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RESEARCH ARTICLE

IMPULSE RESPONSE METHOD APPLIED TO THE GROUND ANCHORS

Jean-Jacques Rincent

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Abstract

The test, a mechanical impulse in the axis of the tie rod, leads to obtain a vibrational response of the tested element. This allows to calculate the total and free lengths of the tie rod. The dynamic stiffness obtained from this vibratory response is related to the tensile force in the tie rod. This article concerns the analysis of tension forces values in tie rods less than 3 months and 4 months after their construction. The results are interesting and raise the question of controlling the tensioning process of tie rods.

Introduction:-

Method

This method for diagnosing tie rods is widely used in Brazil, where 3,000 tie rods have been tested over the last four years, with eight tests carried out on each tie rod. This article has therefore been written based on the experience gained during the analysis of these 24,000 tests. This expertise is complemented by the analysis of static tensile test results. For each contention wall, at least two direct tensile tests are carried out, during which dynamic tests are perf ormed simultaneously.A compression wave generated by an impact made with a hammer equipped with a force sensor induces a vibratory response. The attachment of the geophone to the metal plate in contact with the head of the tie rod is essential, it is unrealistic to expect to measure the dynamic stiffness of an element with a poor attachment.Our procedure is as follows: stick a small plate onto the cleaned metal plate and secure the geophone by screwing the 3D geophone support

Figure 1 Test devices

Corresponding Author:-Jean-Jacques Rincent

The acquisition made in the time domain is transformed into the frequency domain to produce the curve Velocity/Force as a function of frequency.

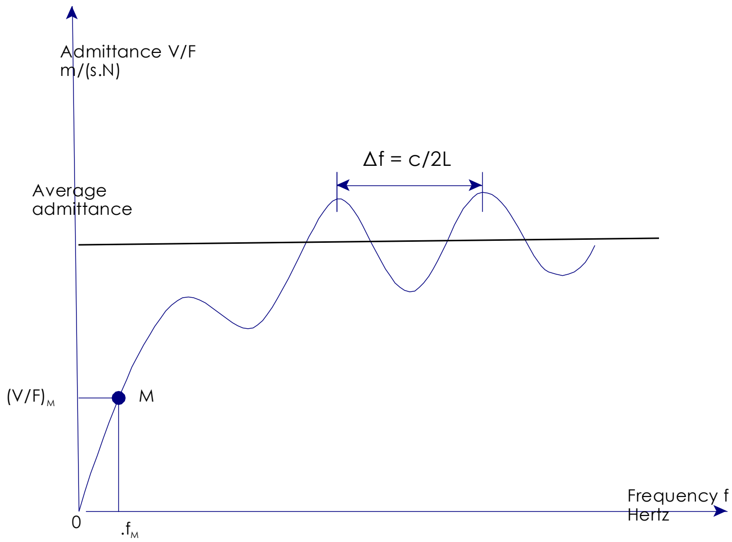

Figure 2Velocity/Force as a function of frequency
C wave velocity in the anchor, m/s
F Force of the hammer impact, N
V velocity of the anchor head m/s
V/F Admittance, m/(sN)
The vibration response obtained is used to calculate the total length of the tie rod, the free length, and the equivalent diameter of the tie rod with the grout adhering to the reinforcement.

The example chosen is a recent wall where the request was to determine the short-term evolution of tension in the tie rods. This wall has 49 tie rods, 20% of which have been tested.

Figure 3 General view of the wall

The curve below is representative of the type of curve obtained on tie rods with the responses of the elements encountered in this configuration.

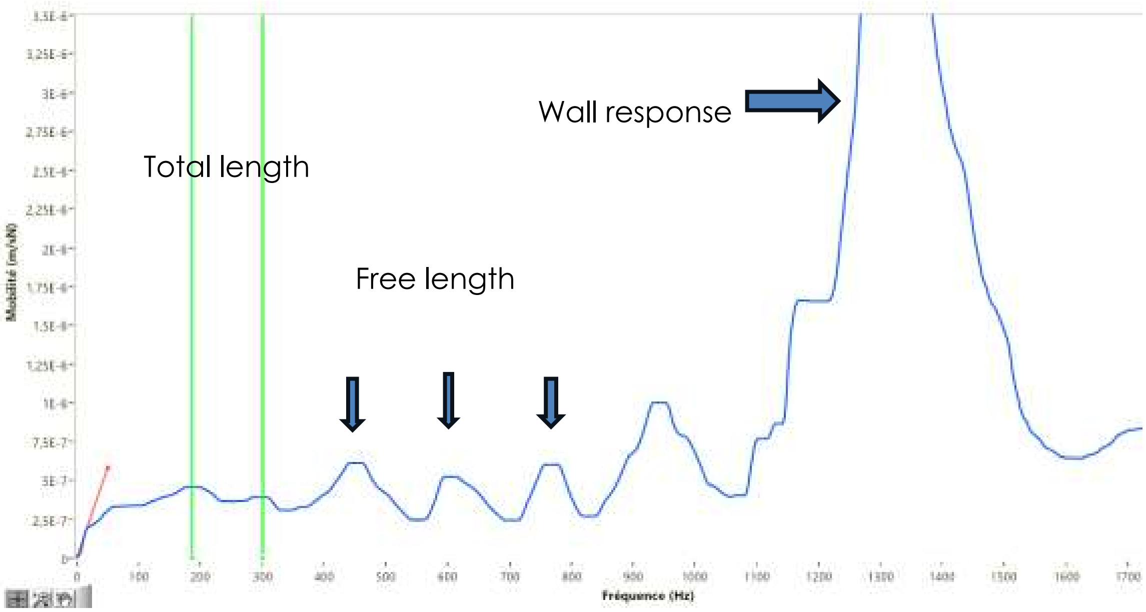

Figure 4 Typical response curve

Mechanical impedance is the inverse of mechanical admittance or mobility. Mobility as a function of the cross section of the tested element:

$V/F = 1 / \rho_b V_b A$

V/F m/sN

Wave velocity in the tie rod V_b m/s

Concrete volume mass ρ_b in kg/m3

Cross section area A (m²)

In our example the average mobility is V/F = 4,7E-7 m/(s.N) which corresponds to an equivalent diameter of 0.53 m. The shape of the tie rod with its cement grout is in fact oblong and more developed towards the bottom.This type of calculation makes it possible to detect the presence of cement bulbs stuck to the retaining wall.

Dynamic stiffness – Force:

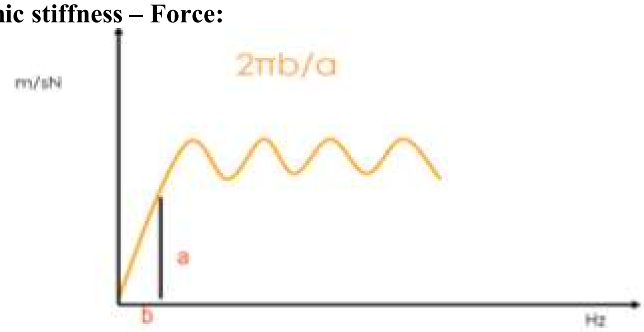

Figure 5 -Dynamic stiffness

La raideur dynamique est égale à 2πb/a et est un nombre complexe. La réalisation simultanée d'essais statiques et d'essais non destructifs permet de construire la figure ci-après.

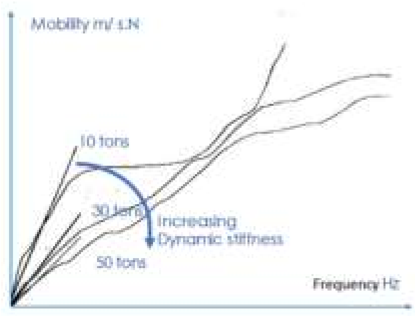

Figure 6 Increase of the dynamic stiffness as a function of the tension force

Dynamic stiffness is related to tensile force by the following relationship:

$(R_d)^{1/2} = aF + b$

Where Rd is the dynamic stiffness and F is the tensile force. It should be noted that for each wall undergoing dynamic testing, at least two static tests are carried out, with the particularity that at each level, dynamic tests are carried out to calculate the dynamic stiffness.

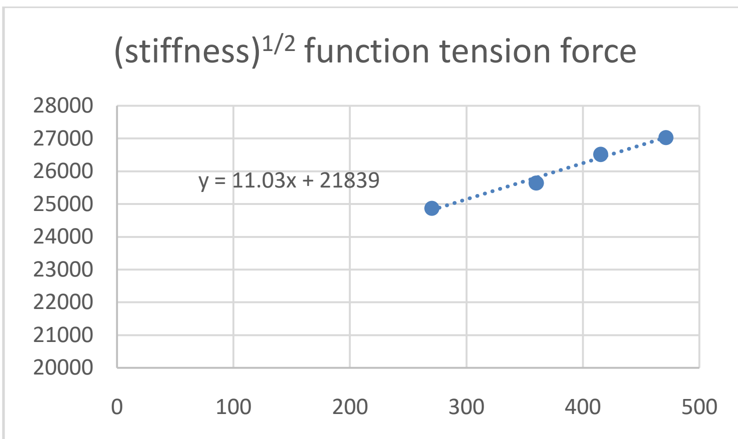

Figure 7 Example of curve

On this wall, two tensile tests were carried out simultaneously with dynamic tests. It is necessary to design a metal part that allows access to the head of the tie rod in order to carry out the dynamic tests at the same time as the static tensile test.

Figure 8 Testing device

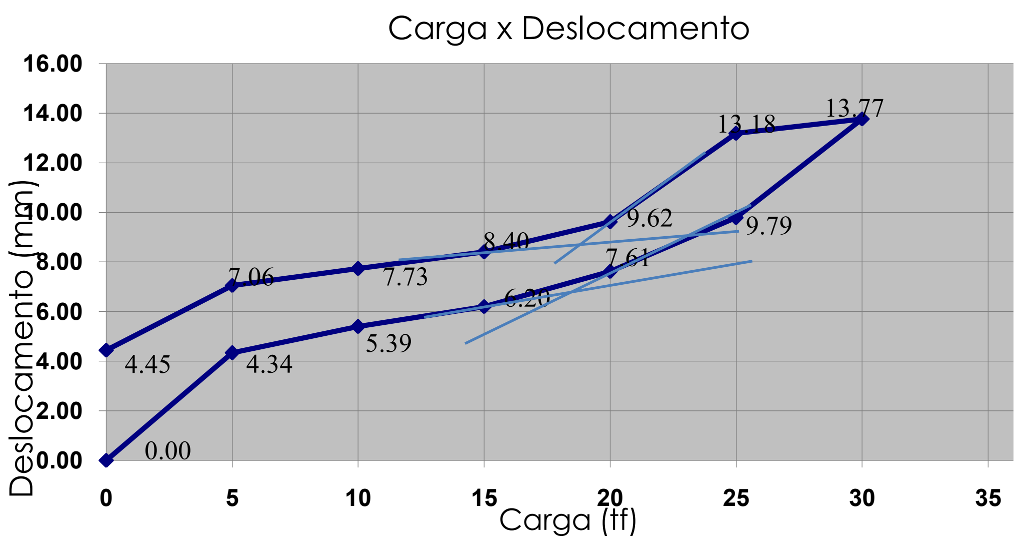

Figure 9 – Static test

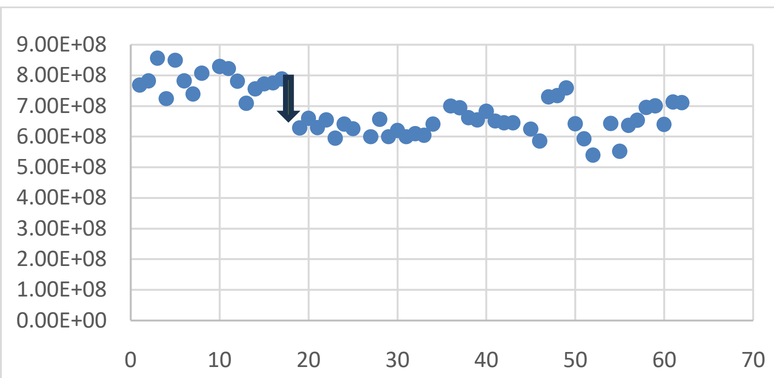

Figure 10–Dynamic stiffness (N/m) measured at each stage of unloading

The curve indicates a change in the behaviour of the tie rod when passing from the 20-tonne level to the 15-tonne level, which corresponds to the tensile force.

All of these tests make it possible to establish the formula that links dynamic stiffness and tensile force. La courbe indique un changement de comportement du tirant lors du passage du palier de 20 tonnes au palier de 15 tonnes qui correspond à la force de tension.

Tension values after three months:

The initial tension of these tie rods was 30 tonnesand the reinforcements are 32 mm diameter bars.The values of the tensions in tonnes obtained are as follows:

14,20	4,41
15,40	0
18,43	18,00
19,40	19,93
30,18	23,19

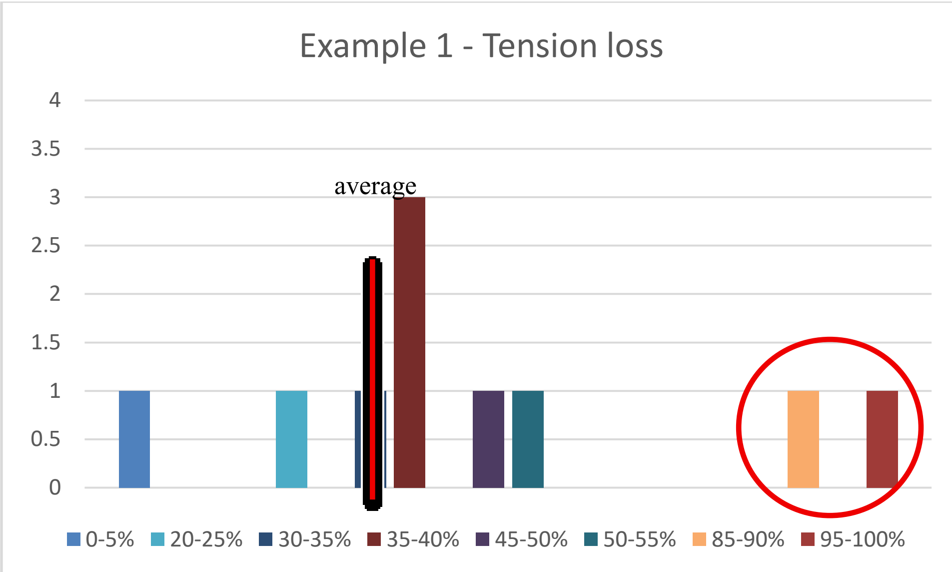

Figure 11Tension loss less than 3 months after tensioning

The average force is 16.31 tonnes. If we remove the two values below 5 tonnes, which are likely to be handling errors during tensioning, the average is 19.84 tonnes. The ratio of the average value to the tensioning force is 1.51, which is the safety coefficient taken into account in stability calculations. Equilibrium tension is reached less than 3 months after tensioning, with a tension 20 to 45% lower than the original tension. Note the two abnormally low values due to non-compliant tensioning.

Three types of behaviour can be identified:

- The first type corresponds to tie rods that have lost more than 80% of their tension value.
- The second, largest group shows stabilisation in a situation of equilibrium between soil thrust and the forces exerted by the tie rods.
- The third group concerns tie rods that have lost no tension; in general, this observation is linked to specific construction and implementation characteristics.

Second example

Figure 12General view of the retaining wall

On this wall, 37 tie rods were tested. The tension forces values are:

1		5		9		13		17	
	23,67		27,15		25,09		24,26		21,15
2		6		10		14		18	
	6,96		26,06		13,96		30,29		22,08
3		7		11		15		19	
	25,42		17,51		25,42		26,37		25,09
4		8		12		16		20	
	26,92		20,68		29,15		19,90		21,71
21		25		29		33		37	
	22,62		30,01		23,92		29,51		29,58
22		26		30		34			
	21,62		17,29		32,45		28,79		
23		27		31		35			
	18,26		11,70		31,92		30,22		
24		28		32		36			
	26,99		22,35		28,64		29,08		

Tension values in tonnes

Distribution of tension force values in the tie rods, initial tension was 35 tonnes:

	F in tonnes	En %	
1	5 à 10	2,70%	
2	10 à 15	5,41%	
3	15 à 20	8,11%	
10	20 à 25	27,03%	
16	25 à 30	43,24%	83,78%
5	Sup 30	13,51%	

Excluding the highest tension loss, the average tension is 24.63 tonnes, which is 1.42 times less than the tension setting value.

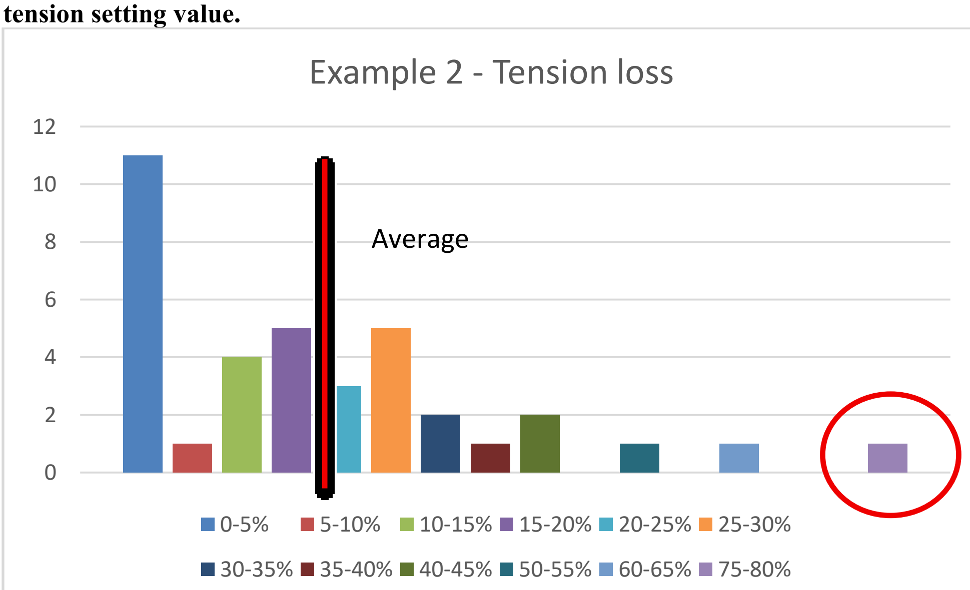

Figure 13 Tension loss less than 3 months after tensioning

Given the high number of tie rods that did not lose their initial strength, additional static tests were carried out up to 40 tonnes. The deformations measured are as follows:

Tie rod number	Deformation under 40 tonnes	Calculated length of bar under load
2	12mm	5,06m
10	11mm	4,64m
13	19mm	8,02m
17	8mm	5,91m
18	12mm	5,06m
27	14mm	5,91m

The length of the bar bearing the load takes into account the length of the bar used for the test, which is slightly more than one metre. Therefore, for most of these tie rods, there is a seal in concrete or cement grout in the immediate vicinity of the wall in the embankment, which affects the results of the static tests.
The deformation of tie rod 13 results in a stressed tie rod length of 8.02 m, which corresponds to the free length of 7.6 m calculated from dynamic tests and indicates normal functioning.

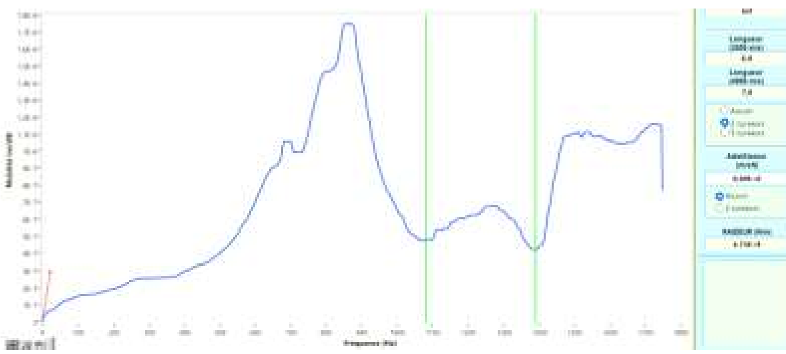

Figure 14
The operator conducting the tensile tests gives an internal tension of 25 tonnes, while the calculation based on dynamic stiffness gives 24.26 tonnes.
Generally, tie rods that do not lose load in the months following tensioning are often in a particular configuration. In this case, after investigation, it appeared that existing deep foundations were interfering with the operation of the tie rods.

Thirdexample:-
The thirdexampleoftensionloss comes fromworkcarried out byNelson Marcos Zeitoune:"Instrumentação e análise de uma cortina atirantada localizado no Km 74 da ferrovia Santos - São Paulo". Dec. 1982.
Instrumentation was carried out using conventional methods, i.e. extensometers, for four months after the ground anchors were tensioned. A total of 38 anchors were instrumented.

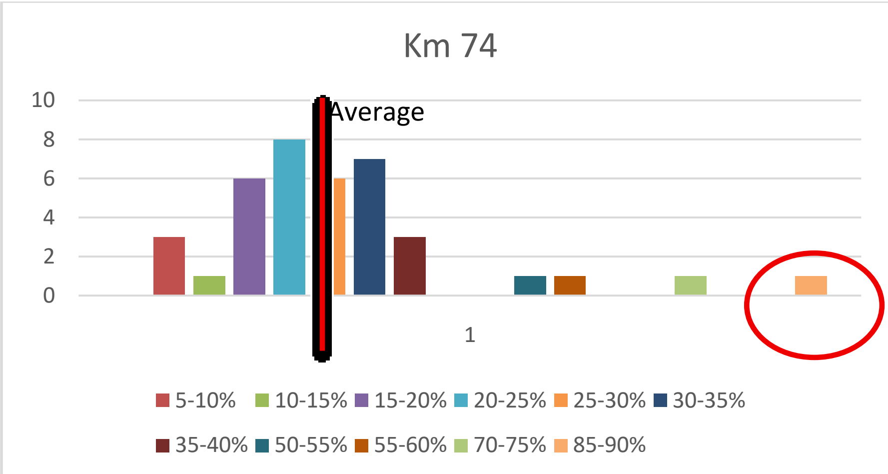

Figure 15 Loss of tension less than 4 months after tensioning

It is interesting to note that the same type of distribution appears. If the result where the voltage loss is 85-90% is removed, the average voltage loss is 27.19%, which corresponds to an equilibrium configuration and a safety coefficient of 1.37.

Conclusions:-

The mechanical impulse method is used to determine the internal tension of tie rods based on dynamic stiffness. This method is calibrated using static tests. Most of the tests were carried out on old tie rods that were 30 to 40 years old. The example here concern recent tie rods, where the aim is to measure the evolution of tension shortly after they have been tensioned. Three types of behaviour have been identified:

- A minority of tie rods where the initial tension varies little due to specific conditions
- The majority of tie rods are in a state of equilibrium where the tension is approximately 30% lower than the tensioning value
- Finally, another minority of tie rods which, for mechanical reasons, have lost more than 80% of their internal tension.

This diagnosis makes it possible to check the tension on all or a representative part of the tie rods and allows the identification of tie rods with high tension loss so that they can be re-tensioned.

Bibliography :-

1. Paquet J. (1968) Etude vibratoire des pieux en béton, réponse harmonique- Annales I.T.B.T.P.
2. Davis A.G. et Dunn C.S. (1974) From theory to field experience with non-destructive vibration testing of piles. https://doi.org/10.1680/iicep.1974.3895
3. Davis, A. G., and Robertson, S. A. (1975). ‘‘Vibration testing of piles.’’ Struct. Engrg., London, June, A7
4. Paquet J. Briard M. (1976) Contrôle non destructif des pieux en béton – Annales de l'ITBTP n° 337
5. Davis A.G. Guillermain P. (1979) Interprétation géotechnique des courbes de réponse de l'excitation harmonique d'un pieu. Revue française de géotechnique nº8.
6. Zeitoun N.M. (1982) Instrumentação e analise de uma cortina atirantada localizado no Km 74 da ferrovia Santos – São Paulo. Tese de Mestrado. Dpt. Eng. Civil Universidade católica de Rio de Janeiro.
7. Davis. A.G. The non-destructive impulse response test in North America: 1985–2001
8. https://doi.org/10.1016/S0963-8695(02)00065-8
9. Norme française NF P 94 160-4 Sols : reconnaissance et essais. Auscultation d'un élément de fondations partie 4 méthode par impédance. (1994)
10. Knothe K. Yu M. Illias H. (2002) Measurement and modelling of resilient rubber rail-pads System. Dynamics and long-term behaviour of Railway Vehicles Track and Subgrade, Concluding Colloquium of the DFG-Priority-Program Stuttgart
11. https://doi.org/10.1007/978-3-540-45476-2_16
12. Rincent JJ. - Method and device for determining the tensile stress exerted on a sealed element. Patent OMPI n° WO 2006/010830 A1, 2 February 2006.

13. Mitaine L. Rincent JJ. (2015) Innovative non-destructive technique for determining tension in ground anchors Revue Paralia Volume 8 pp s01.1-s01.7.
14. http://dx.doi.org/10.5150/revue-paralia.2015.s01
15. Wilquin F. Horb C. Feng Z.Q. Porcher G. (2016) Dynamic non-destructive evaluation of rock anchorage. 3rd international Rock Slope Stability.
16. HAL Id : hal-02416682 , version 1
17. Horb C. Saurel J. Rincent JJ. (2021) Preventive maintenance and non-destructive monitoring of rock anchorages Tools resulting from dynamic tests and their correlation with static tests. 5E Stabilité de la pente rocheuse RSS Symposium, Chambéry.
18. Ladiges S. Wark R. Rodd R. (2019) Maintenance and Testing of Post-Tensioned Anchors for Dams and Appurtenant Structures ANCOLD Proceeding of Technical Group.
19. Rincent JJ. (2023) Ensaios não destrutivos Análise vibratória Aplicações em Tirantes – Força. Livro RG EDITORES LTDA ISBN: 978-65-87604-77-0
20. Rincent JJ. (2024) Ground Anchors Tension Force—Vibratory Analysis https://doi.org/10.1007/978-981-97-4414-5
21. Rincent JJ. (2025) Anchors―Tests Procedures and Vibratory Analysis
22. https://doi.org/10.1007/978-981-96-3777-5
23. Coelho, E. G. C. ., Ferreira, L. D., Rincent, J.-J., Gomes, A. J. de L., Pereira, A. B., Fernandes, M. T., Elacoste, T. S. and Porto, T. B. (2025) "A study on dynamic non-destructive testing of ground anchorages - dynamic stiffness method", International Journal of Geoscience, Engineering and Technology , 11(1), pp. 19–30. Doi: 10.70597/ijget. v11i1.556