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AU 3 JUIN
2022

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27TH CONGRESS
90TH ANNUAL
MEETING

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27ÈME CONGRÈS
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Embankment Dam Committee E Workshop

Rhone Delta levees – Feedback from 5 worksites

completed between 1998 and 2021
evolution of the design and specifications of earthworks

Thibaut Mallet
SYMADREM

Syndicat Mixte Interrégional d'Aménagement
SYMADREM
des Digues du Delta du Rhône et de la Mer

Presentation

- General context information
- First generation of works : emergency works from 1998 to 2001
- Second generation of works : « invariant » works from 2002 to 2007
- Third generation of works : Rhone Plan works from 2007 to 2030
- Conclusion

Presentation of SYMADREM

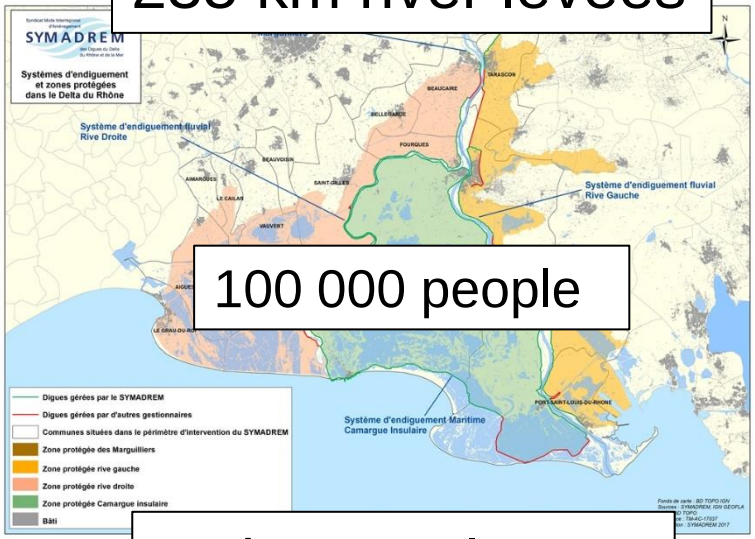
A public institution responsible (27 people) for :

- operations and maintenance of levees in all circunstances
- levees improvement works (450 millions euros over 25 years)

Q_{10} = 8 800 m³/s
Q_{100} = 11 800 m³/s
Q_{1000} = 14 300 m³/s

3 river levees systems and 1 sea levees system

235 km river levees



100 000 people

50 km sea levees

Mainly embankment levees
(10 km resisting to overflow)

Sheet piling

30 closing gates

350 crossing hydraulic structures

Quays or masonry levees

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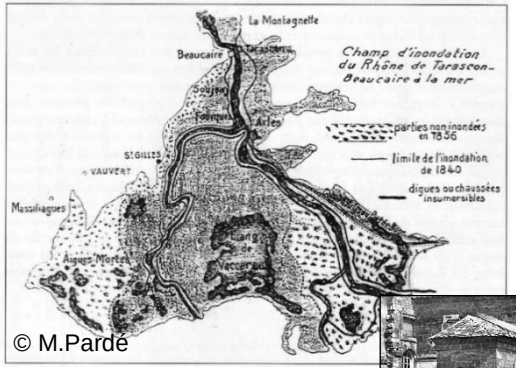
Inundations by breaches

in 1840, 1841, 1843, 1846, 1856, 1993, 1994, 2002, 2003

December 2003 Q = 11 500 m³/s T ≅ 100 years

4 breaches and spilled volume ≅ 230 million m³
People flooded : 12 000 à 14 400 (no dead)
Cost of damages ≅ 365 à 700 million €

November 1840 & May 1856



Q ≅ 12 500 m³/s

T >> 100 years

Spilled volume in 1840 and 1856 ≅ 2,8 & 1,8 billion m³

Estimated cost of damages today > 2 billion €

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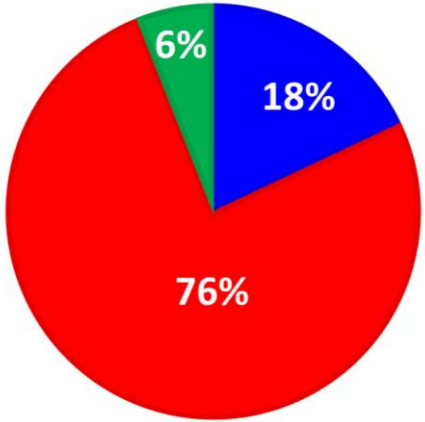
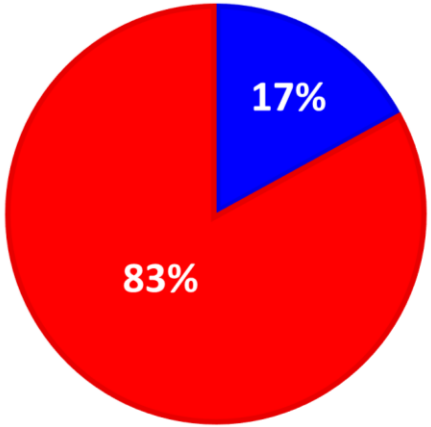
Accidentology from 1840 to today

57 breaches (with inundation) and 57 breaches in progress (no inundation)

1840-2022



1993-2022



Breaches and breaches in progress

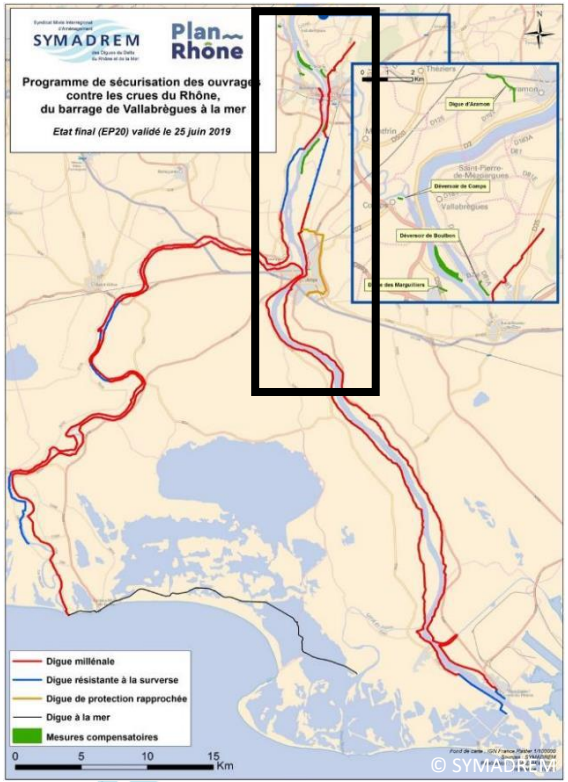
overflowing internal erosion scour

Internal erosion => **concentrated leak erosion**

80 % in badger burrows

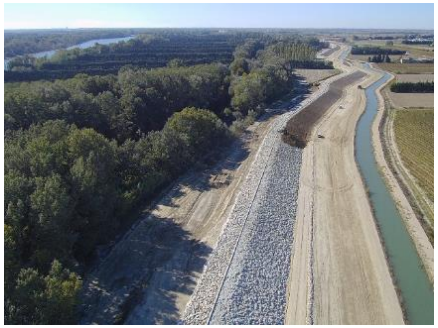
20 % along crossing pipes

The response : a global plan of improvement works



Response of Rhône plan :

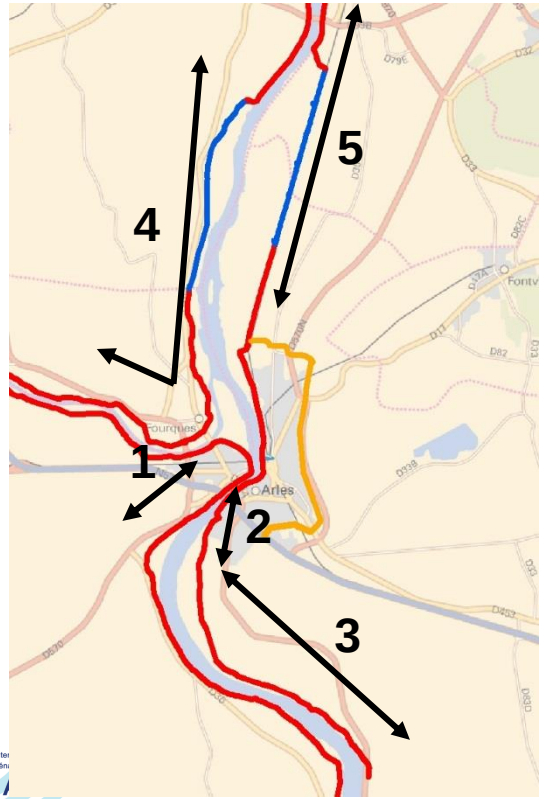
- **do not raise the levees**
- **accept overflowing for rare floods** (T = 100 or 50 years)
- **do not accept breaches** in the levees until millenium floods



Levees with long spillways
(5 km respectivement by banks) set at Q_{50} or Q_{100}
and resisting to overflow until Q_{1000}

« millenium » levees
set at Q_{1000} + 50 cm

Feedback from 5 worksites



1. Emmaus–Passerons (emergency works)
2. Barriol (invariant works)
3. Sud d'Arles (Rhone Plan works)
4. Beaucaire-Fourques (Rhone Plan works)
5. Tarascon-Arles (Rhone Plan works)

Plan Rhône

Annual probability of breach ≤ 10^{-4}

Vocabulary

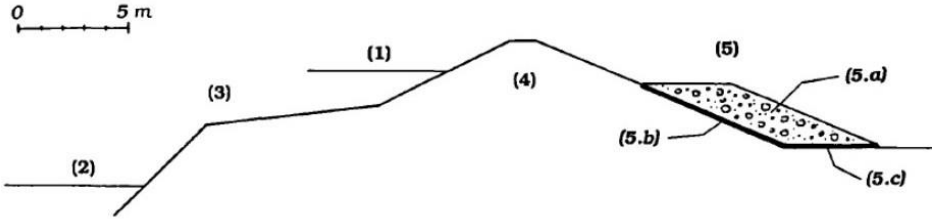
Control

- Internal control : control performed by the works company
- External control : control performed by geotechnical engineering office under the responsability of the works company
- Exterior control : control performed by geotechnical engineering office under the responsability of the project owner and its prime contractor

Classification of geotechnical missions (NF P 94-500 novembre 2013)

- G3 : geotechnical follow-up of execution under the responsability of the works company
- G4 : geotechnical follow-up of execution under the responsability of the project owner and its prime contractor

Emergency works 1998-2001 post-flood 1993-1994



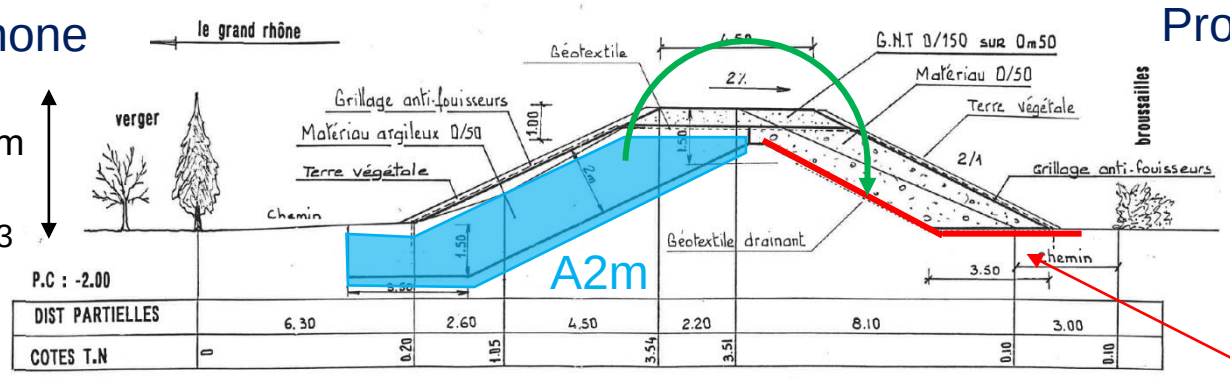
Emmaus – Passerons levee (1998)

Rhone

Protected area

≈ 3,3 m

V = 18 500 m³



contractual technical specifications :

Reference to french guidelines for roads (guide SETRA/LCPC)

D ≥ 95 % of Standard Proctor Density (SPD) over 97,5 % measures

0,9.OMC < W < 1,1.OMC

3 control types but frequency = ∅

Emmaus – Passerons levee (1998)

Realisation

Assembly plan = ∅

Compaction (V3 ; d = 0,30 m N = 6)

6 gamma measures (1/3 < objective)

1 measure ≈ 3100 m^3

Synthesis

1 road technical referencing

1 compactness objective

∅ Frequency of control

Freedom in realisation (compaction material) and control

Feedback floods

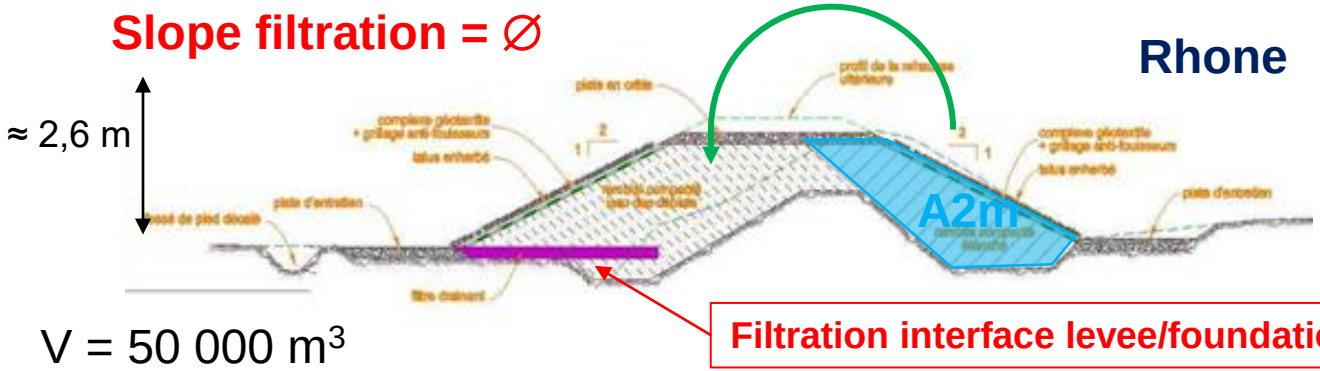
1 Q_{100} + 2 Q_{20}

No observed damage

Barriol levee (2007) – invariant works

Slope filtration = ∅

Rhone



V = 50 000 m³

contractual technical specifications (more detailed) :

D ≥ 98 % SPD over 90 % measures and ≥ 95 % SPD on 100 %

0,9.OMC < W < 1,1.OMC

Trial tests :

- 1 simplified identification (granulo + Methylene Blue Value) every 500 m³
- 2 daily measures of W
- 1 complete identification (IP) + sedimento + SPD test every 1500 m³

Barriol levee (2007)

contractual technical specifications suite

Material means :
Smooth compactor proscribed and scarification between layer at least 5 cm

Compaction methods let to company free initiative
but with maximal and minimal values - d = 0,30 m ; N = 6

Control tests : daily gamma with 1 minimal test every 100 linear meter

Barriol levee (2007)

Construction :
Use of a vibrating roller with padfoot
Preparation phase : 2 SPD tests + 12 identifications (Gr, W, Vbs)
Realisation phase : 4 SPD tests + 32 gamma measures, including 14 for the field compaction trial test and 18 continuous control tests, either 1 measure every 2700 m^3

On the 18 control tests :
0,95.SPD < Density < 1,1.SPD (reached objective)
Moisture content : 20 % compliant and for 80 %
8,7 % < W < 15,6 % for a 18 % < OMC < 19,5 %

Barriol levee (2007)

Synthesis

- Significant improvement in the contractual technical specifications
- Significant difference between the contractual requirements and the effective implementation of external controls (partially explained by the homogeneity of the deposit).
- Densification objective preferred to water content
- The materials used was too dry (after consuming quite all its budget to dry the materials, the company didn’t want to go the extra mile to remoisten them)

Barriol levee (2007) – 10 years later

Investigations conducted as part of our hazard studies :

- 6 core surveys in the waterproof siding with intact sampling
- identification to confirm the classification of granular material (A2)
- Dry density and Standard Proctor density to evaluate *a posteriori* the compaction level
- Hole Erosion Tests measurements to evaluate the resistance to concentrated leak erosion

Résults

13,5 % < OMC < 17,7 % vs. 18 % < OMC < 19,5 %

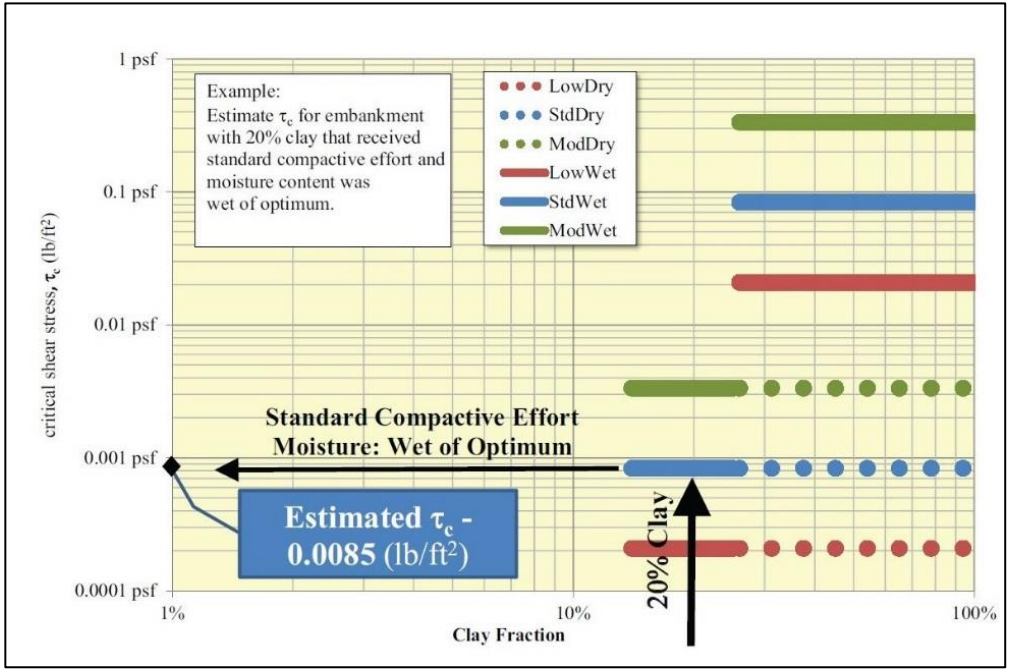
3 samples :

- $10 < \tau_c < 40$ Pa and $2,8 < I_e < 3,6$ for a material with $19 < 2\mu < 25$ %
- 0,88.SPD < Density < 0,94.SPD

3 samples :

- $160 < \tau_c < 350$ Pa and $3,8 < I_e < 4,2$ for a material with $30 < 2\mu < 40$ %
- 1,02.SPD < Density < 1,12.SPD

Barriol levee (2007) – 10 years later

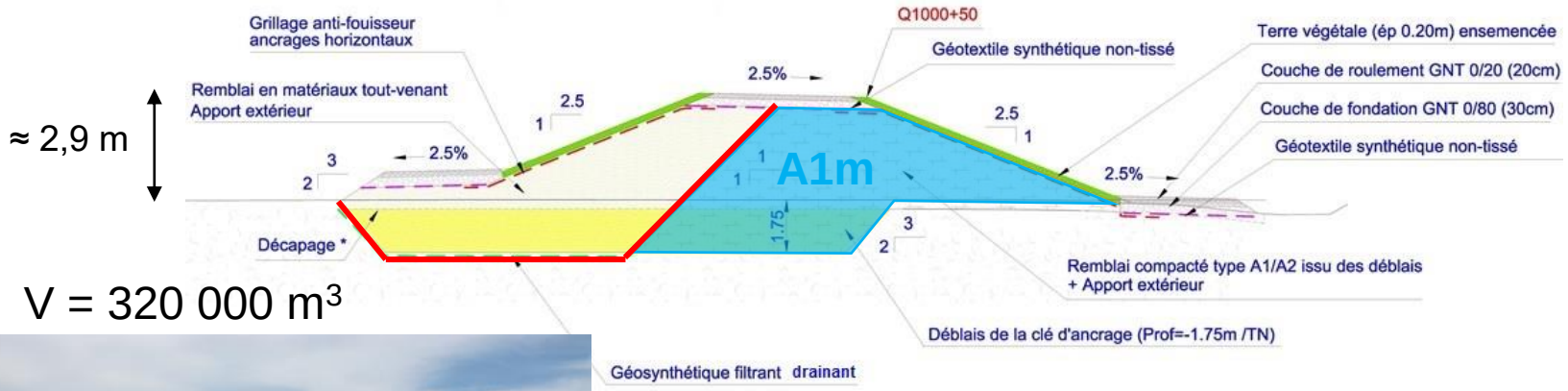


Hanson, G. J., D. M. Temple, S. L. Hunt, R. D. Tejral. 2011. Development and Characterization of Soil Material Parameters for Embankment Breach Applied Engineering in Agriculture. 27(4): 587-595.

South Arles levee (2016)

South Arles levee (2016)

Levee and foundation filtration = géocomposite



V = 320 000 m³

South Arles levee (2016)

Contractual technical specification ≈ Same as for Barriol levee + vibrating roller with padfoot

Report of the works (Assembly file) ≈ 1 m³

Program G3 (control test by the company)

- 1 simplified identification (granulo + Methylene Blue Value) every 1500 m³
- 1 complete identification (granulo + IP) + sedimento + SPD tests every 4500 m³
- Daily measurements with gamma-densimetre every 50 linear meter of levee
- Daily moisture contents

Design Office in charge of executions with an ministerial approval for levees and small dams

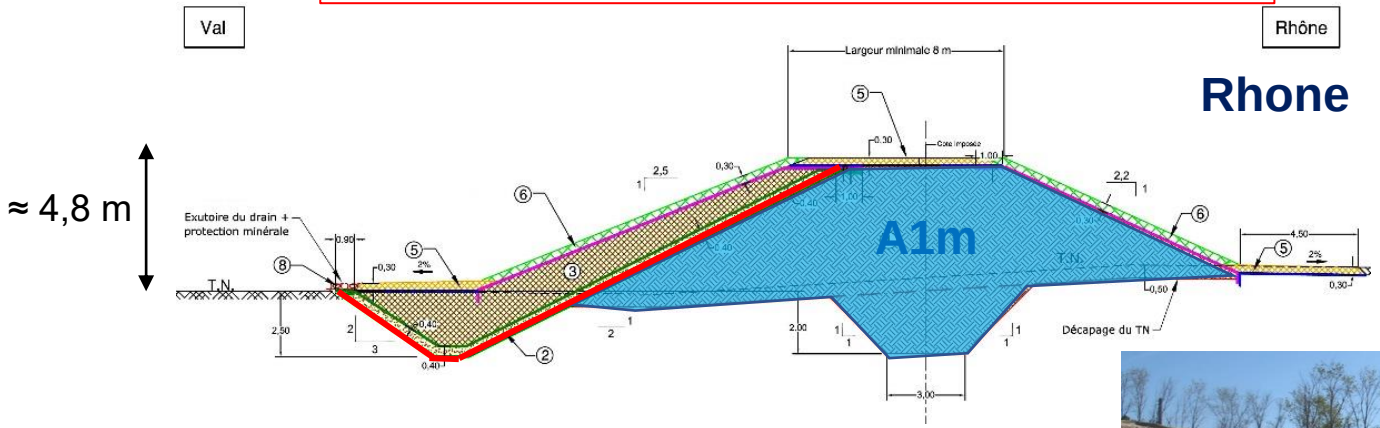
Prime contractor also has a G4 mission + use of an exterior control under its responsability

Synthesis : realisation ≈ contractual technical requiments

Beaucaire-Fourques levee (2018)

Beaucaire-Fourques levee (2018)

Levee and foundation filtration = geotextile + gravel



V > 1 million of m^3

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Beaucaire-Fourques levee (2018)

Contractual technical specifications ≈ South Arles levee

Report of the works **≈ 1 m³**

Design office in charge of execution with an ministerial approval for levees and small dams

Prime contractor

External service provider : G4 mission + exterior control

Beaucaire-Fourques levee (2018)

G3 program (control by the company)

- 1 identification + sedimento + Organic matters every 2500 m^3 (1180)
- 1 SPD test every 2500 m^3 (1410)
- 1 moisture content every 200 m^3 (115)
- 1 gamma-densimeter measurement every 200 m^3 (125)
- 1 panda every 40 linear metre on 1 m (3 layers control) (20)

Objective of dry density adapted before the construction
Dry density ≥ 0,95.SPD for 100 % of measurements
OMC < W < OMC + 3 % with tolerance of 20% OMC – 1 % < W < OMC

Measure W in a heat chamber

Beaucaire-Fourques levee (2018)

Construction of a levee between Tarascon-Arles (2021)

V > 1 million of m^3

Same requirements as for Beaucaire-Fourques levee
With 1 an additional specification and 1 innovation

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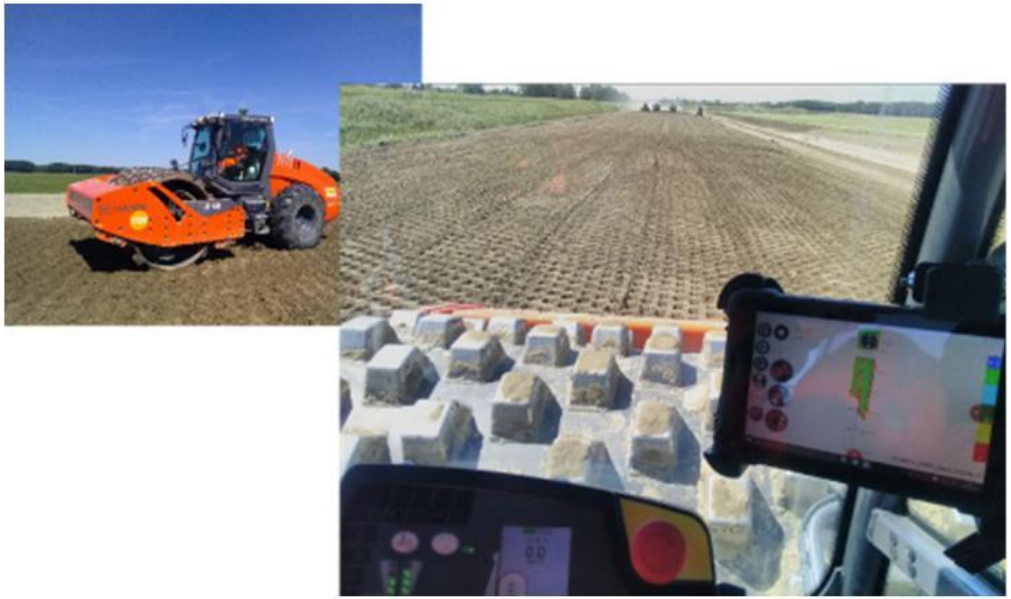
Tarascon-Arles levee (2021)



- Smooth compactor prohibited even with scarification
- Vibrating roller with padfoot equipped with a satelitte guidance for Q/S control

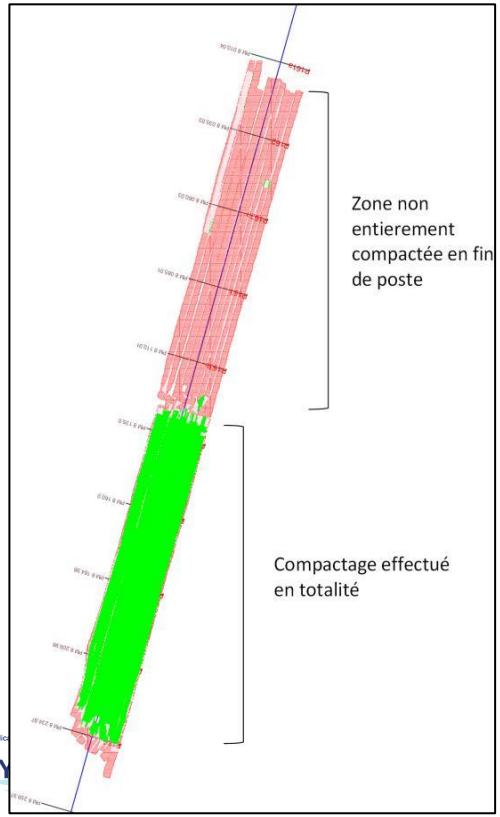
Tarascon-Arles levee (2021)

- For several decades, compaction control has been based mainly on the analysis of the ratio between the amount of material applied and the distance covered by the compactor (Q/S method).
- The evolution of tests and practices as well as the increase of the geotechnical controls on the building sites make it possible to check the good quality of compaction by sampling the materials.
- GPS compaction monitoring introduces a new type of control that allows to integrate a spatial dimension, in addition to quantitative Q/S controls and spot geotechnical sampling.

Tarascon-Arles levee (2021)

- A procedure of verification and validation of the GPS system was set up by the company at the beginning of the construction site and at the start-up of each equipped compactor
- The tests demonstrated a total coherence between the data from the GPS piloting and those from the tachograph disks

Tarascon-Arles levee (2021) – GPS innovation



- Color code for number of compaction passes
  Completed and not completed

Positive points

- the disappearance of the constraint of counting the number of passes,
- direct control of the sweep,
- the precise positioning of the compactor during the resumption of work. This advantage is all the more relevant on linear worksites with no topographic stakes

Tarascon-Arles levee (2021) – GPS innovation

Improvments during the works

- Companies continued the development of prototypes
- The metric precision of GPS required the development of algorithms for smoothing the tracks which, in the case of evasive maneuvers or U-turns, could give erroneous records
- The group has improved the metric accuracy of GPS to a centimetric accuracy
- The autonomy of the antenna has been improved by the addition of high capacity batteries to be able to last a week without charging.

Tarascon-Arles levee (2021) – GPS innovation

Areas of improvement to pursue.

- Post processing of data for the mapping restitution
- The work with several compactors on the same station. The systems are independent and the GPS of a compactor cannot count the passes of the other machine.The driver's intervention is then necessary

Synthesis and conclusion for this innovation

- The use of this technology can be used to calculate the Q/S ratio but this operation on the prototypes remains perfectible and the usual practices with tachographs are well mastered by the site supervisors.
- This new driver assistance system was unanimously approved by all the compactor drivers on the site.

Global conclusion

Objective of compaction

Density ≥ 0,95.SPD on 100 % of control measures

OMC < W < OMC + *3* % with a tolerance for 20 % of OMC -1% < W < OMC

=> to increase resistance to internal and external erosion

G3 Program (control test by companies)

- 1 identification + OM + 1 STD test every 5 000 m^3 in preparation phase and every 5 000 m^3 in execution phase
- 1 gamma-densimetre measure + W in a heat chamber every 200 m^3
- 1 panda every 50 linear meter and every 3 layers (thickness and homogeneity control). Homogeneity is conditioned by a drop in peak resistance at the interface between 2 layers less than 20% on a less than 10 cm height)
- 1 sedimento (3 every 200 linear metres (lower 3rd /medium /superior => hazard studies)

Global conclusion

Organisation :

- Execution by a company and execution by the execution design office with the approval for levees and small dams
- Prime contractor holder of a G4 mission
- external control under the Prime Contractor direction

Material obligations :

- Supply dump truck
- Bulldozer equipped with a 3D guidance system
- Sprinkler and burial machine (« à la carpe » watering prohibited)
- Pulvimixer to mix and homogenise the moisture content
- Vibrating roller with padfoot (smooth compactor prohibited even with scarification) equipped with a satelitte guidance for Q/S control

Thank you for attention

And welcome for the technical visit on may 31th

Levees resisting to overflow between Beaucaire and Arles

Beaucaire-Fourques (right bank)

Tarascon-Arles (left bank)

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