Caractérisation mécanique des plateformes ferroviaires par ondes sismiques de surface

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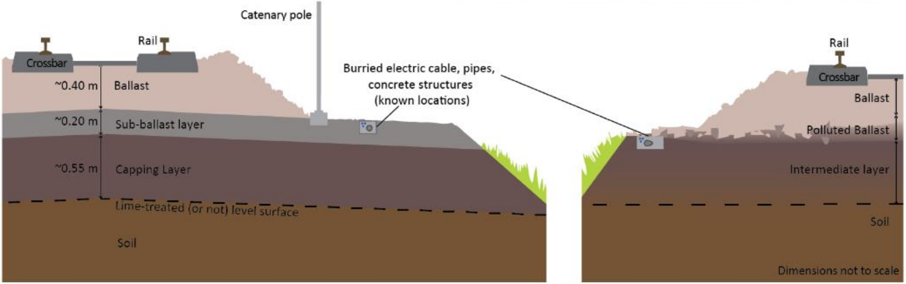
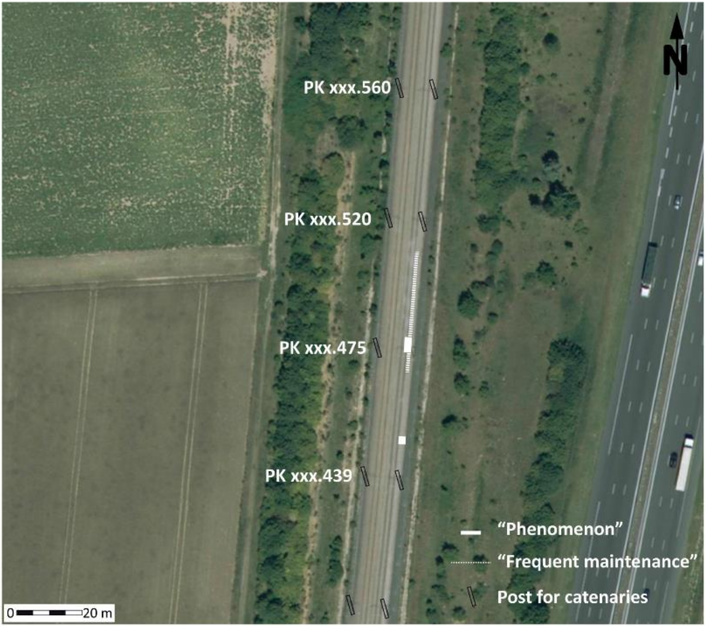
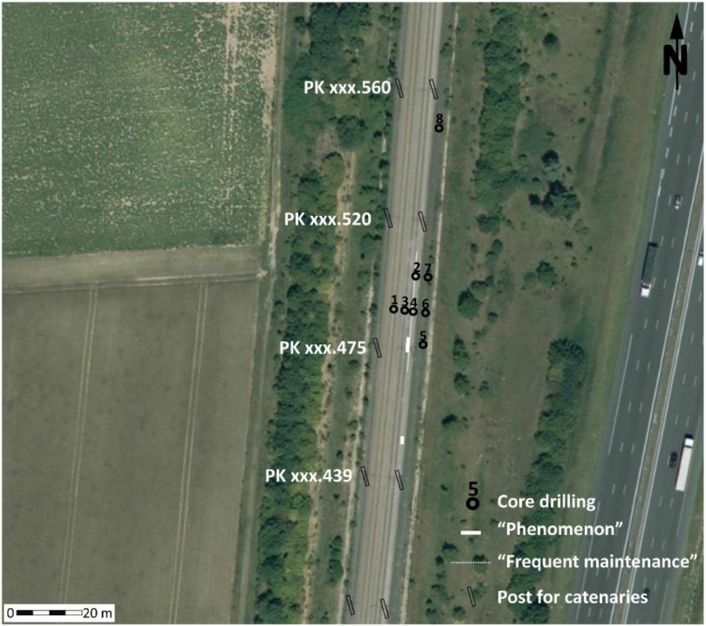
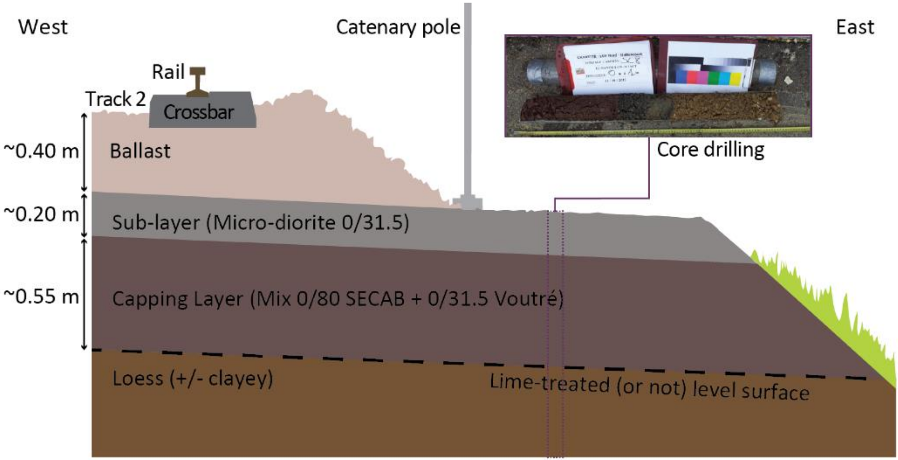


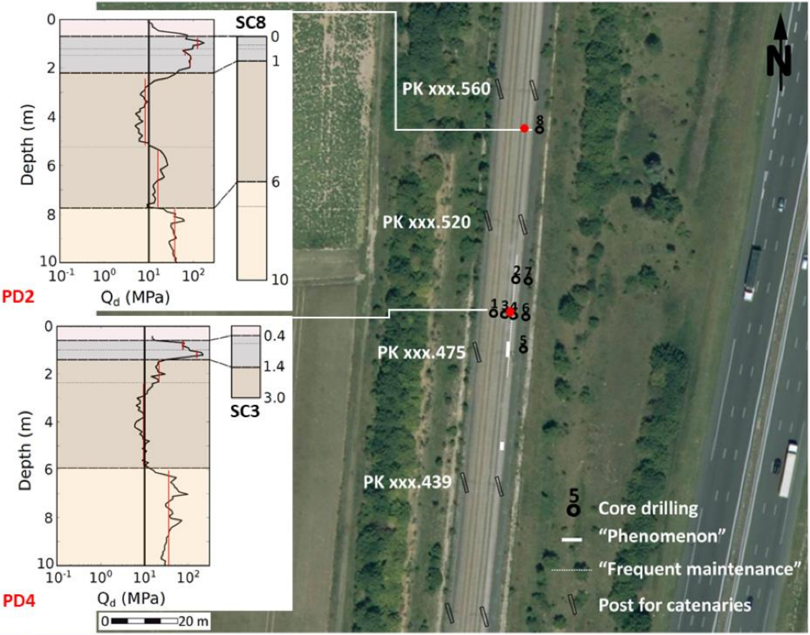
SU-UPMC/CNRS/SNCF contracts C13411/L13P208 and C150781/J15P252, 2013-2107

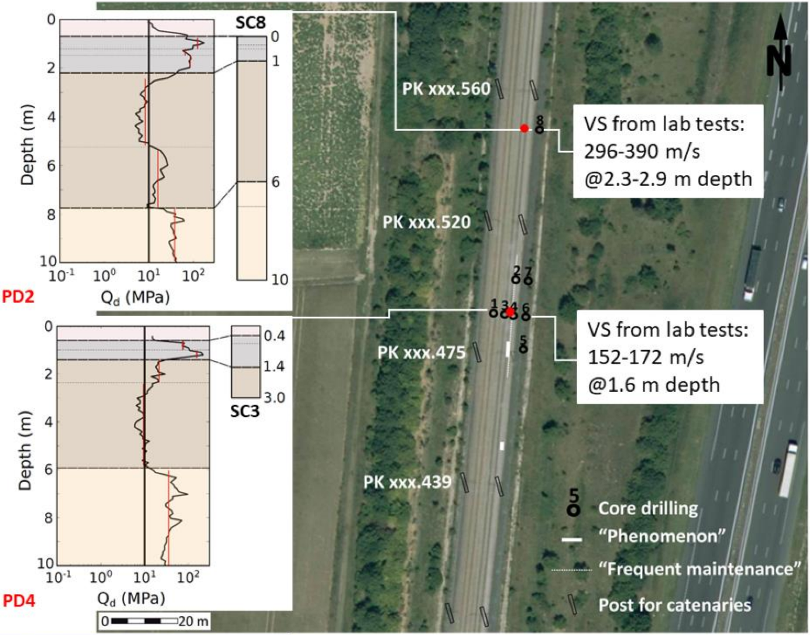

N
PK xxx.560
PK xxx.520
PK xxx.475
PK xxx.439
"Phenomenon"
"Frequent maintenance"
Post for catenaries
0 20 m


PK xxx.560
8
PK xxx.520
2 7
1 3 4 6
5
PK xxx.475
PK xxx.439
N
5
Core drilling
"Phenomenon"
"Frequent maintenance"
Post for catenaries
0 20 m

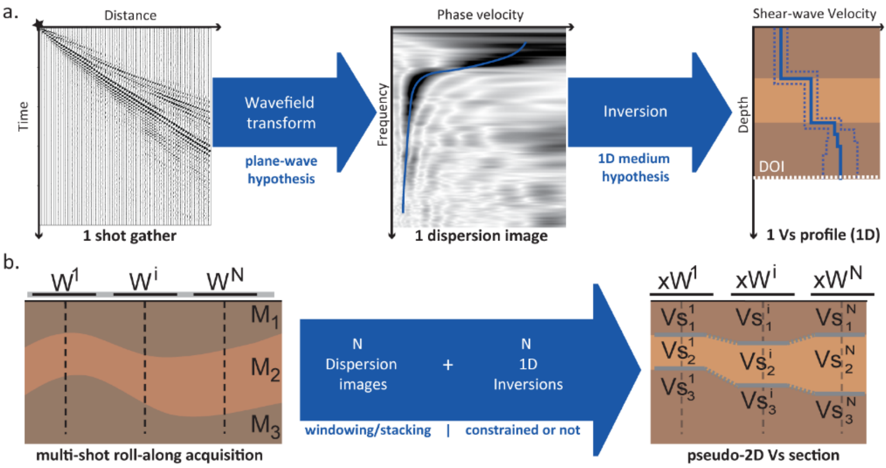


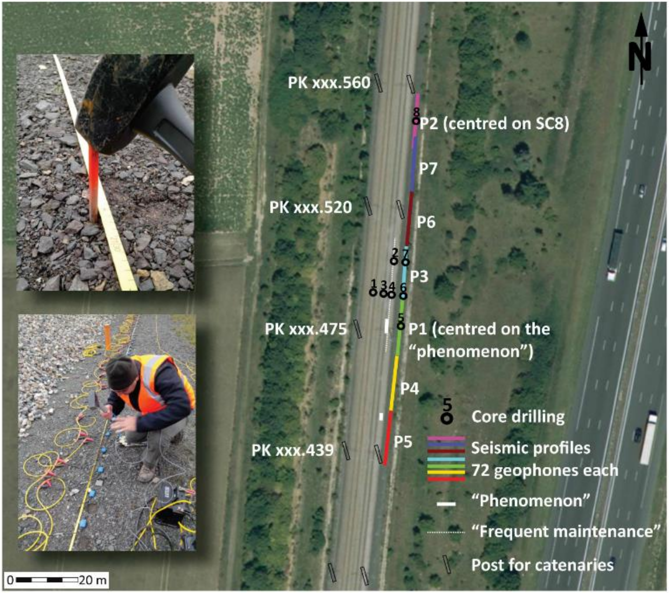
Water content, Atterberg limits, methylene blue test, density, grain size distribution *etc* + shear-wave velocity (VS) from Bender Elements (BE) (see details in Dhemaied, *et al.* 2014)

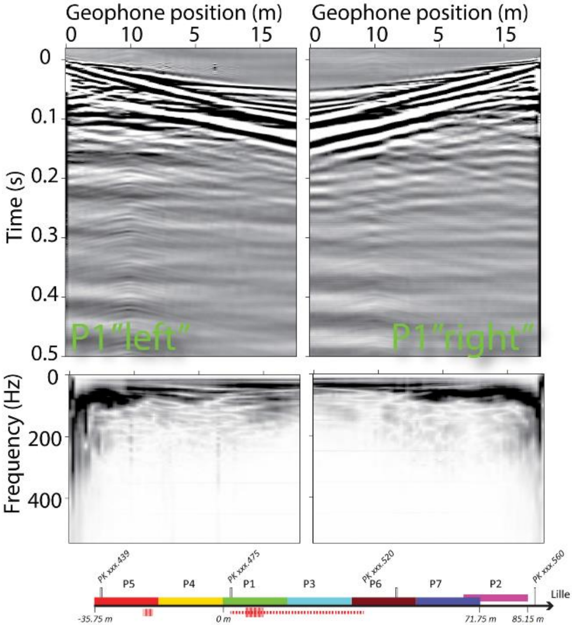

SC8
PD2
Depth (m)
Qd (MPa)
PD4
SC3
0.4
1.4
3.0
PK xxx.560
PK xxx.520
PK xxx.475
PK xxx.439
N
Core drilling
"Phenomenon"
"Frequent maintenance"
Post for catenaries
0
20 m

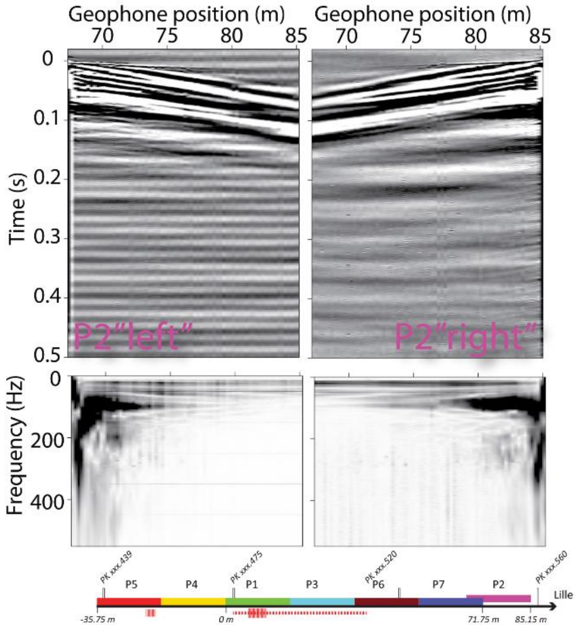

SC8
Depth (m)
Q_d (MPa)
PD2
SC3
PD4
0
20 m
PK xxx.560
PK xxx.520
PK xxx.475
PK xxx.439
N
VS from lab tests:
296-390 m/s
@2.3-2.9 m depth
VS from lab tests:
152-172 m/s
@1.6 m depth
Core drilling
"Phenomenon"
"Frequent maintenance"
Post for catenaries

- Shear-wave velocities from BE seem to be a good indicator of this railway embankment's state ;
- Yet, BE results remain local and how to obtain them is destructive, expensive...
- => shear-wave velocity from (non-destructive) seismic surveys ?

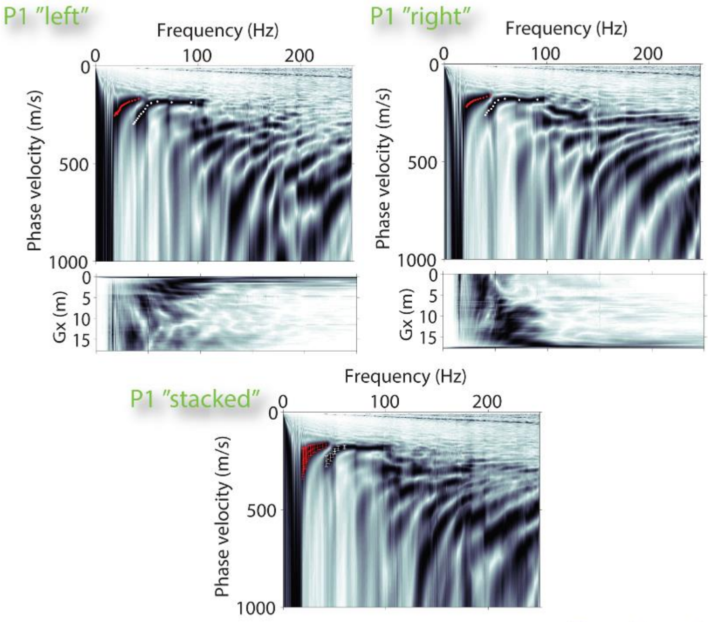

a.
Distance
Time
1 shot gather
Wavefield transform
plane-wave hypothesis
Phase velocity
Frequency
1 dispersion image
Inversion
1D medium hypothesis
Shear-wave Velocity
Depth
DOI
1 Vs profile (1D)
b.
W^1 W^i W^N
M_1
M_2
M_3
multi-shot roll-along acquisition
N Dispersion images
+
N 1D Inversions
windowing/stacking | constrained or not
xW^1 xW^i xW^N
Vs_1^1 Vs_1^i Vs_1^N
Vs_2^1 Vs_2^i Vs_2^N
Vs_3^1 Vs_3^i Vs_3^N
pseudo-2D Vs section


PK xxx.560
8
P2 (centred on SC8)
P7
PK xxx.520
P6
2 7
P3
1 3 4 6
5
PK xxx.475
P1 (centred on the "phenomenon")
P4
5
Core drilling
PK xxx.439
P5
Seismic profiles
72 geophones each
"Phenomenon"
"Frequent maintenance"
Post for catenaries
0 20 m
N

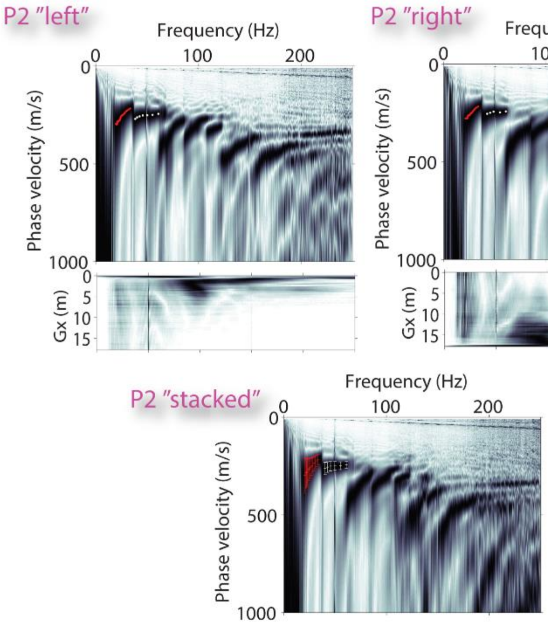

Geophone position (m)
0 10 5 15
Time (s)
0 0.1 0.2 0.3 0.4 0.5
P1"left"
P1"right"
Frequency (Hz)
0 200 400
PK xxx.439
PK xxx.475
PK xxx.520
PK xxx.560
P5 P4 P1 P3 P6 P7 P2
Lille
-35.75 m
0 m
71.75 m
85.15 m

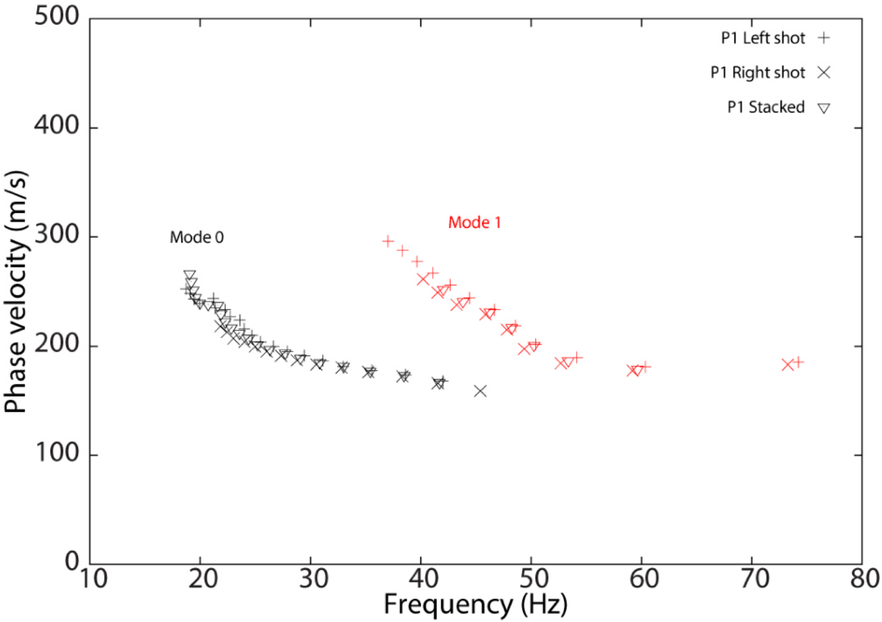

Geophone position (m)
70 75 80 85
Geophone position (m)
70 75 80 85
Time (s)
0 0.1 0.2 0.3 0.4 0.5
P2"left"
P2"right"
Frequency (Hz)
0 200 400
PK xxx.439
PK xxx.475
PK xxx.520
PK xxx.560
P5 P4 P1 P3 P6 P7 P2
Lille
-35.75 m
0 m
71.75 m
85.15 m

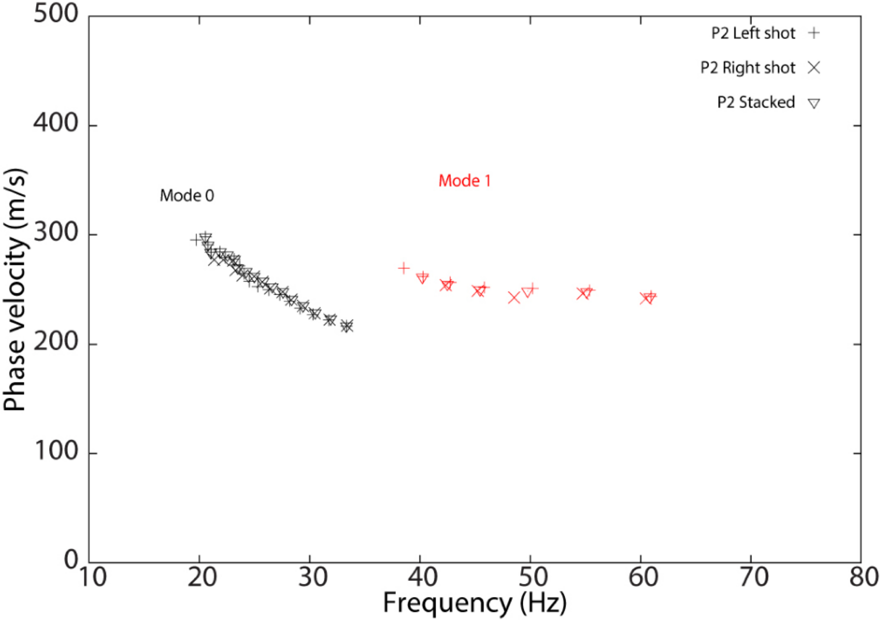
see detailed work-flows in O'Neill (2003) or Pasquet and Bodet (2017) ...



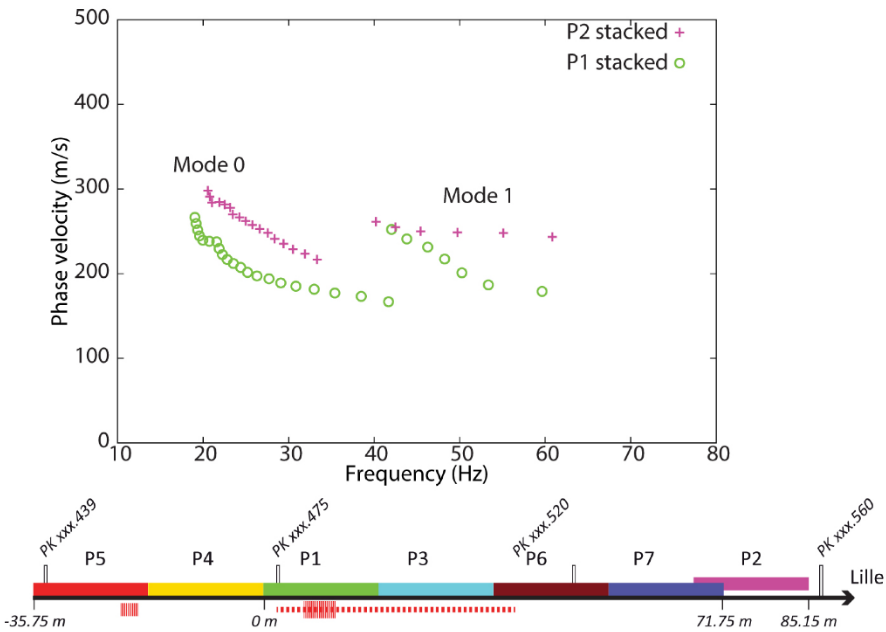
see detailed work-flows in O'Neill (2003) or Pasquet and Bodet (2017) ...

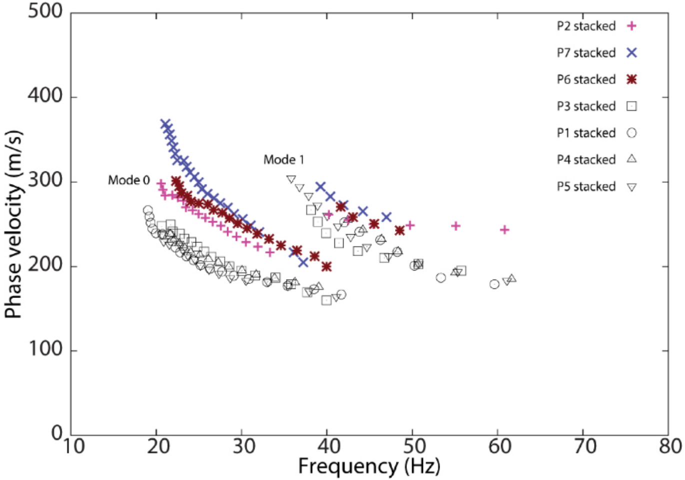



P1 Left shot
P1 Right shot
P1 Stacked
Mode 0
Mode 1
Phase velocity (m/s)
Frequency (Hz)
0
100
200
300
400
500
10
20
30
40
50
60
70
80

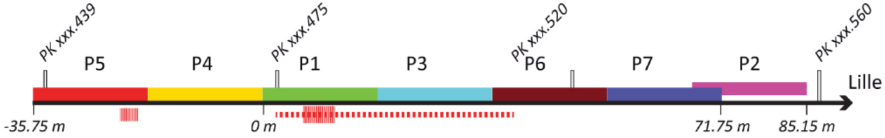


500
400
300
200
100
0
10
20
30
40
50
60
70
80
Phase velocity (m/s)
Frequency (Hz)
P2 Left shot
P2 Right shot
P2 Stacked
Mode 0
Mode 1

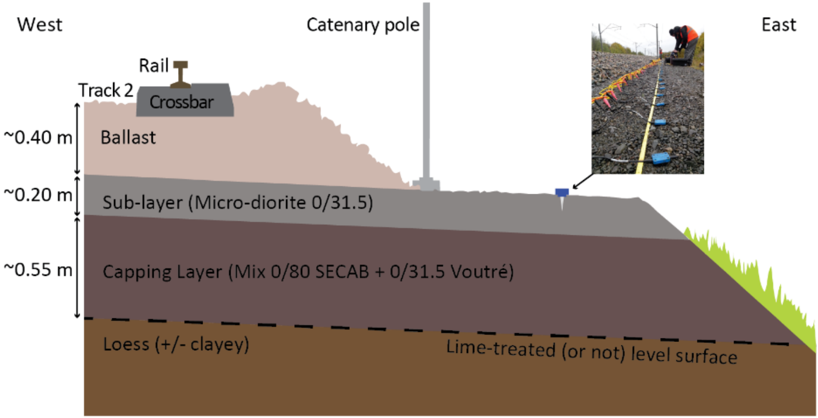

P2 stacked
P1 stacked
Mode 0
Mode 1
Phase velocity (m/s)
Frequency (Hz)
500
400
300
200
100
0
10
20
30
40
50
60
70
80
PK xxx.439
PK xxx.475
PK xxx.520
PK xxx.560
P5
P4
P1
P3
P6
P7
P2
Lille
-35.75 m
0 m
71.75 m
85.15 m



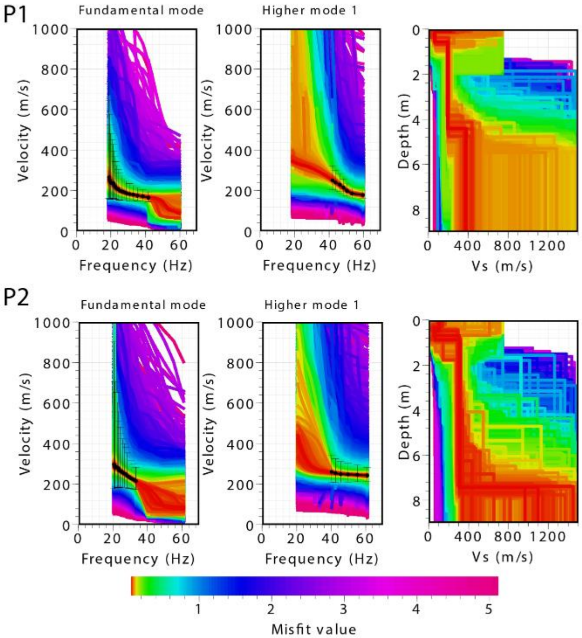
Phase velocity (m/s)
Frequency (Hz)
0
100
200
300
400
500
10
20
30
40
50
60
70
80
Mode 0
Mode 1
P2 stacked
P7 stacked
P6 stacked
P3 stacked
P1 stacked
P4 stacked
P5 stacked



PK xxx.439
PK xxx.475
PK xxx.520
PK xxx.560
P5
P4
P1
P3
P6
P7
P2
Lille
-35.75 m
0 m
71.75 m
85.15 m



- layer 0 (sub-layer) : $10 < VS0 < 750$ m/s and $0.1 < HVS0 < 1$ m
- layer 1 (capping layer) : $10 < VS1 < 750$ m/s and $0.1 < HVS1 < 1$ m
- layer 2 (loess) : $10 < VS2 < 750$ m/s and $1 < HVS2 < 7$ m
- Half-space (chalk) : $10 < VS3 < 1500$ m/s


P1
Fundamental mode
Higher mode 1
Velocity (m/s)
Frequency (Hz)
Depth (m)
Vs (m/s)
P2
Fundamental mode
Higher mode 1
Velocity (m/s)
Frequency (Hz)
Depth (m)
Vs (m/s)
Misfit value

Sublayer: 10 <Vs0< 750 m/s ; 0.1<Hs0<1 m

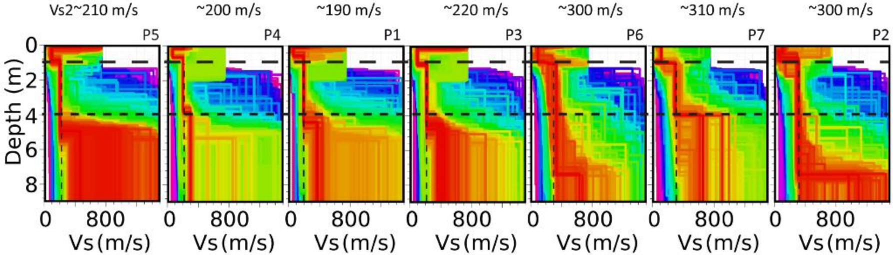
Subgrade: 10 <Vs1< 750 m/s ; 0.1<Hs1<1 m

} ~80 cm + LVL

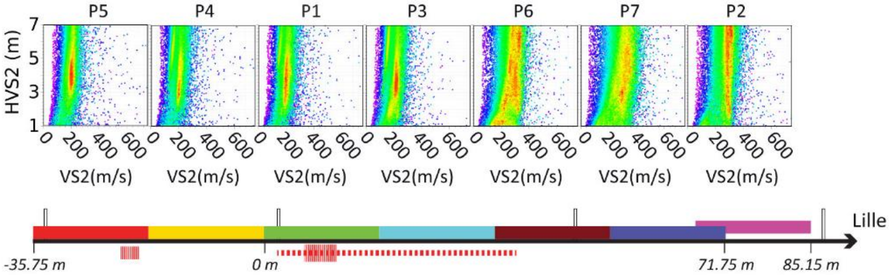
Loess: 10 <Vs2< 750 m/s ; 1<Hs2<7 m

Chalk: 10 <Vs3< 1500 m/s ; 1.2<HSD<9 m

}ZChalk > 4 m

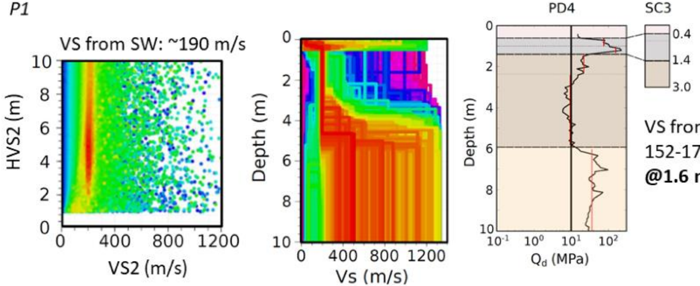


see more details about the inversion technique in Sambridge (1999) or Wathelet (2008)...



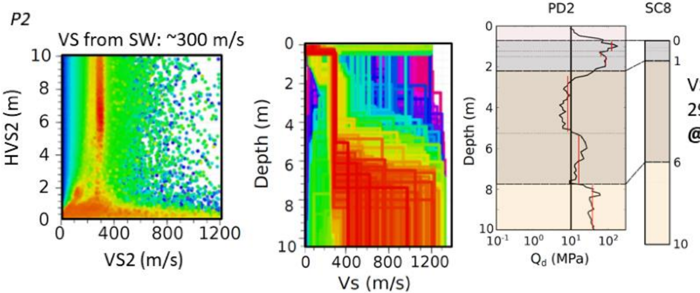
see more details about the inversion technique in Sambridge (1999) or Wathelet (2008)...

P1



VS from BE:
152-172 m/s
@1.6 m

P2



VS from BE:
296-390 m/s
@2.3-2.9 m

- VS from Bender Elements is a good indicator of soils "quality" in the railway embankment (Dhemaied *et al.*, 2014)
- Surface-wave prospecting is suggested (see also Bergamo *et al.*, 2016a,b)
- Strong a priori knowledge allowed for inverting dispersion measurements
- VS in the loess showed a contrast correlated with the phenomenon
- SW dispersion can be considered as a control criterion of the the railway embankment's state on LGV (Bodet *et al.*, 2017)
- -> **Applicability on classical lines ?**

- Bergamo, P., Dashwood, B., Uhlemann, S., Swift, R., Chambers, J., Gunn, D., Donohue, S., 2016a. Time-lapse monitoring of climate effects on earthworks using surface waves. Geophysics 81 (2), EN1–EN15.
- Bergamo, P., Dashwood, B., Uhlemann, S., Swift, R., Chambers, J. E., Gunn, D. A., Donohue, S., 2016b. Time-lapse monitoring of fluid-induced geophysical property variations within an unstable earthwork using P-wave refraction. Geophysics 81 (4), EN17–EN27.
- Bodet, L., Rahmania, I., Kyrkou, K., Wacquier, L., Dangeard, M., Pasquet, S., Vitale, Q., Dhemaied, A., Boisson-Gaboriau, J., Nebieridze, S., 2017. Estimation in situ des variations de propriétés mécaniques de la plateforme ferroviaire par ondes sismiques de surface. Tech. rep., Rapport interne, SNCF.
- Dhemaied, A., Cui, Y.-J., Tang, A. M., 2014a. Etude de la sensibilité de la raideur mécanique des sols supports à la variation de la teneur en eau. Rapports d'activité, ENPC/SNCF.
- Donohue, S., Gunn, D. A., Bergamo, P., Hughes, E., Dashwood, B., Uhlemann, S., Chambers, J. E., Ward, D., 2014. Assessing climate effects on railway earthworks using MASW. In : Near Surface Geoscience 2014-20th European Meeting of Environmental and Engineering Geophysics.
- Gunn, D., Dashwood, B. A., Bergamo, P., Donohue, S., 2016. Aged embankment imaging and assessment using surface waves. Proceedings of the Institution of Civil Engineers-Forensic Engineering 169 (4), 149–165.
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- O'Neill, A., 2003. Full-waveform reflectivity for modelling, inversion and appraisal of seismic surface wave dispersion in shallow site investigations. Ph.D. thesis, The University of Western Australia, School of Earth and Geographical Sciences.
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- Sambridge, M., 1999. Geophysical inversion with a neighbourhood algorithm—I. Searching a parameter space. Geophysical Journal International 138 (2), 479–494.
- Wathelet, M., 2008. An improved neighborhood algorithm : Parameter conditions and dynamic scaling. Geophys. Res. Lett. 35, L09301.
- Wathelet, M., Jongmans, D., Ohrnberger, M., 2004. Surface-wave inversion using a direct search algorithm and its application to ambient vibration measurements. Near Surface Geophysics 2 (4), 211–221.