LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

RAILWAY SUBSTRUCTURE EVALUATION USING FWD

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Railway substructure evaluation using FWD – main issues

- MEASUREMENT SYSTEM - STUDIES PERFORMED ON AN EXISTING RAILWAY LINE
- CLIMATIC INFLUENCE - TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE
- LOAD INFLUENCE - TESTS PERFORMED ON PHYSICAL MODEL – GRANULAR VS BITUMINOUS
- INTERPRETATION - BACK-CALCULATION OF GRANULAR MATERIAL LAYERS
- CONCLUSIONS

MEASUREMENT SYSTEM

STUDIES PERFORMED ON AN EXISTING RAILWAY LINE

- FWD UPGRADE TO RAILWAYS
- LOAD PLATE ADDAPTED TO MEASURE ON BALLAST

STUDIES PERFORMED ON A OLD RAILWAY LINE

- The experimental studies presented in this work aimed to construct and evaluate four solutions for structural reinforcement of old railway tracks, maintaining the ballast layer as structural layer.

- Ballasted track section
  - 36 m long, (4 experimental sections)
  - Iberian gauge (1.668 m)
  - bi-block sleepers
  - limestone ballast.

Before reinforcement

- FWD upgrading for railways tests

Load tests – PLT and FWD before reinforcement

FWD

0.40 m diameter plate/ 500 kPa

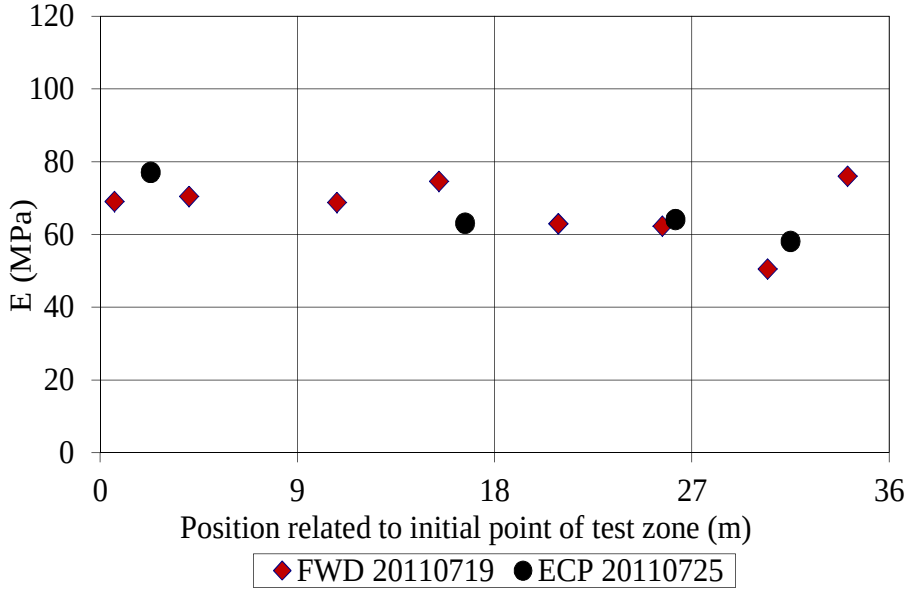
Plate load tests (PLT)

0.45m diameter plate / 200 kPa

PLT & FWD results

Deformation moduli (E)

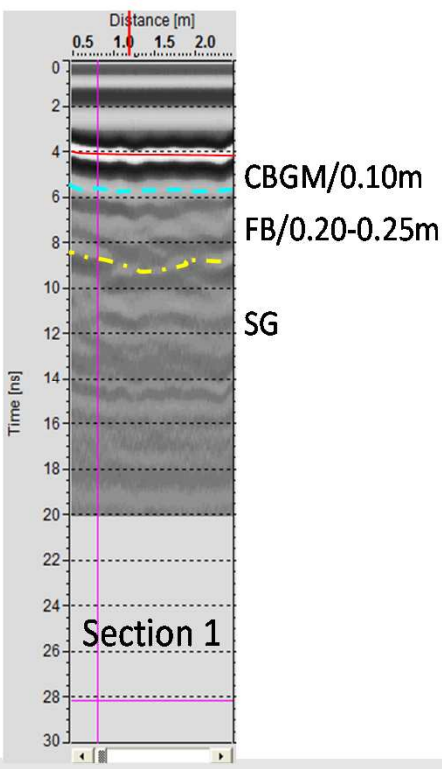
$$E = 0.75 . d \frac{p}{\delta}$$

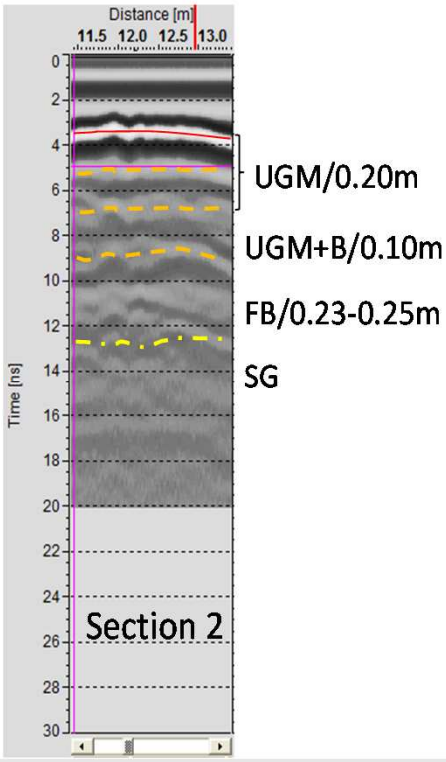


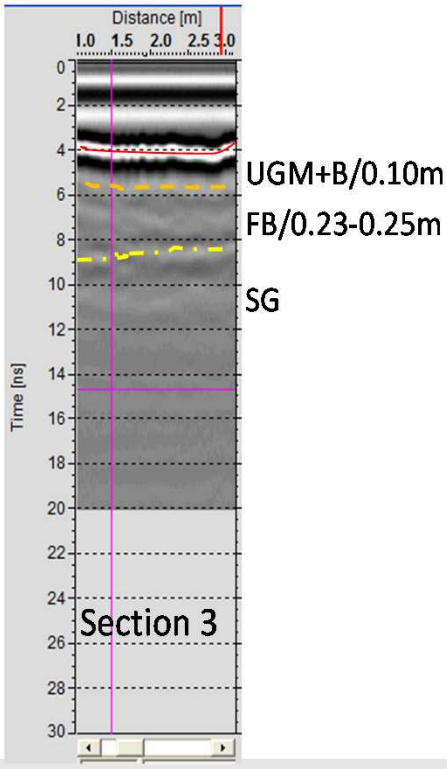
- 60 - 80 MPa existing
- 120 MPa design

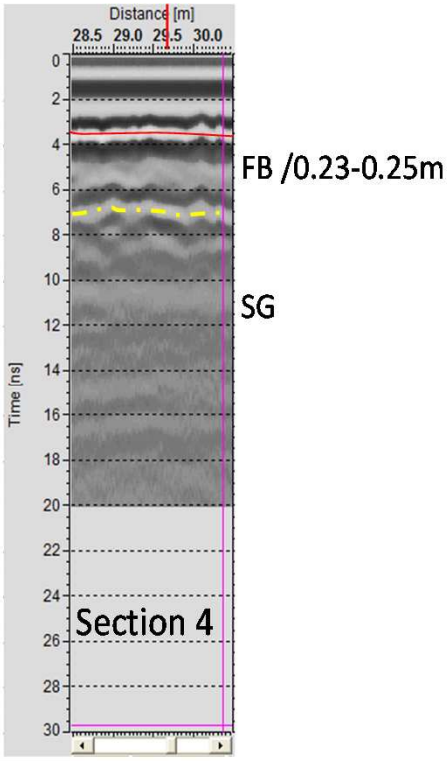
GPR results on experimental sections









Load tests on experimental sections

LFWD on the subgrade

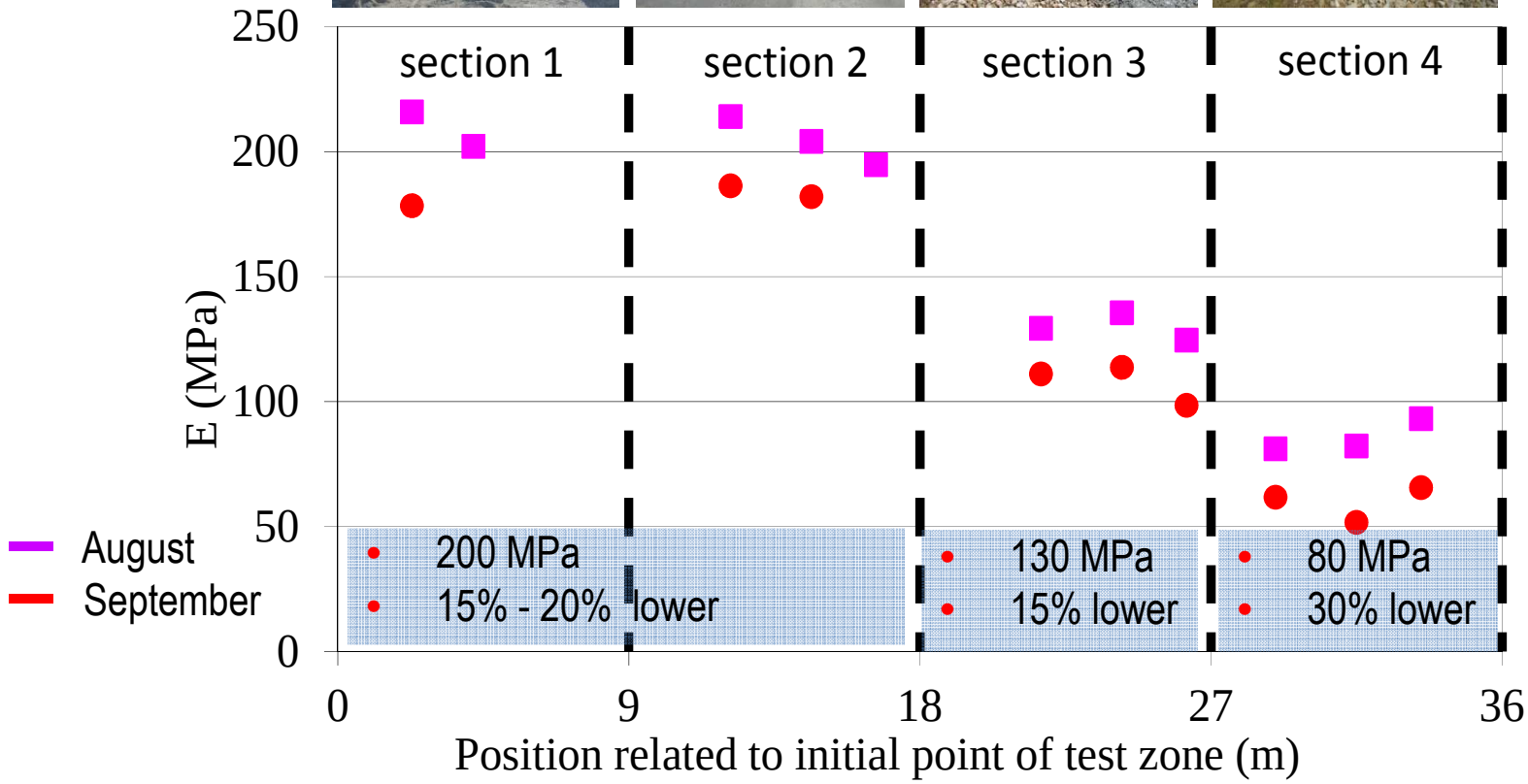
- 0.30 m diameter plate
- 200 kPa
- E ~ 70-80 MPa.

FWD on the top of the reinforcement

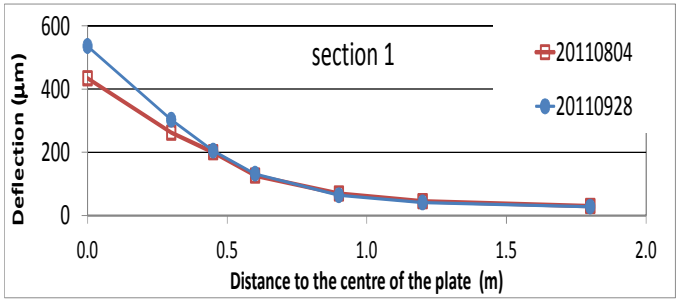
- 0.30 m diameter plate
- 400 kPa

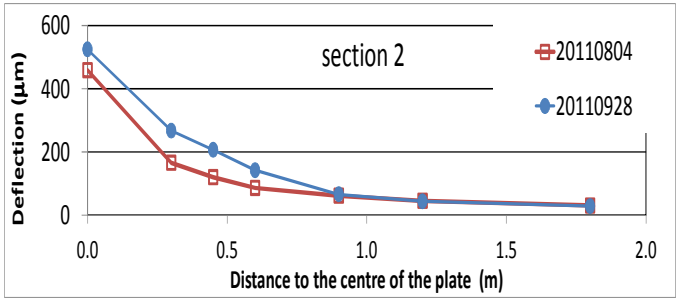
- 2 FWD test series
  - August
  - September

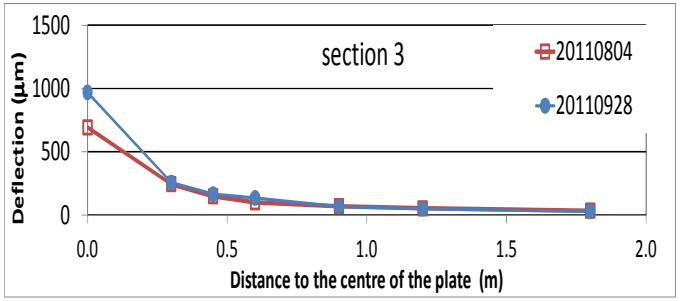
FWD results on experimental sections



FWD results on experimental sections







August
September

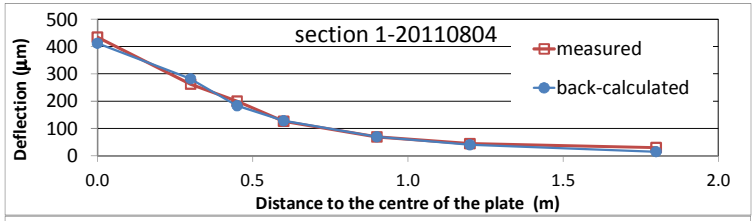
Backcalculation of FWD results

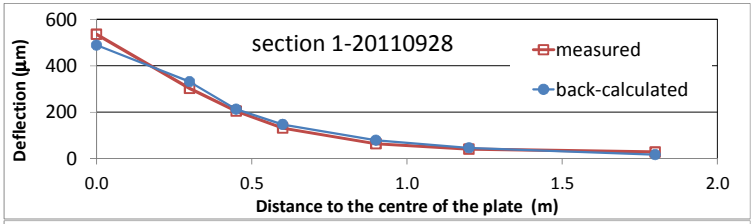
Deformation moduli obtained E (Mpa)

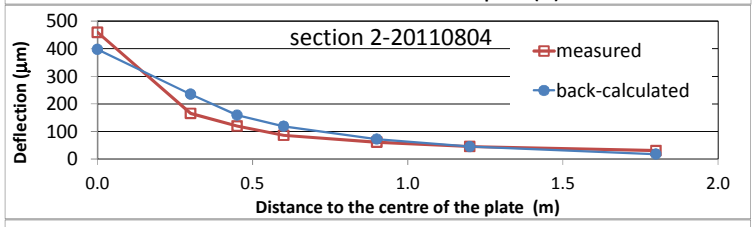
	FWD-August E (MPa)	FWD-September E (MPa)
Cement bound granular material (CBGM)	600	500
Unbound granular material (UGM)	150	120
UGM mixed with ballast (UGM+B)	180	160
Fouled Ballast (FB)	180	160
Subgrade (SG)	80	60

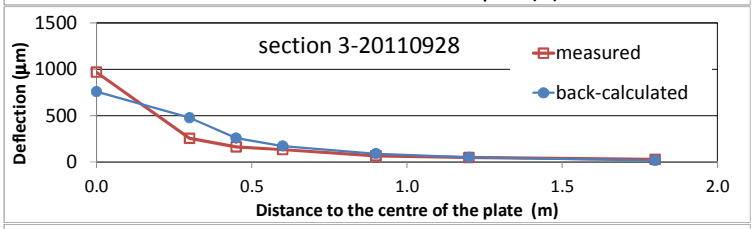
- UGM and fouled ballast modulus are adequate and similar to resilient modulus obtained in triaxial tests
- Subgrade soil modulus is similar to the LFWD results.
- Cement bound granular material modulus is low probably due to the difficulty of adequately mix the materials on site
- Decrease in the modulus values after rainfall: subgrade soils, UGM.

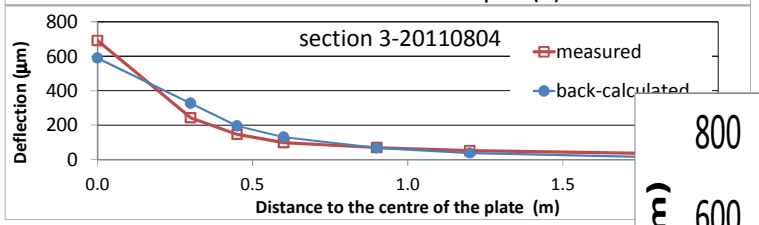
Backcalculation of FWD results

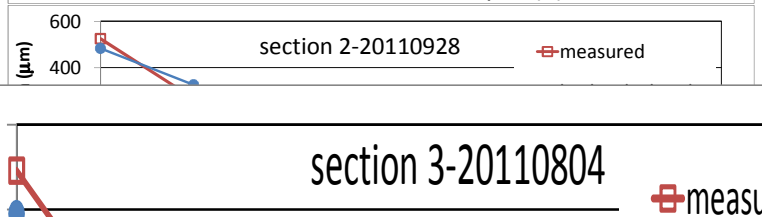












a)

DIFFICULIES IN BACKCALCULATION

CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

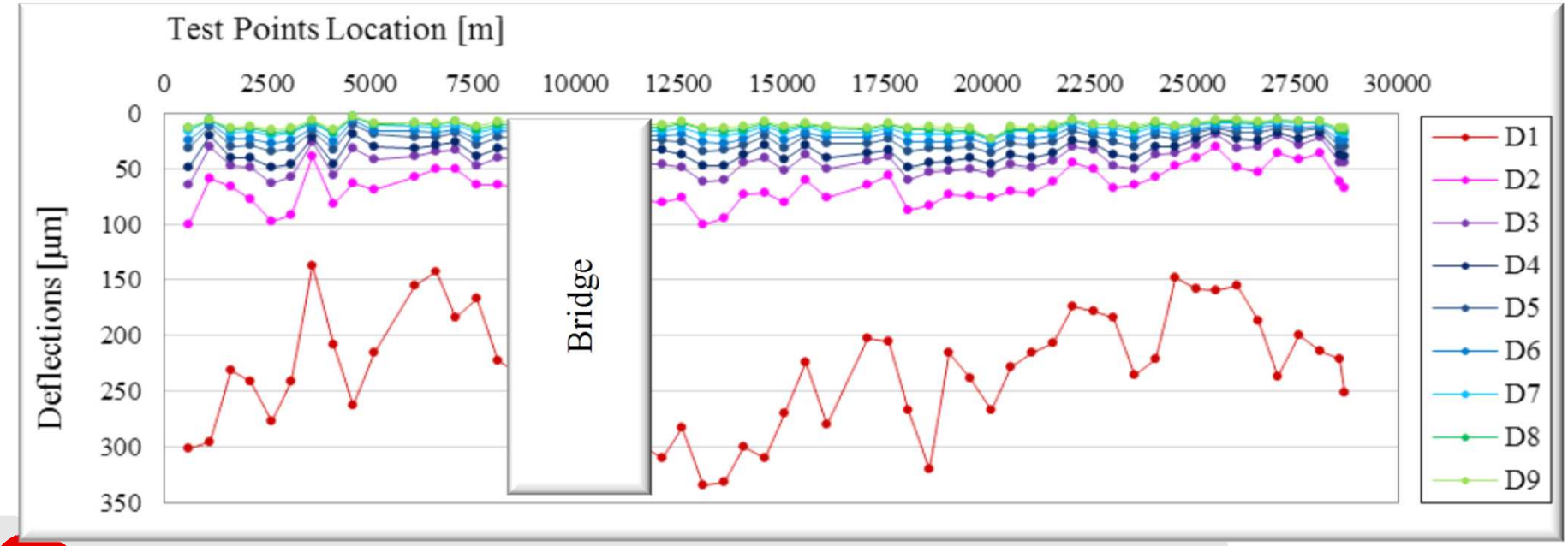
- E MODULI INCREASE DURING DRY WEATHER SIGNIFICANTLY
- MEASUREMENT PROBLEMS - DEFLECTION MEASUREMENT
- MEASUREMENT PROBLEMS - INCREASE NUMBER OF DROPS UNTIL DEFLECTIONS STABILISE
- DIFFICULIES IN BACKCALCULATION

CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

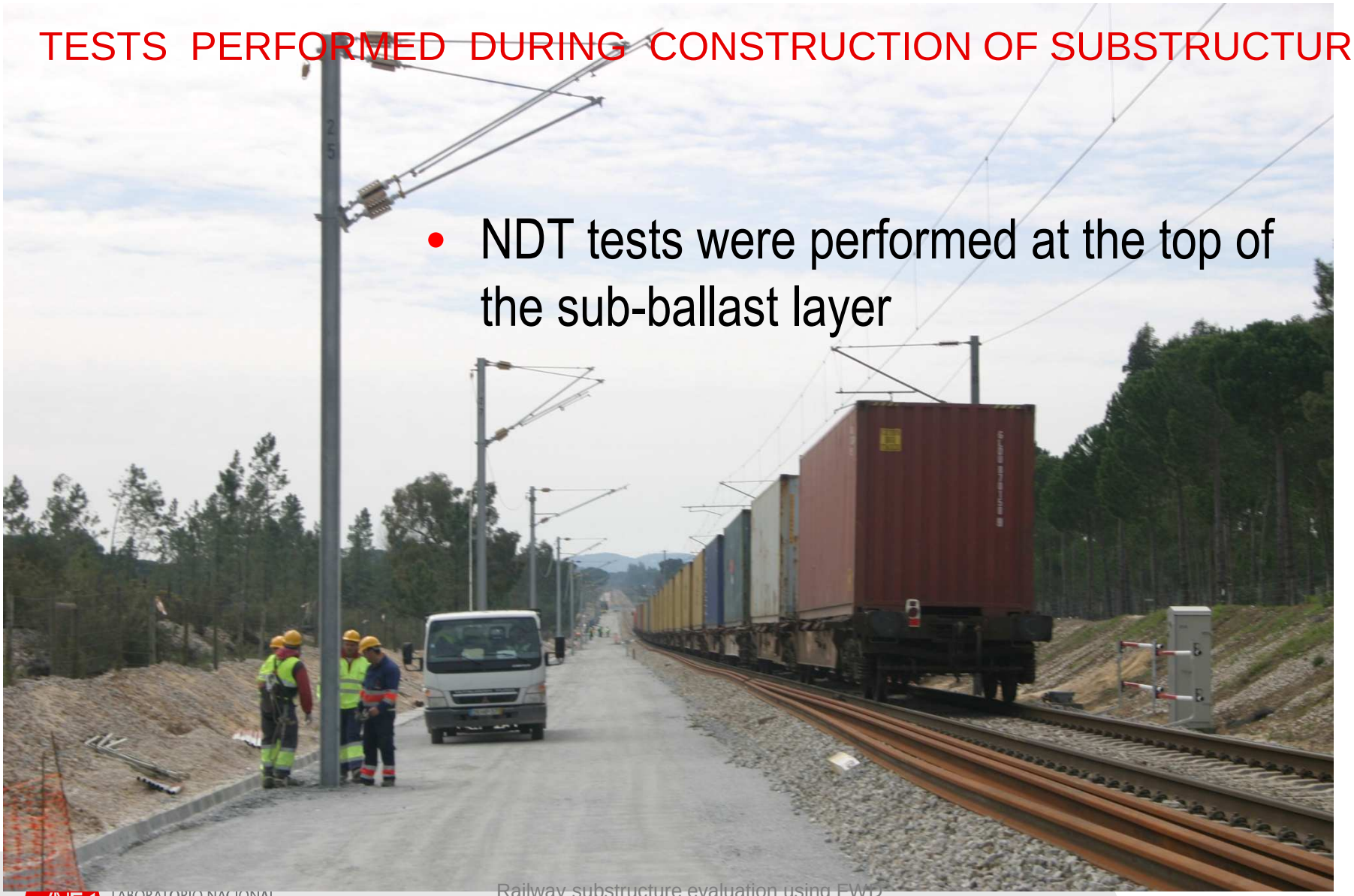
Falling Weight Deflectometer (FWD) tests were undertaken during the construction of a **29 km new railway line**, at the top of the substructure and in different months **November , December, January and March *(June)***

- **Quality control** during construction.
- Analyse and compare test results for **different climatic conditions**



CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE



- NDT tests were performed at the top of the sub-ballast layer

CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

- Several load levels
  - in service traffic
  - construction traffic
- Testing campaigns in different seasons

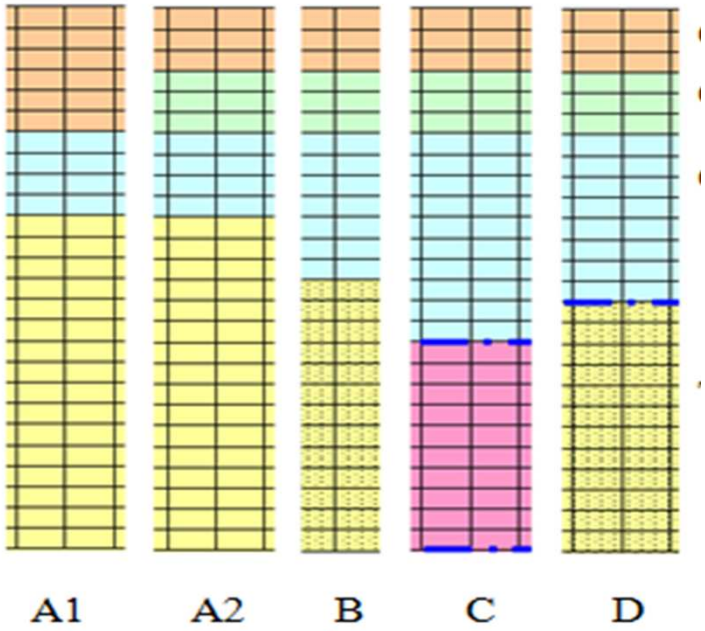
Several other tests were performed

- PLT
- HFWD
- Portancemetre

CLIMATIC INFLUENCE

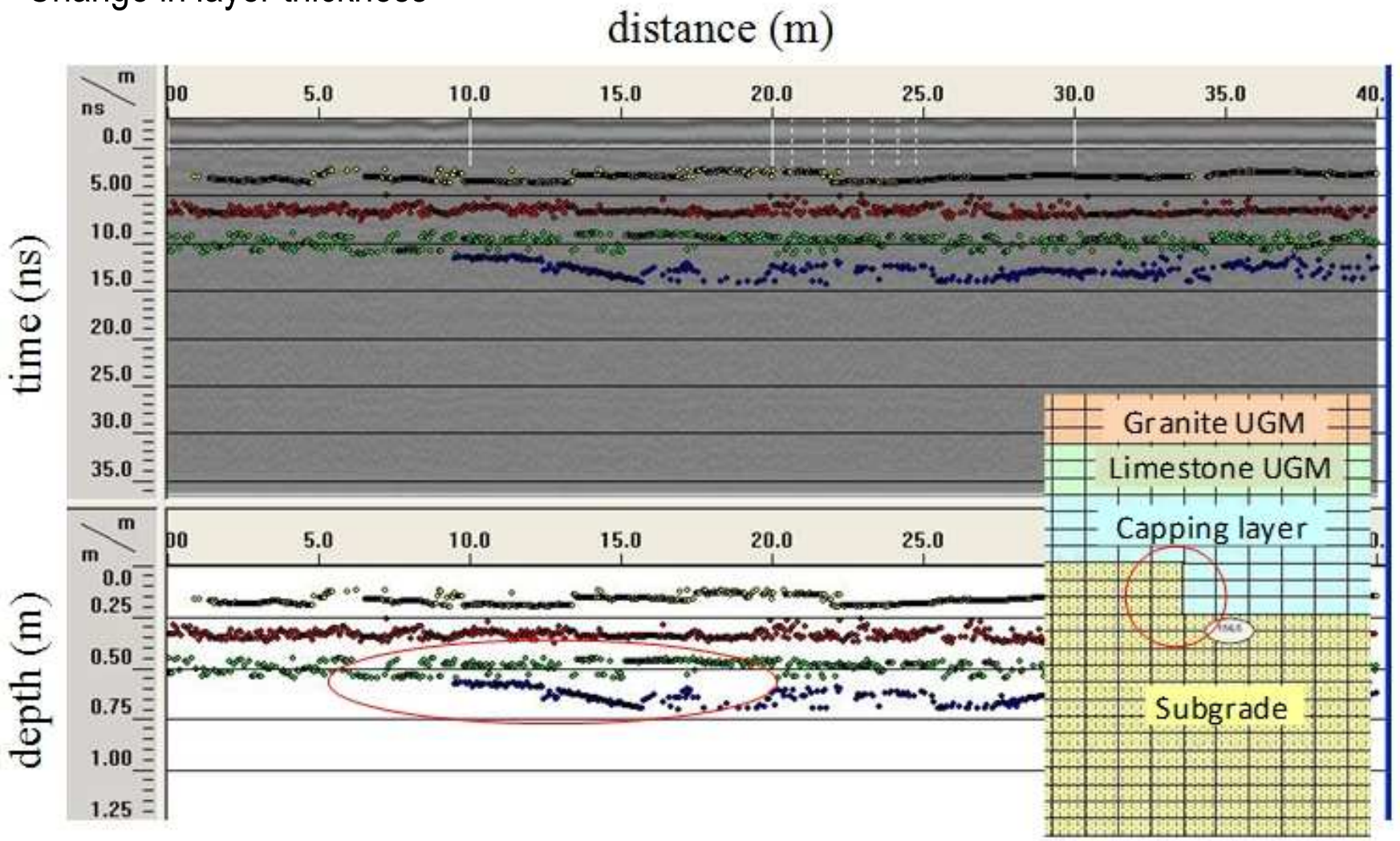
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Section	A1	A2	B	C	D
Sub-ballast (granite)	0.30 m	0.15 m	0.30 m	0.30 m	0.30 m
Capping layer (limestone)	0.20 m	0.35 m	0.35 m	0.50 m	0.40 m
Subgrade	0.80 m	0.80 m	0.65 m	0.50 m	0.60 m



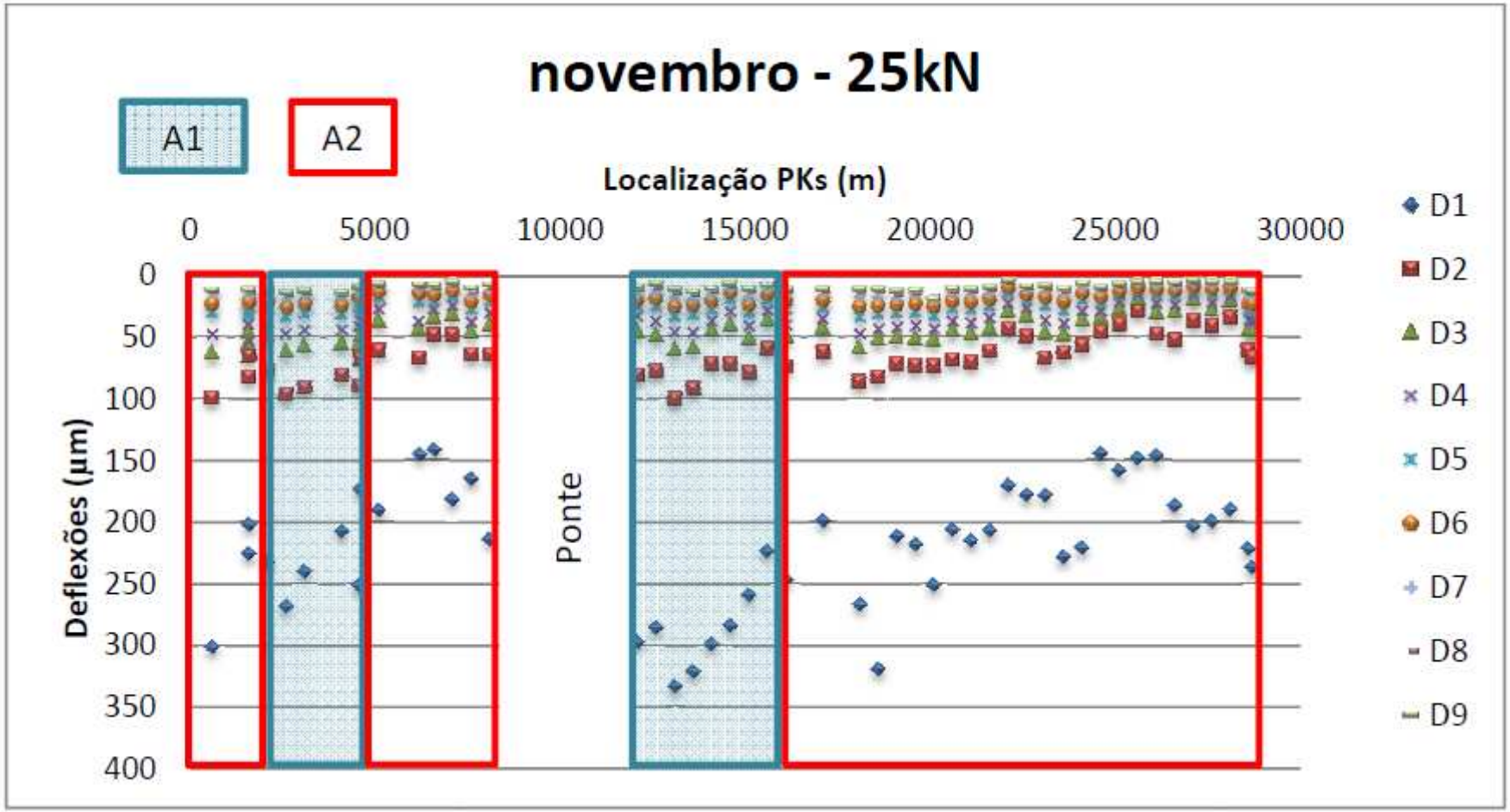
GPR MEASUREMENT

- Change in layer thickness



CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE



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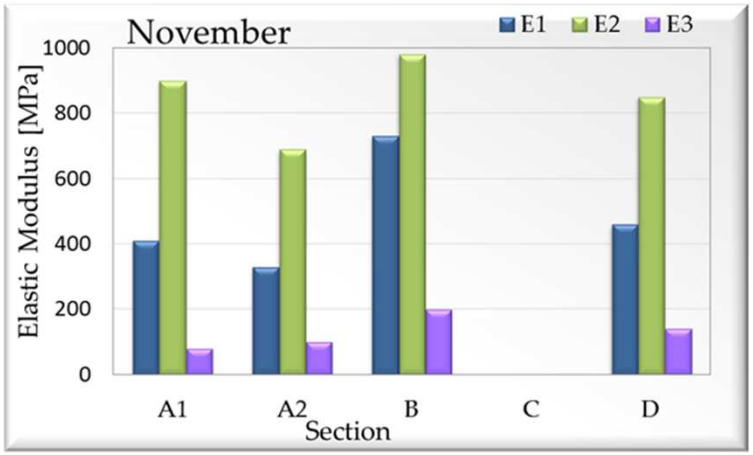
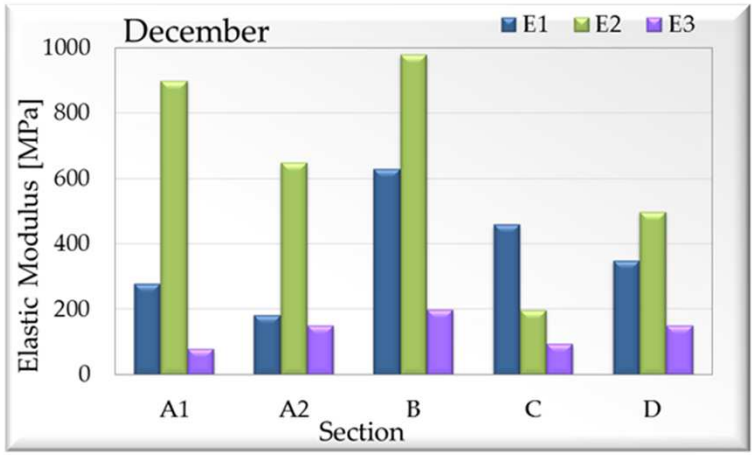
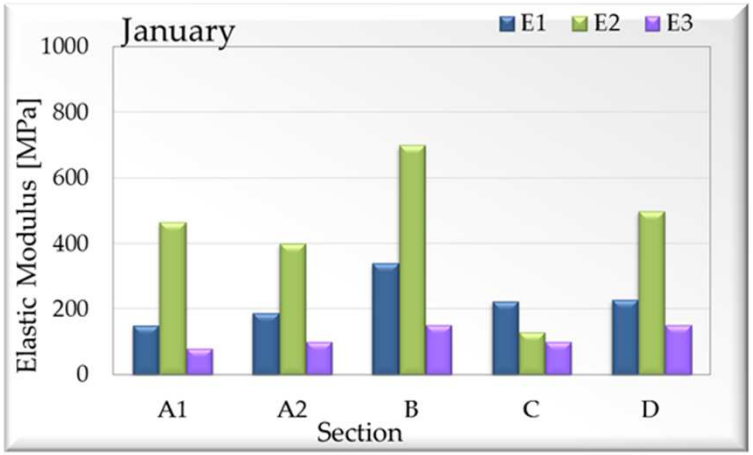
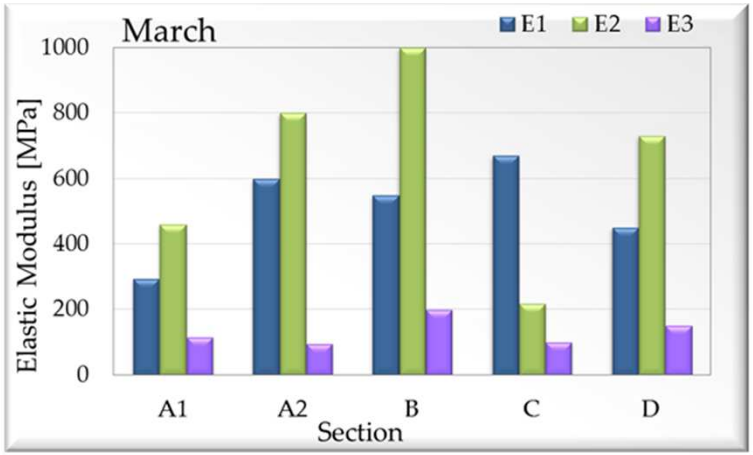
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE





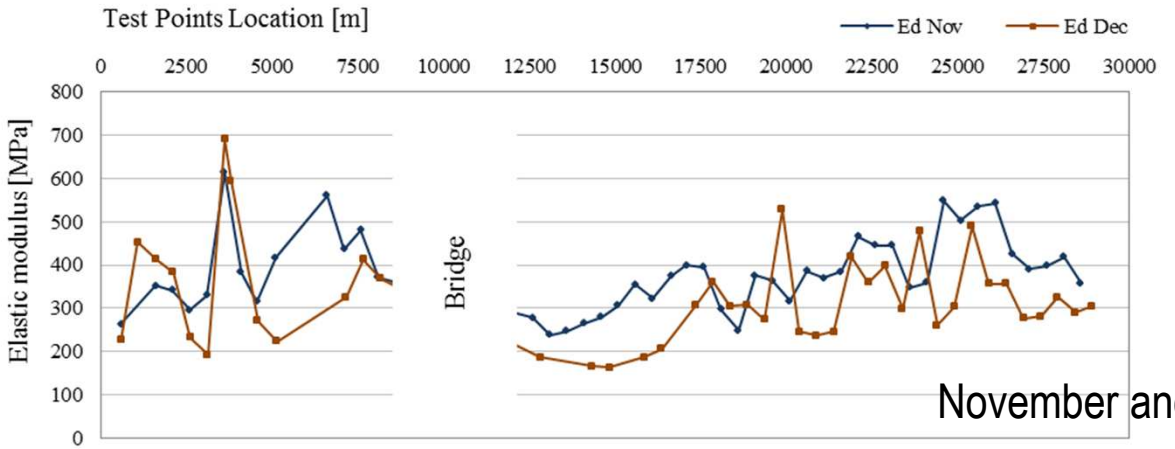




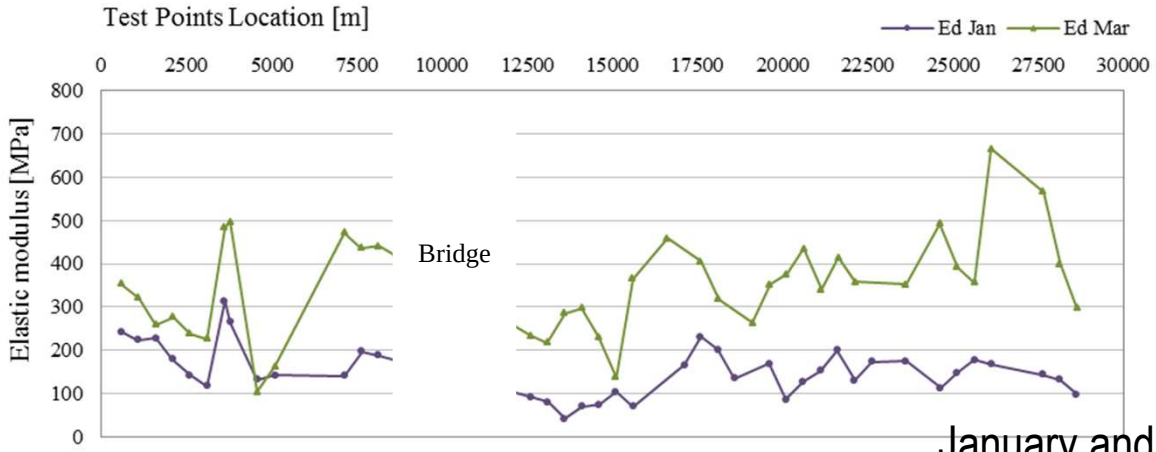
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Deformation modulus values



November and December

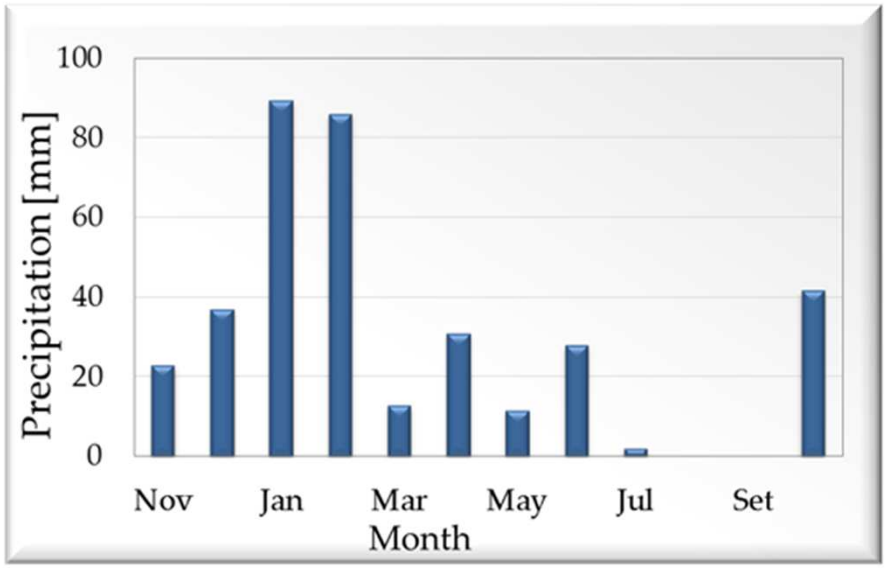


January and March

CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Sec	RP	Nov	Dec	Jan	Mar
A1	2600	296	232	143	238
A2	18100	298	305	202	318
B	3600	613	691	314	484
C	3800	-	594	265	497
D	17600	395	362	231	405



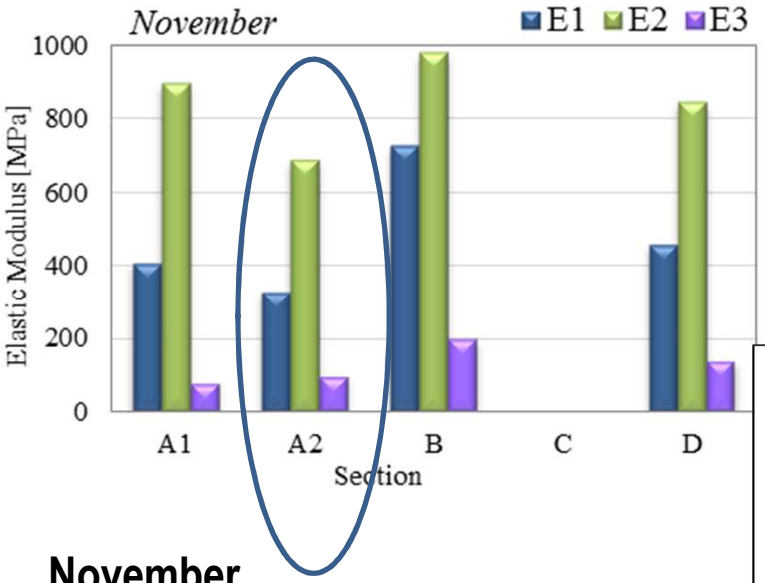
- It can be observed that the values obtained in November and December are quite similar, while in **January** they are **30 to 50% lower** than those obtained in November.

- Then, in March, the deformation modulus values tend to increase again to values closer to the ones obtained in the first two campaigns.

CLIMATIC INFLUENCE

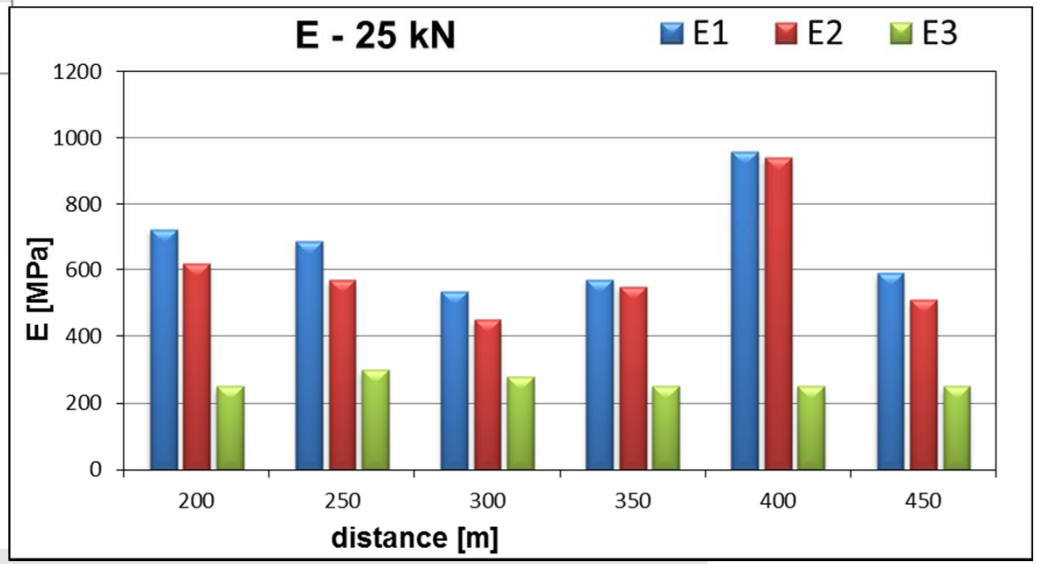
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

- Backcalculated sub-ballast elastic moduli variation with load peak
  November vs June



November

June



LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL

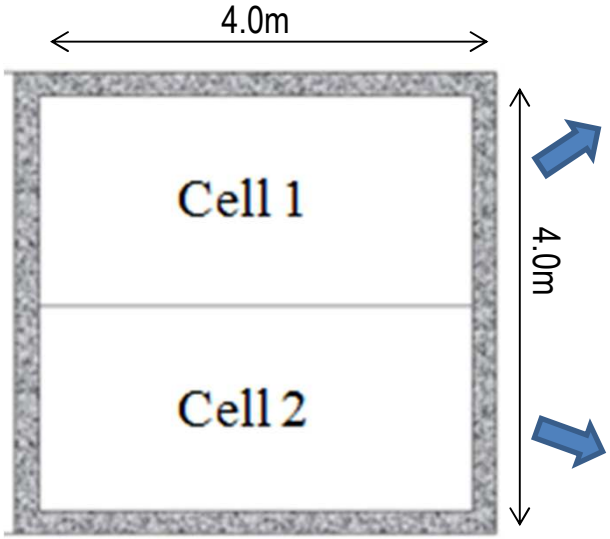
- E MODULI INCREASE WITH LOAD
- MEASUREMENT PROBLEMS - DEFLECTION MEASUREMENT
- MEASUREMENT PROBLEMS - INCREASE NUMBER OF DROPS UNTIL DEFLECTIONS STABILISE
- DIFFICULIES IN BACKCALCULATION

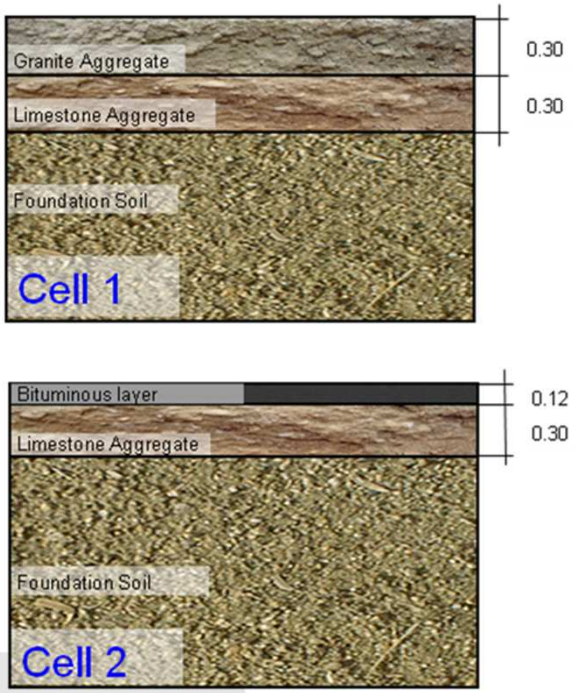
LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL

- Two different substructures were reproduced in physical models, with different subballast materials:
  - Traditional solution – 0.30m granite unbound granular material (UGM)
  - Italian HSL solution – 0.12m bituminous material

- Cells dimension: 4.0x2.0m^2 by 2.8m depth





Non destructive tests

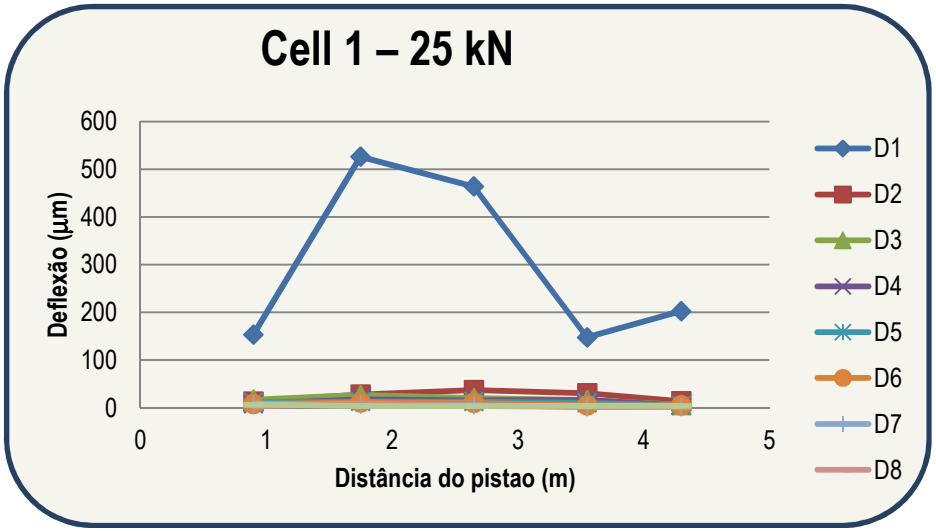
- Non destructive tests
  - Falling Weight Deflectometer (FWD)
  - Ground Penetrating Radar (GPR)

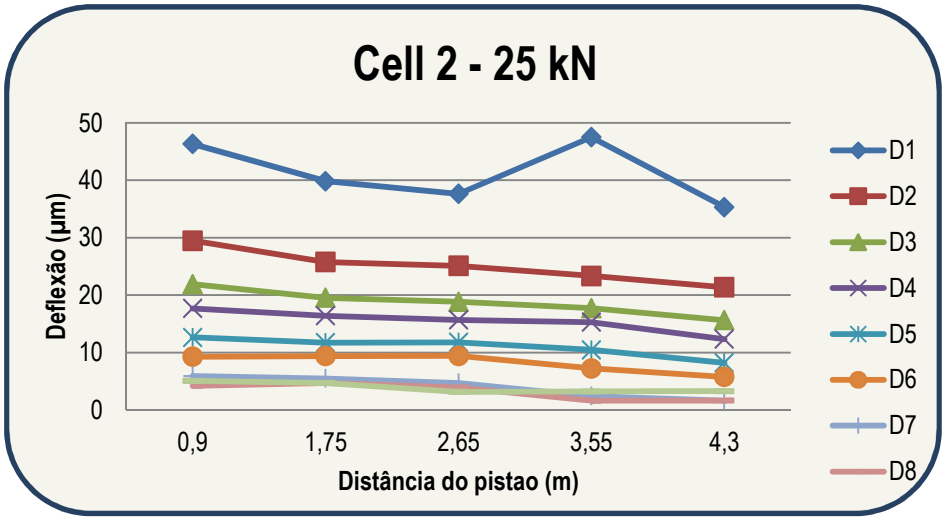
> FWD tests location
  - six locations (A, B, C, D, E and F)
  - spaced approximately by 0.50 m

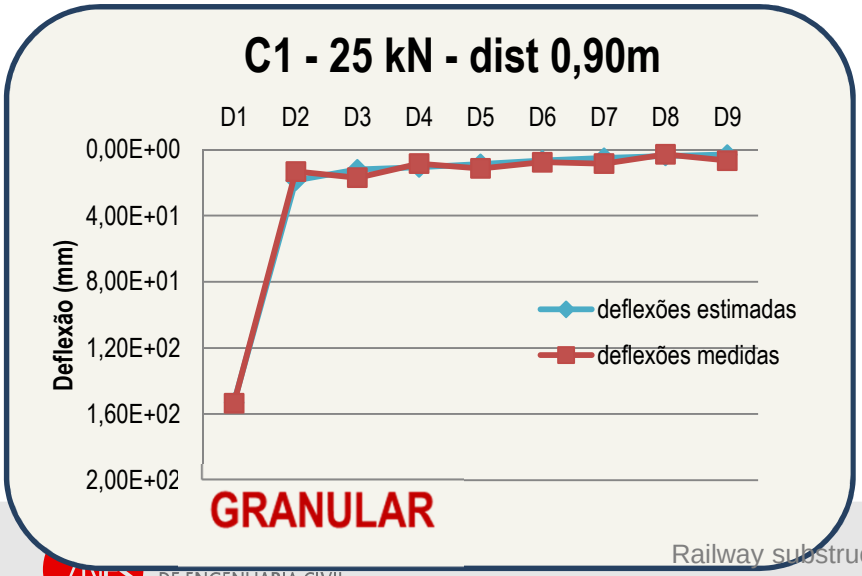
> FWD tests characteristics
  - nine transducers (D1 to D8)
  - 30 mm load plate (segmented)
  - Stress levels applied (160 to 520 kPa)

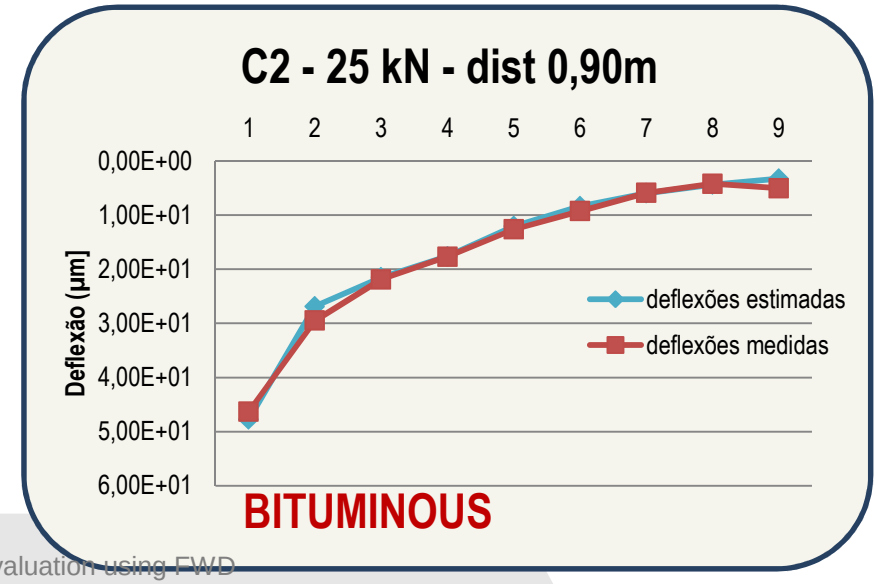
LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL





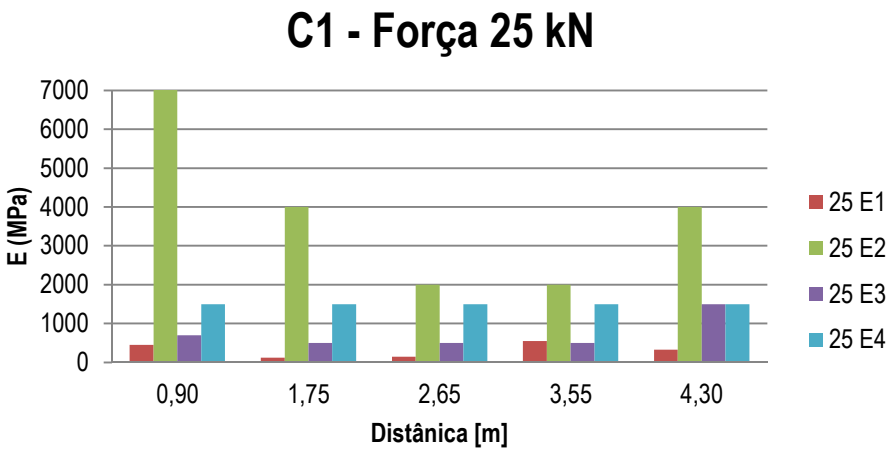




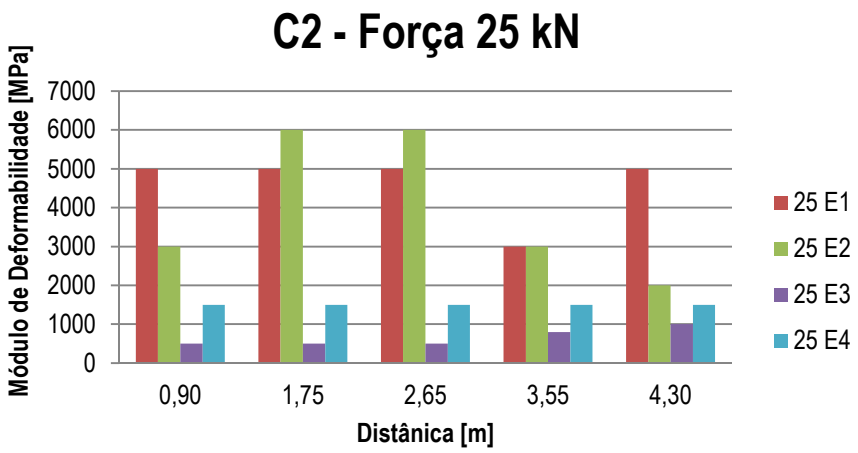
LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL

- E 1 moduli for top layer



GRANULAR

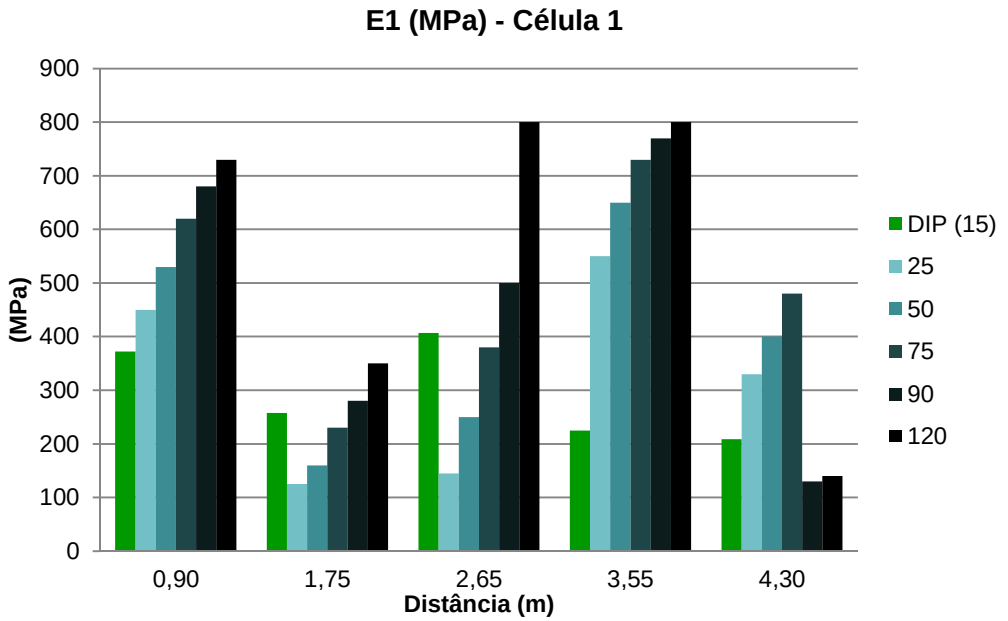


BITUMINOUS

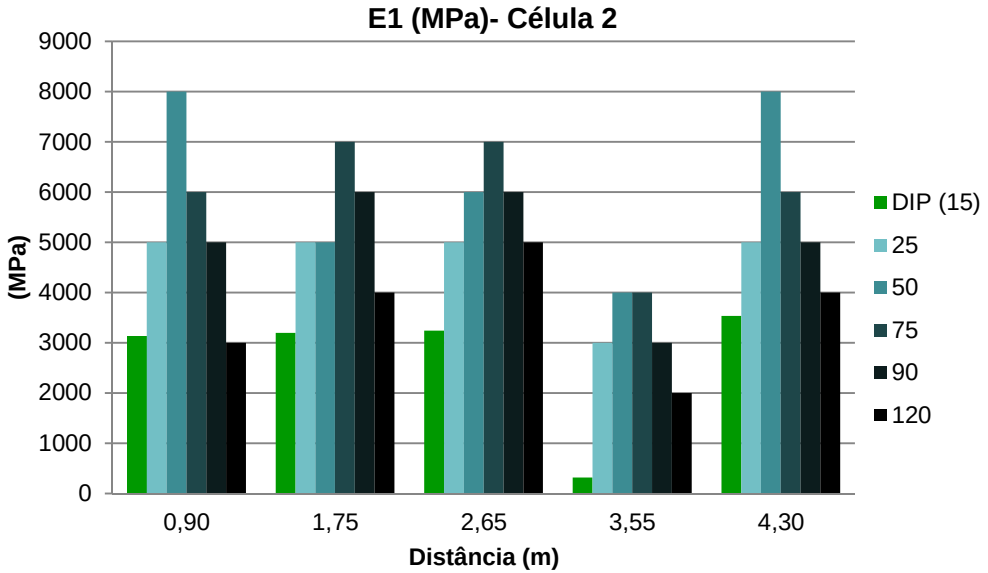
LOAD INFLUENCE

Five levels of loading were applied:
25, 50, 75, 90 e 120 kN

GRANULAR



BITUMINOUS



Railway evaluation using FWD
DEBATE

- MEASUREMENT SYSTEMS ON RAILWAY LINES ??
  - TEST LOCATION
  - GEOPHONES POSITION ON SURFACE
- CLIMATIC INFLUENCE
  - THE E MODULI CAN BE SO DIFFERENT?? (5 X)
  - LIMESTONE GRANULAR E > 1000 MPa
  - HOW YOU CORRECT THE VALUES ACCORDING TO SEASON??
- LOAD INFLUENCE– GRANULAR VS BITUMINOUS
  - HOW YOU CORRECT THE VALUES ACCORDING TO SEASON??
- TESTING AND INTERPRETATION
  - TESTING PROCEDURE, NUMBER OF DROPS , NUMBER OF TESTS , GEOPHONES POSITION ON SURFACE
  - BACK-CALCULATION OF GRANULAR MATERIAL LAYERS.

Thank you for your attention!

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