + \begin{bmatrix} K_{FF} & K_{FS} \\ K_{FS} & K_{SS} \end{bmatrix} \begin{bmatrix} \tilde{U}_F \\ \tilde{U}_S \end{bmatrix} = \begin{bmatrix} -\tilde{P}_F \\ 0 \end{bmatrix} \quad (\text{Éq. 4})$$

B: Structure displacement. S: Soil displacement, F: Soil-structure interaction displacement. FB:

Degree of freedom of the structure subsystem. FS: Degree of freedom of the soil subsystem.

La condensation se modélise comme suit : $\tilde{S}_F(\bar{w}) \tilde{U}_F^I(\bar{w}) = -\tilde{P}_F(\bar{w})$.

The SF matrix is the 'impedance matrix' of the foundation. The nodal forces are :

$$-w^2 \begin{bmatrix} M_B & 0 \\ 0 & m_{FB} \end{bmatrix} \begin{bmatrix} \tilde{U}_B \\ \tilde{U}_F \end{bmatrix} + \begin{bmatrix} K_{BB} & K_{FS} T^T \\ T^T K_{FS} & T^T K_{FF} + \tilde{S}_F T \end{bmatrix} \begin{bmatrix} \tilde{U}_B \\ \tilde{U}_F \end{bmatrix} = \begin{bmatrix} 0 \\ \tilde{S}_F U_F^* \end{bmatrix}$$

This approach is illustrated by the following figure.:

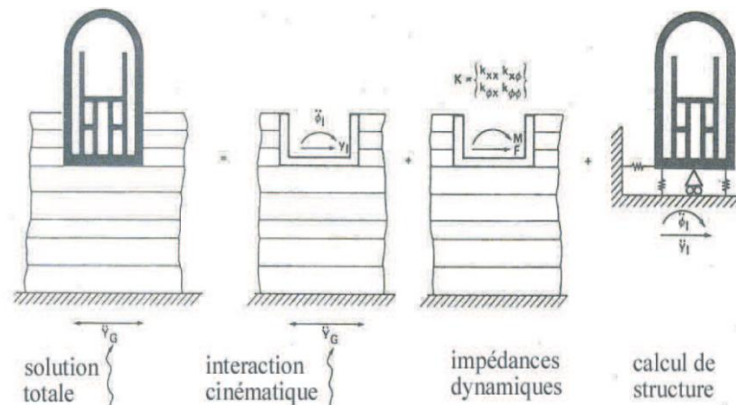


Diagram 2 : Soil-structure interaction for substructures

2-4 Méthode hybrides

It combines the advantages of both the direct and substructure methods. The hybrid approach divides the system into far-field and near-field sub-domains. The method integrates the superstructure and can also be processed using the direct method. It uses numerical, empirical, and analytical modeling as follows:

- ✓ **Numerical modelling** uses advanced calculation software (such as finite elements or discrete elements) to simulate the interactions between soil and structure.
- ✓ **Empirical analysis** integrates experimental data from in situ or laboratory tests to validate and adjust numerical models
- ✓ **The analytical approach** uses simplified theoretical solutions to understand specific aspects of interactions.

The key factors influencing the hybrid method are :

- ✓ **Sols argileux Soil type:** clay, sand, rock, etc.:
- ✓ **Foundation depth:** shallow or deep foundations.
- ✓ **Applied loads:** Static, dynamic (wind, earthquake, traffic).
- ✓ **Environmental conditions:** climatic variations, erosion, soil liquefaction

2-5 Summary

The application of these approaches has led to significant advances. With the direct approach, it is now possible to conduct a local interactive study, observe the progressive evolution of failure, and analyze the behavior of the tower under seismic effects. With the substructure approach, it is now possible to simplify the study by breaking it down into several

sub-systems (soil, foundation, and structure) that are easier to analyze. The hybrid method, on the other hand, enables significant advances, such as sophisticated 3D modeling, the application of probabilistic approaches, and new in situ testing technologies, such as triaxial and cyclic loading tests.

3- Results

3-1 Summary of Models from 2003 to 2024

A summary study of the contributions, methods, parameters, and authors was carried out as follows :

Table 2 : Synthesis of Soil-Structure Interaction Models for Pylons from 2003 to 2024

Date	Author (s)	Object	Method	Contributions
2003	F.Belhamel et al,	Ensure the reliability of the pylon for a minimum service life of 20 years.	Utilize the Finite Element Method (FEM) and the UBC 1997 regulations.	Determination of loads and the bearing capacity of the soil.
2004	M. Gioffre	Study the wind forces and determine the aerodynamic coefficients on guyed pylons.	Experimental testing in the wind tunnel, numerical modeling, and sensitivity analysis of the structure.	Determine the drag and lift coefficients on the main structure.
2007	A.L. Materazzi, I. Venanzi	Examine the stability of the guyed pylon under the action of gusting winds.	Equivalent Static Analysis of Linear Structures	Incorporation of the gust wind coefficient in the structural analysis.
2009	Giuseppe Vairo	Propose a methodology for analyzing the elastic behavior of guyed cables by optimizing the second-order equation.	The catenary theory and the Dischinger-Ernst formulation	The description of the nonlinear elastic behavior of guy wires
2011	S. Ali Ghafari Oskoei.	Proposal of a calculation model for the overall stiffness of guyed pylon cables under seismic loads..	Simplified methods.	Development of a simple and efficient method for analyzing the overall behavior of guy wires..

2011	Ningli Zhu and al,	Study the systematic validation and calibration of existing analytical models for correlation with the full-scale pylon data.	Experimental studies and wind tunnel tests.	The studies showed that the wind gust factor load approach is not suitable for guyed masts.
2012	M. Harte and al.	Study of forced vibration analysis along a wind turbine pylon.	Eulerian and Lagrangian modeling, impedance functions, motion equations, and standards.	They showed the influence of soil-structure interaction on bending moment, rotational speed, and frequency.
2012	S. Ali Ghafari Oskoei	Provide a quick seismic analysis method for guyed pylons.	Numerical modeling with a local approach.	Development of a quick analysis approach for vulnerability assessment.
2015	ABIR JENDOUBI	Assessment of soil-structure interaction on the dynamic behavior of an electrical energy pylon.	Numerical simulation (FLAC code), finite element method, finite difference method.	He demonstrated the effect of dynamic loads in the foundation calculations.
2015	Ilaria Venanzi	Propose a simple model for the optimal calculation of excited guy wires.	The deterministic and optimistic method, the probabilistic method, calculation using the Latin Hypercube Sampling (LHS) technique.	Reduces computation time and costs of the structure, considers variable, stable, and dynamic loads.

2016	Junqi Chen	Study the influence of soil-structure interaction on the vibration behavior of pylon structures in power lines..	Finite element method, and 3D numerical modeling and simulation.	He demonstrated the realistic behavior of soil-structure interaction effects on the pylon (displacements and forces)
04/6/2017	Kolousek Vladimir,	Study of the buckling of the guyed pylon with static and dynamic calculations.	Analysis of natural and forced vibrations.	Address the problem of the pylon's natural vibrations.
2017	Gian Felice Giaccua	Study the pre-tension forces of guyed cables in the structure of guyed pylons..	The displacement method, average linear and nonlinear approach, using a safety factor	Using safety factors to size the guy wires, and utilizing pre-tension forces to stabilize dynamic loads
2017	Thiago B. Carlos	Static and dynamic study of the transmission line pylon structure.	Static and dynamic study of the transmission line pylon structure	Determine displacements and stresses, static analysis of equivalent loads, dynamic behavior analysis of the structure.
2018	Sami Alshurafa	Integrate Glass Fiber Reinforced Polymers (GFRP) into the pylon structure.	Experimental tests, theoretical analysis, Finite Element Method (ANSYS).	Reduces costs, increases structural rigidity, and decreases maximum tensile and compressive stresses.
2018	Jorge S. Ballaben · Marta B. Rosales	assurer l'équilibre du pylône pour un meilleur service par la précontrainte initiale des câbles haubans.	Euler–Bernoulli theory, nonlinear equations, Newmark algorithm, and Newton-Raphson 3D.	The formulation with a large number of elements shows the complexity of obtaining results for

				the overall pylon structure at the structural scale.
2021	David GUILBEA ULT	Study the influence of foundation flexibility on the load recovery in pylons.	Analysis using simplified theories, open-source software Code_Aster.	Evaluate the effects of foundation flexibility on the structural response; considering foundation flexibility may lead to an increase in the overall strength of pylons.
2022	Luiz Eduardo Fernandes Sequeira	Study the plastic behavior at failure of guyed cables under the influence of static and dynamic loads.	Rupture and plasticity calculations, finite element method, linear and nonlinear calculations, free and damped forced vibration analyses, Fourier transforms.	Quantification of the influence of the loss of one or more cables, dimensioning the structure with consideration of both dynamic and static effects.
2024	Majid Bahari	Study the rigidity of the soil-foundation system. Analyze the effects of differential settlements. Enhance the safety and reliability of pylons	Advanced numerical modeling techniques and nonlinear incremental static analysis..	Design pylons suited for complex conditions.

Table 3 : Simulation software for soil-structure interactions.

Software	Objective	Observations
Code FLAC (Fast Lagrangian Analysis of Continua)	Simulations of soil-foundation interaction with boundary elements.	Determine the impedance values for static and dynamic loads.
Calculation code PLAXIS.	simulation complexe des fondations	
The ASTER – MISS3D code	It allows the consideration of soil-structure interaction (soil-foundation + superstructure) through frequency coupling validation methods.	Calculation code designed to solve numerical simulations in mechanics (e.g, soil-structure interaction), thermo-hydro-mechanical, and other associated phenomena using the MMC and FEM
The CESAR-LCPC calculation code.	Numerically model the nonlinear dynamic behavior of the soil.	A set of software (MAX+CESAR+PEGGY) that uses the finite element method.
The Matlab software	It allows evaluating the behavior of soil-structure interaction in the fourth generation, within a simple syntax numerical calculation software.	Matlab allows matrix calculations, developing and executing algorithms, creating user interfaces (UIs), and visualizing data.
Composite Module Columns (CMM)with Rigid Inclusions and granular mattress (IR)	A numerical modeling of Composite Module Columns (CMM) systems and the systems of Rigid Inclusions and granular mattresses (IR).	A numerical modeling of Composite Module Columns (CMM) systems and Rigid Inclusions and granular mattress (IR) systems.
le code de calcul SAP2000	Numerical modeling providing a response spectrum and time-domain analysis for Soil-Structure systems.	It is a structural analysis program that allows calculating internal forces, processed by the computer

Code-Bright	This software simulates soil-structure interactions for swelling soils using the finite element code.	Digitization is done using the BExM model.
The ABAQUS software.	It is a finite element calculation software. It performs multi-physics numerical simulations.	ABAQUS was developed by Dassault Systèmes.
OpenSees software	It is a software that simulates (2D) the behavior of the superstructure, foundation, and soil under seismic loads.	It is a software well-suited for seismic loading.
LS-DYNA	It is a software that analyzes the linear or nonlinear behavior of soil-structure interactions using finite element codes in the time domain.	It is a fast finite element analysis software for dynamics developed by Livermore Software Technology Corporation, acquired by Ansys, Inc. in 2019.
PLAXIS 3D	It is a geotechnical modeling and numerical simulation software that analyzes soil-structure displacement in 3D using the finite element method.	The Plaxis software uses two supplementary modules: Dynamics and Plaxflow.
FedeasLab dans Matlab	Numerically model the nonlinear response of soil-structure interaction.	It is a macroelement that uses the finite element code.

Ansys Structure	The software allows for numerical simulation and prediction of the mechanical behavior of the soil-structure interaction phenomenon in its environment.	It is a software editor specialized in numerical simulation used to predict the mechanical behavior of a material within its environment.
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Table 4 : Simulation software for soil-structure interactions.

N ^o	Parameter	Models and Date																			n	%
		A ₂	B ₂	C ₂	D ₂	E ₂	F ₂	G ₂	H ₂	I ₂	J ₂	K ₂	L ₂	M ₂	N ₂	O ₂	P ₂	Q ₂	R ₂	S ₂		
		2003	2004	2007	2009	2011	2011	2012	2012	2015	2015	2016	2017	2017	2017	2018	2018	2021	2021	2024		
1	Wind Pressure	Ok	Ok	Ok	Ok	Ok	Ok	Ok		Ok	Ok	Ok	Ok		Ok		Ok	Ok	Ok		15	79 %
2	Approach to substructure				Ok	Ok		Ok	Ok		Ok	Ok				Ok	Ok			Ok	9	47 %
3	Seismic field + ISS					Ok		Ok													2	11 %
4	simplified method		Ok			Ok									Ok			Ok			4	22 %
5	Finite Element Method	Ok				Ok					Ok	Ok				Ok	Ok	Ok	Ok	OK	9	47 %
6	Ground-Structure Interaction (GSI) without Earthquake	Ok							OK		Ok	Ok						Ok		Ok	6	31 %
7	Experimental tests or wind tunnel		Ok				Ok			Ok						Ok		Ok			5	26 %

8	Analytical Models			Ok			Ok						Ok		Ok					Ok	5	26 %
9	Non-linear behavior			Ok						Ok			Ok		Ok	Ok	Ok	Ok	Ok	Ok	8	42 %
10	Elastic and Linear Behavior			Ok	Ok					Ok			Ok								4	22 %
11	Glass Fiber Reinforced Polymers														Ok						1	5,5 %
12	Pre-tensioning of stay cables												Ok			Ok					2	11 %
13	Dynamic analysis		Ok							Ok		Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	8	44 %
14	Direct approach		Ok	Ok			Ok		Ok				Ok	Ok			Ok		Ok	Ok	9	47 %
15	Probabilistic Method								Ok												1	5,5 %
16	static analysis		Ok										Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	9	47 %
17	Numerical modeling and simulation		Ok			Ok		Ok	Ok		Ok	Ok		Ok	Ok		Ok	Ok		Ok	11	58 %
18	fundamental equations of motion			Ok					Ok	Ok	Ok		Ok	Ok	Ok	Ok					8	44 %
19	Forced vibrations								Ok	Ok	Ok							Ok			4	22 %
20	Proper vibrations								Ok	Ok	Ok		Ok					Ok			5	28 %

21	Hybrid Method		Ok	Ok	Ok	Ok	Ok	Ok	Ok		Ok	Ok		Ok	Ok	Ok	Ok	Ok		Ok	3	80 %
22	temperature							Ok													1	5,5 %
	Number parameter	4	9	8	5	8	6	7	8	7	13	7	7	9	9	9	9	11	7	9		
	% parameter	18%	40%	36%	22%	36%	26%	32%	36%	32%	59%	32%	32%	40%	40%	40%	40%	49%	32%	40%		

Table 5 : Authors of Models for Structural Analyses of Pylons from 2003 to 2024

N°	Designation	Date	Observation
1	F. Belhamel et al,	2003	A ₂
2	M. Gioffre 2004	2004	B ₂
3	A.L. Materazzi, I. Venanzi 2007	2007	C ₂
4	Giuseppe Vairo	2009	D ₂
5	S. Ali Ghafari Oskoei	2011	E ₂
6	Ningli Zhu and al	2011	F ₂
7	S. Ali Ghafari Oskoei,	2012	G ₂
8	M. Harte and al	2012	H ₂
9	Ilaria Venanzi	2015	I ₂
10	Abir JENDOUBI	2015	J ₂
11	Junqi Chen	2016	K ₂
12	Kolousek Vladimir	2017	L ₂
13	Gian Felice Giaccua	2017	M ₂
14	Thiago B. Carlos	2017	N ₂
15	Sami Alshurafa	2018	O ₂
16	Jorge S. Ballaben and al	2018	P ₂
17	David GUILBEAULT	2021	Q ₂
18	Luiz Eduardo Fernandes Sequeira	2022	R ₂
19	Majid Bahari	2024	S ₂

3-2 Statistical analysis of parameters from 2006 to 2024

For $n' =$ number of years = 19 *et* $n =$ Parameters = 22.

- The arithmetic mean of the parameters is; $\bar{x} = \frac{\sum_{i=1}^n x_i}{n'} = \mathbf{6,84}$ (Éq. 5)

The percentage is: $\frac{\bar{x}}{n} = \frac{6,84}{19} = 0,37 \rightarrow \mathbf{36,00\%}$ of Parameters.

- The variance $v = [(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots + (x_n - \bar{x})^2] \frac{1}{n} = \mathbf{3,92}$ (Éq. 6)

- the standard deviation of = $\sigma_{ecart-type} = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2}$, (Éq. 7)

Soit $\sigma_{ecart-type} = \mathbf{1,55}$.

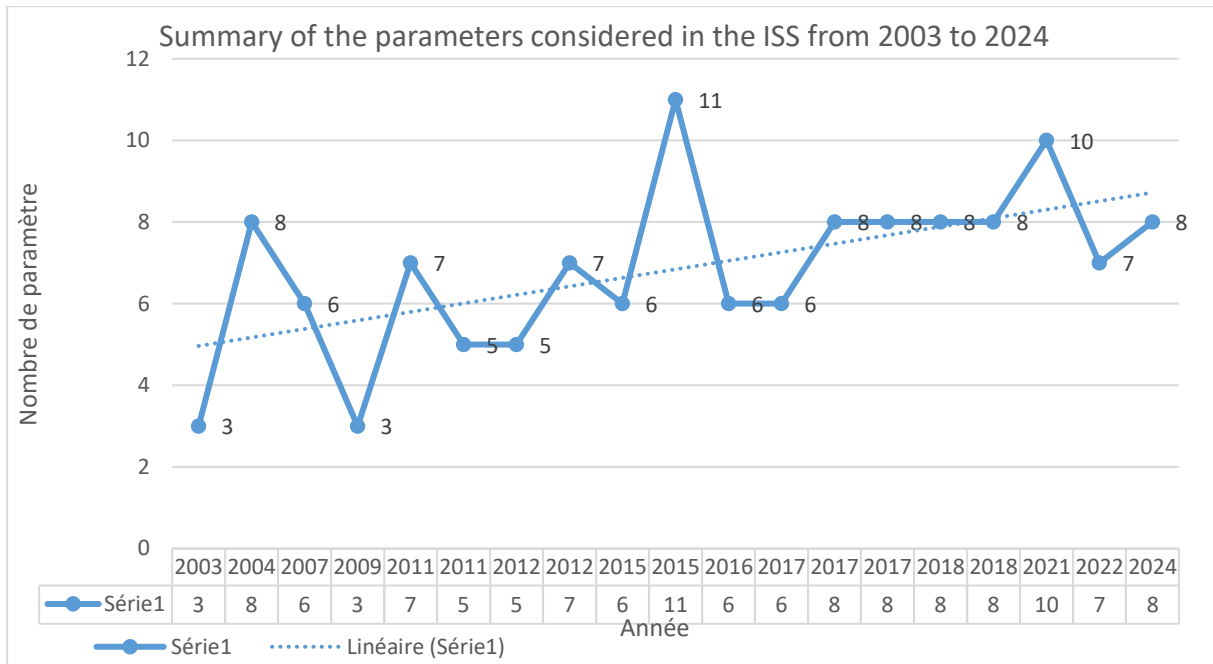


Diagram 3 : Parameter assessment, substructure method (2003 to 2024)

4 Discussion

We have grouped together three main methods: direct, overlay, and hybrid. Each method has its own limitations and advantages.

The direct method allows for the optimization of the safety and durability of pylons right from the design stage. However, numerical modeling remains complex, as the model requires considerable computing power. It also necessitates the use of high-capacity computing tools."

The sub-structure method takes full account of both linear and non-linear behavior. However, simplifications of complex 3D interactions remain approximate, which can lead to the neglect of certain important effects, such as heterogeneous or anisotropic soils.

The statistical study showed us that the hybrid method is the most widely used. An example is the Ilaria Venanzi model with 15 parameters. The hybrid method offers considerable advantages in terms of accuracy and optimization. However, it has limitations in terms of complexity, data requirements, and cost. Its implementation requires advanced expertise, adequate resources, and a good understanding of the uncertainties inherent in soil properties.

5- Conclusion

The aim of our study was to find the ideal method for analyzing soil-structure interactions (SSI) of pylons or guyed masts. The challenge was to find a model capable of considering as many parameters as possible. To achieve this, we reviewed the literature from the last 20 years. The main parameters were grouped into percentages as follows:

- ✚ The analytical approach to dynamic and static calculations is based on 47% of 22 parameters.
- ✚ The sub-structure method has 47% on 22 parameters.
- ✚ The direct method (scale to structure) has 47% on 22 parameters.
- ✚ The hybrid method has 53% on 22 parameters.
- ✚ The numerical simulation method has 47% on 22 parameters.

This study has shown that there is no single best method. Each method is used according to its target objective. However, the hybrid method is the most widely used, as it combines the advantages of the other two. We have also noted that there have been major advances, such as the use of sophisticated 3D modeling, probabilistic approaches, and new in situ testing technologies (triaxial and cyclic loading tests).

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Zeh Steve Brice : is in charge of conceptualization, data curation, Formal analysis, investigation; methodology, Writing – review and editing.

Okpwe Mbarga Richard: Writing – original draft

Baana Abouar: Software, Visualization.

Mamba Mpele : Validation, Supervision, Project administration.

The final manuscript has been read and approved by all authors.

Data availability

Information about this study is available to the corresponding author on reasonable request.

Competing interest

The authors state that there is no conflict of interest linked to financial interests or personal relationships.

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