

2013 Conférence Coulomb

## Géotechnique dans un environnement deltaïque

### Geotechnics in a deltaic environment

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Université Polytechnique de Catalogne, Barcelone

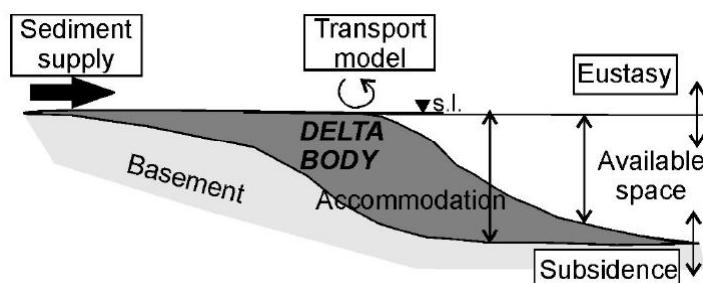


Paris, 25 Juin 2013



#### Introduction

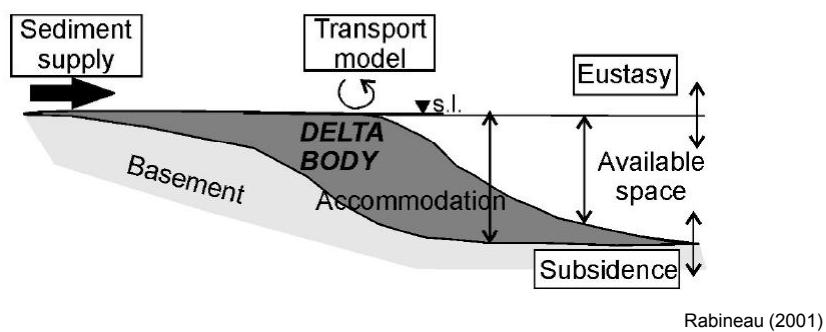
- ❑ Deltas are of great ecological and economical value
- ❑ They are major centres of population and agriculture
- ❑ They provide challenges to geotechnical engineering
  - Presence of soft soils
  - Complex distribution of materials
  - High water table
  - Need to preserve ecosystems



Rabineau (2001)

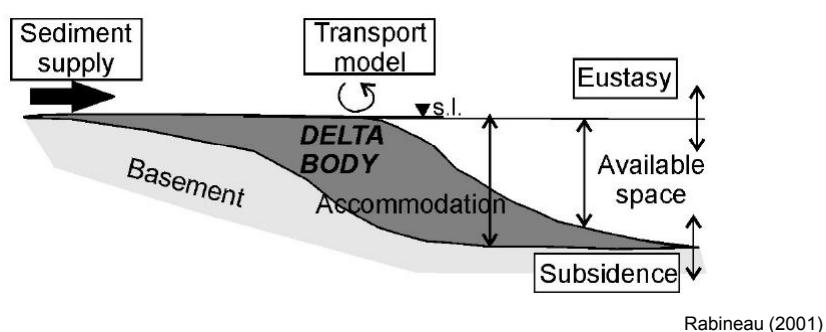
## Introduction

- ❑ Deltas are dynamic coastal systems closely linked to both land-based, fluvial and marine processes
  - Eustasy
  - Sediment supply
  - Erosion and transport by wave/tides/currents
  - Subsidence (tectonics, isostasis, consolidation)

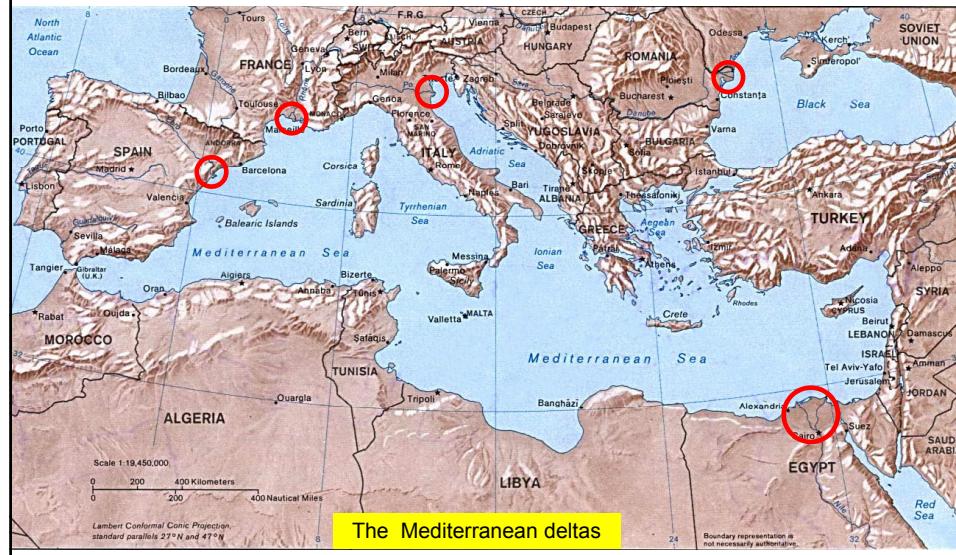


## Introduction

- ❑ Deltas are dynamic coastal systems closely linked to both land-based fluvial and marine processes (+ and anthropogenic influence!)
  - Eustasy (climate change)
  - Sediment supply (deforestation, dam construction)
  - Erosion and transport by wave/tides/currents (costal works, harbours)
  - Subsidence (tectonics, isostasis, consolidation) (water pumping)

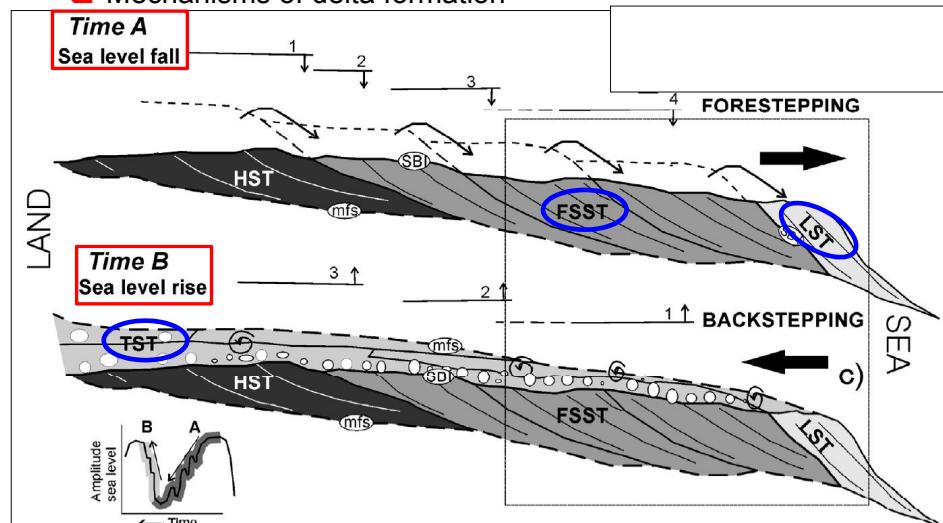


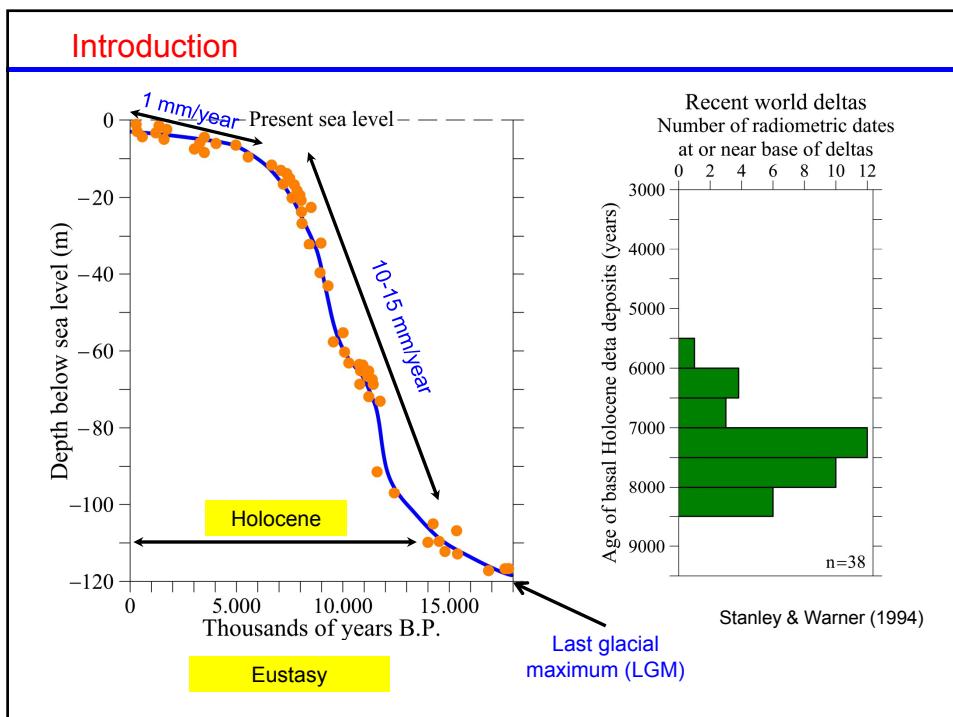
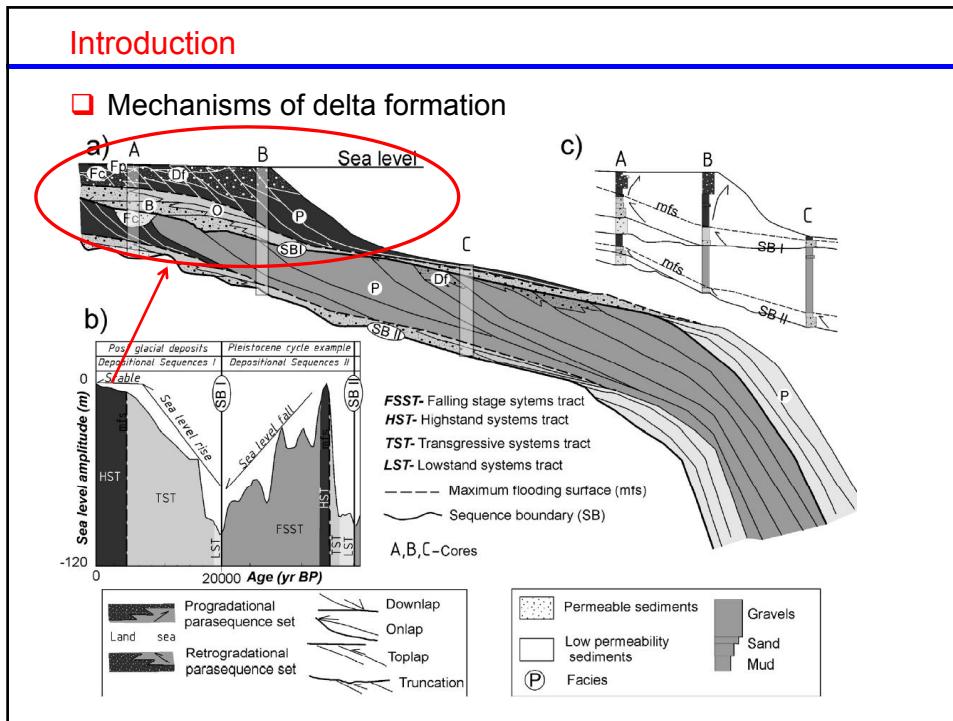
## Introduction



## Introduction

### □ Mechanisms of delta formation





## Introduction



The Mediterranean deltas

## Introduction



Llobregat Delta: Director Plan

## Outline

- ❑ Introduction
- ❑ The Llobregat delta
- ❑ Civil Engineering works in the Llobregat delta
  - Mitigation of long term settlements
    - Water treatment plant
    - Third runway at Barcelona airport
  - Control of excavation movements
    - High speed train Madrid-Barcelona
    - Barcelona Line 9 Metro
  - Stability on soft ground
    - New Breakwaters in Barcelona Harbour
    - New container terminal in Barcelona Harbour
- ❑ Closure

## Indice

- ❑ Introduction
- ❑ Le delta du Llobregat
- ❑ Les travaux de génie civil dans le delta du Llobregat
  - Contrôle et réduction des tassements à long terme
    - Cas de l'usine d'épuration des eaux
    - Cas de la troisième piste de l'aéroport de Barcelone
  - Contrôle des mouvements induits par les excavations
    - Cas de la ligne de train à grande vitesse Barcelone – Madrid
    - Cas de la ligne 9 du métro de Barcelone
  - Stabilité des sols mous
    - Nouvelle digue du port de Barcelone
    - Nouveau terminal de containers du port de Barcelone
- ❑ Conclusions

## Acknowledgements

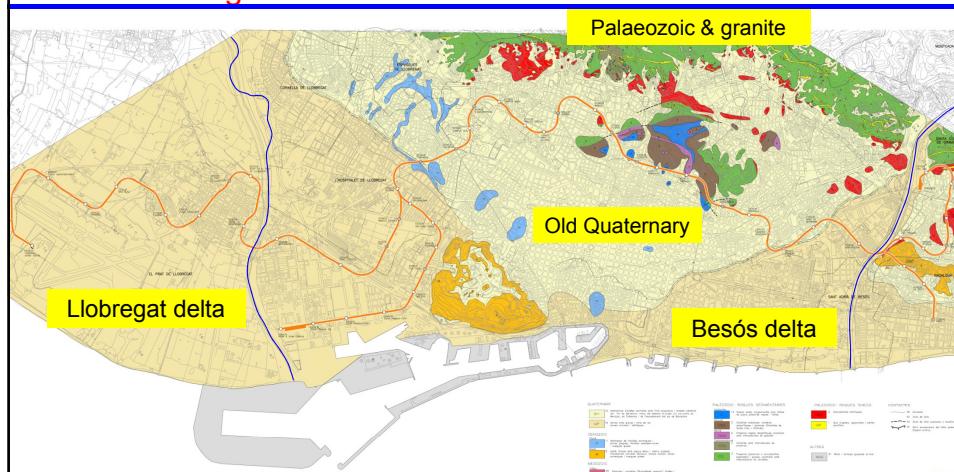
### Organisations

- ADIF
- AENA
- Autoritat Portuaria de Barcelona (APB)
- Depurbaix
- GISA

### People

- Jordi Alcoverro
- Eduardo Alonso
- Marcos Arroyo
- Jesús Carrera
- Amadeu Deu
- Antonio Lloret
- Ricardo Madrid
- Alessandra di Mariano
- Roberto Persio
- Dani Tarragó
- Enric Vàzquez
- Maria Teresa Yubero

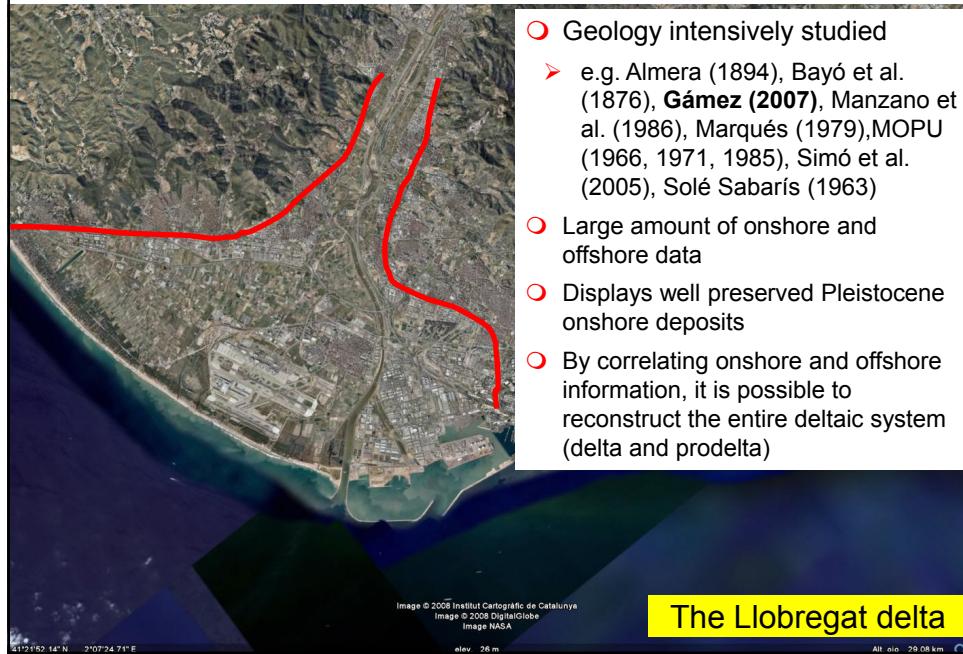
## The Llobregat delta



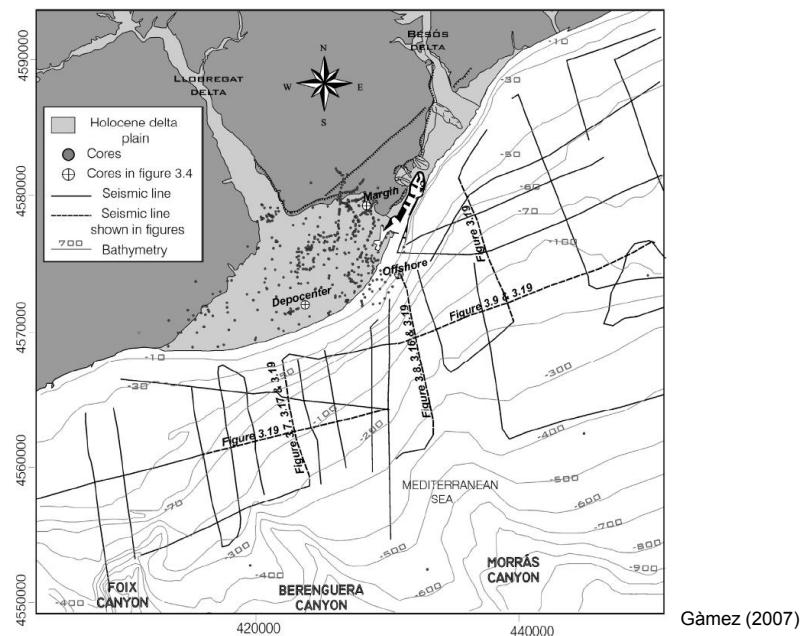
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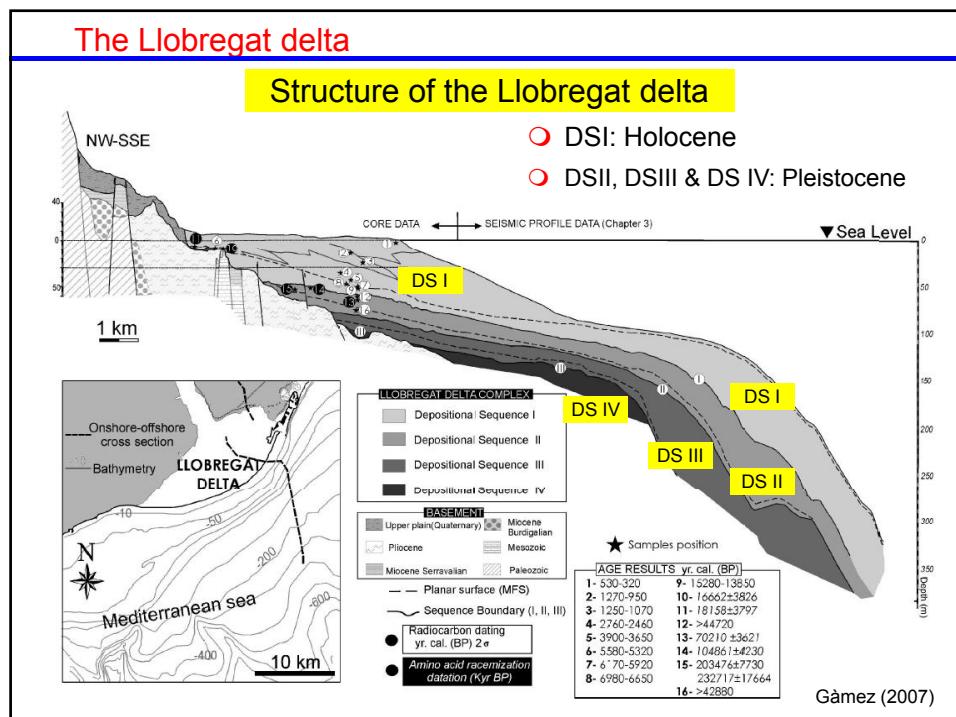
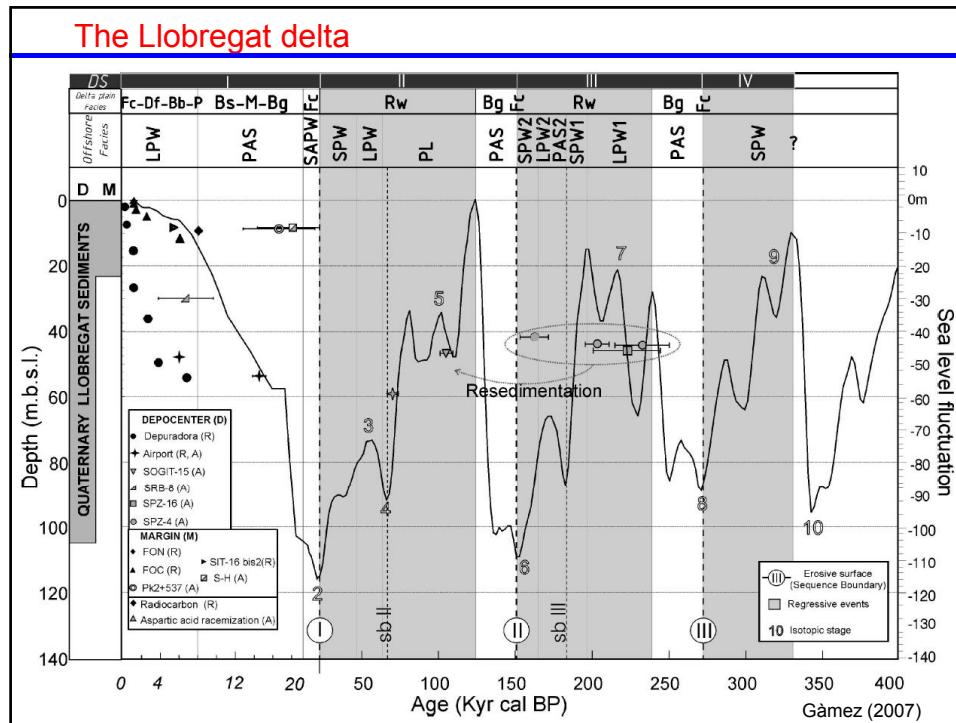
- Llobregat river: 156.6 km long, draining a 5045 km<sup>2</sup> basin
- Delta extension 97 km<sup>2</sup>, 23 km of shoreline
- Confined by the Garraf (SW), Montjuïc (N) and Collserola mountains (NW)

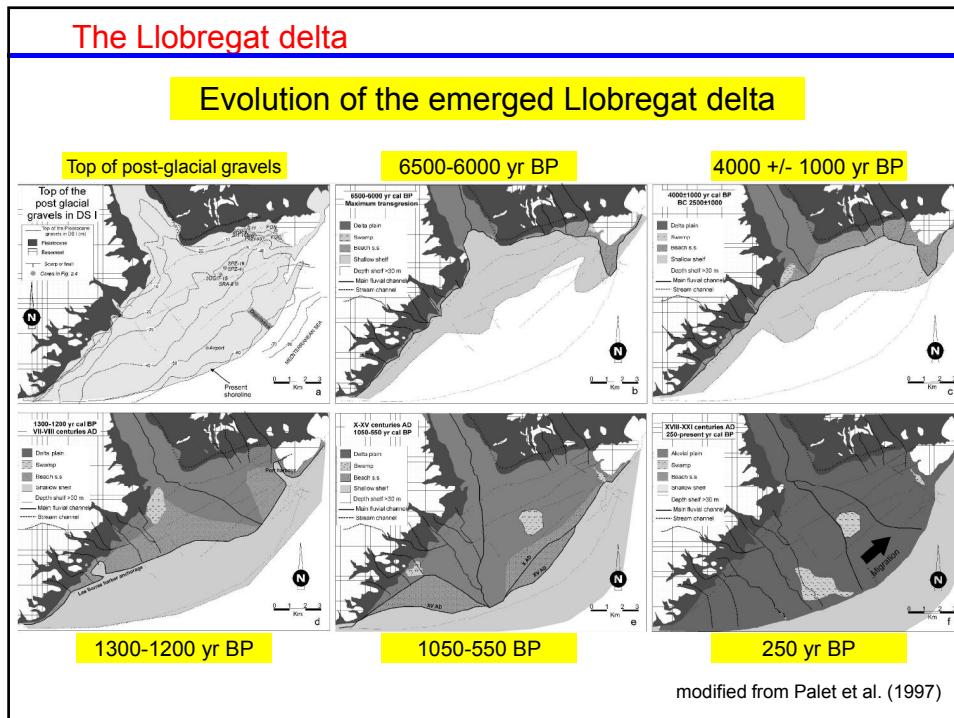
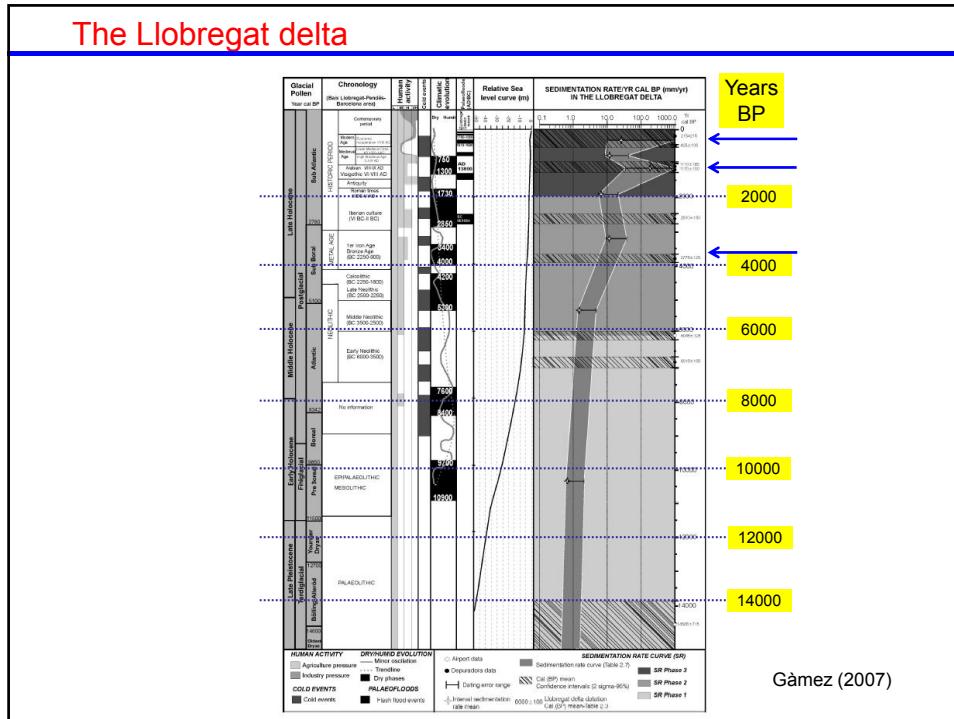
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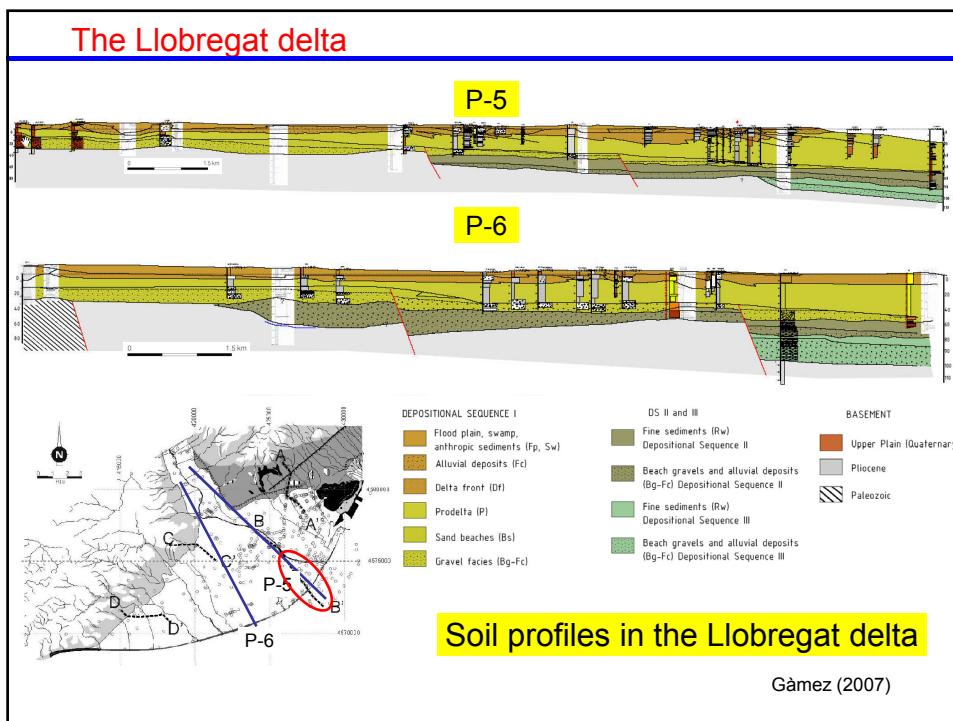
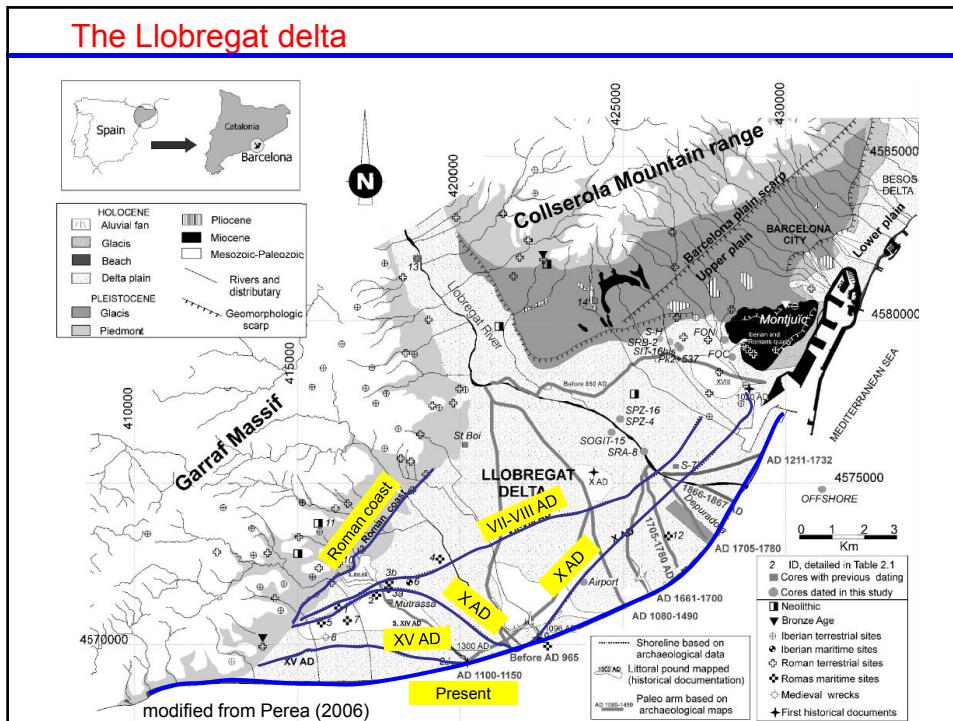


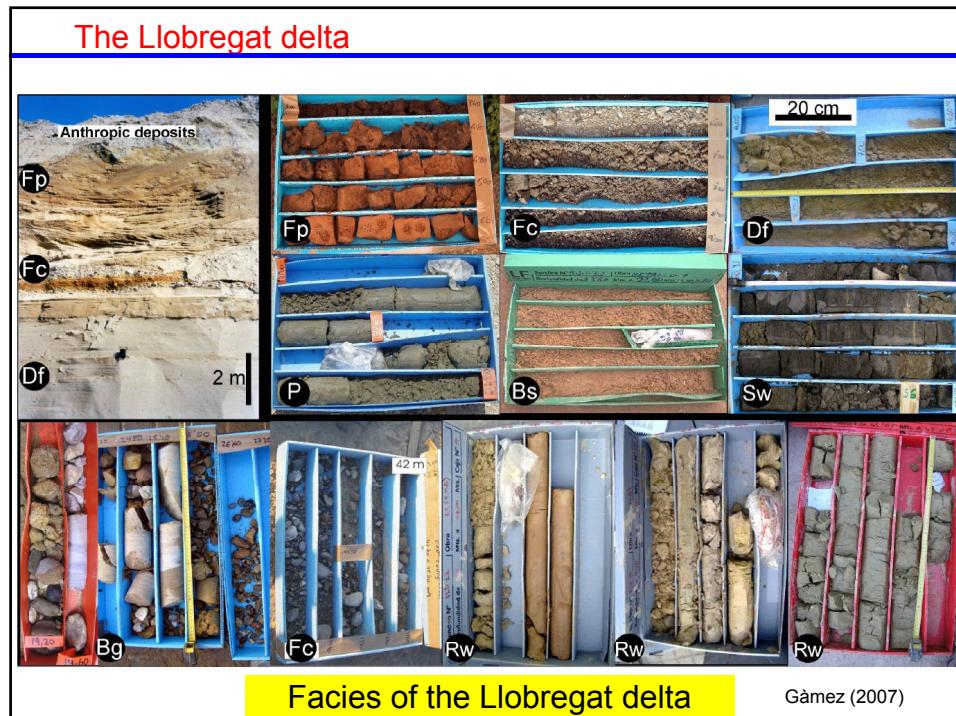
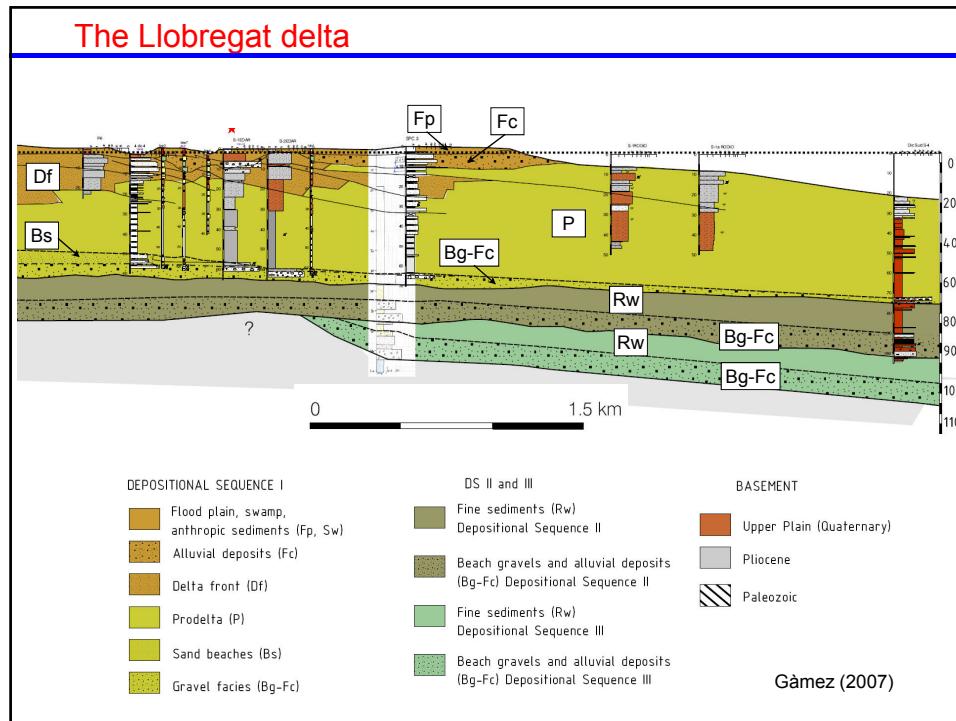
## The Llobregat delta











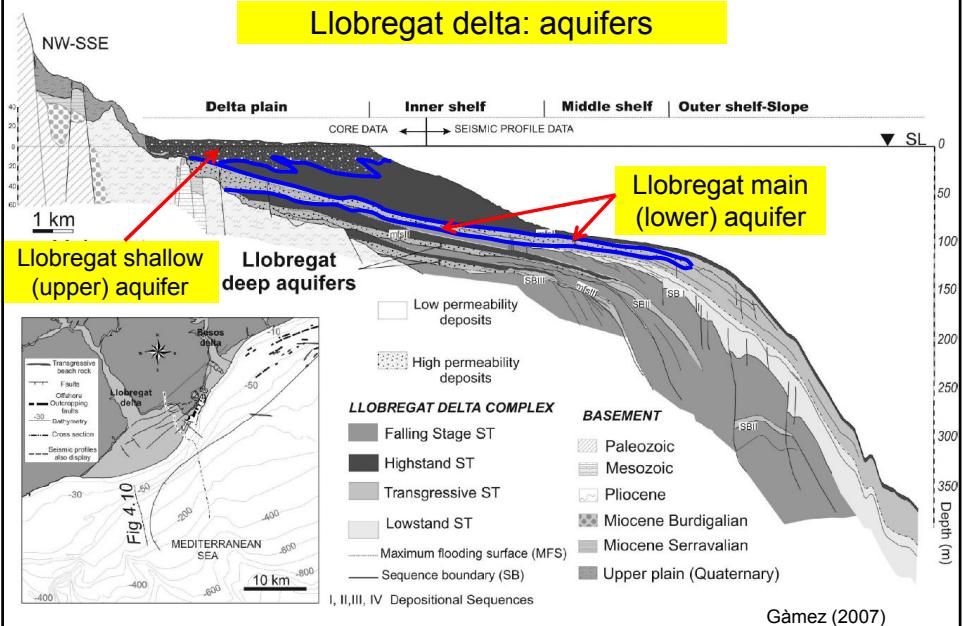
### The Llobregat delta

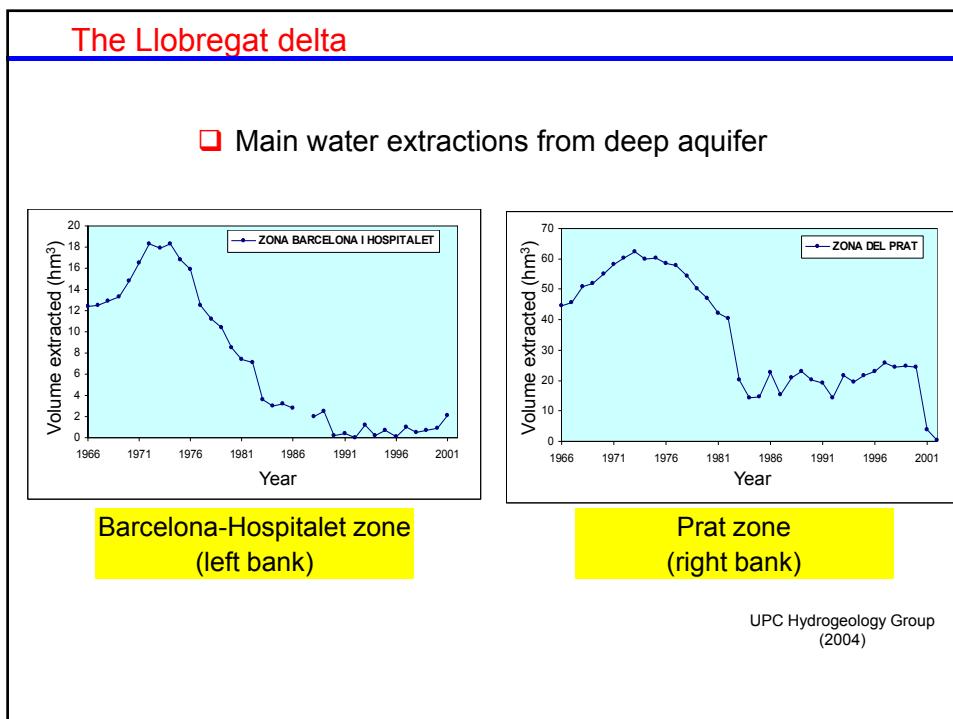
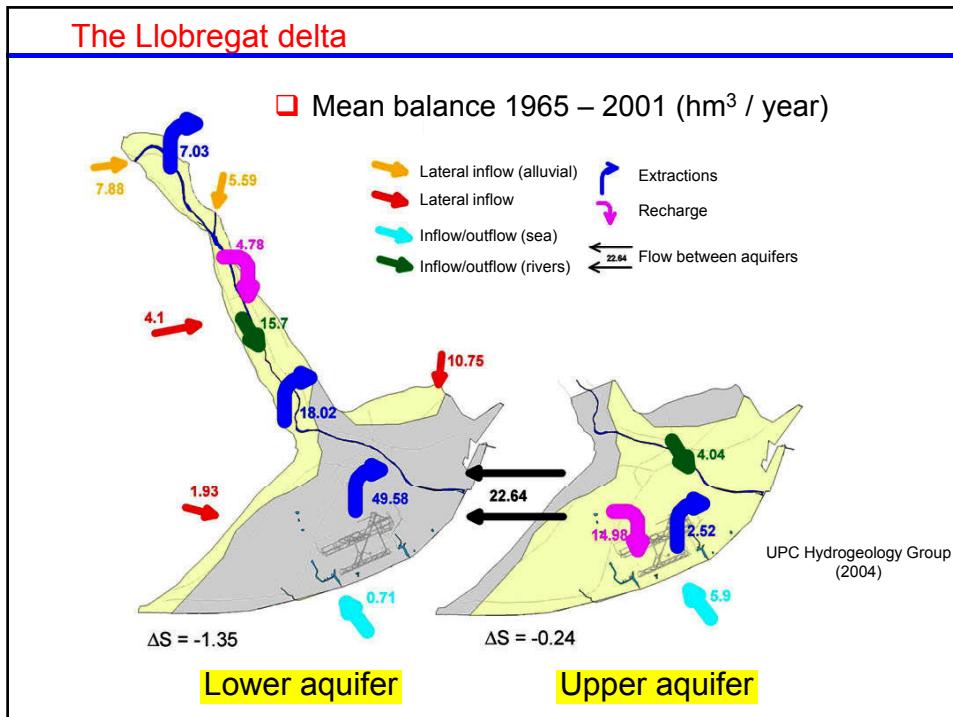


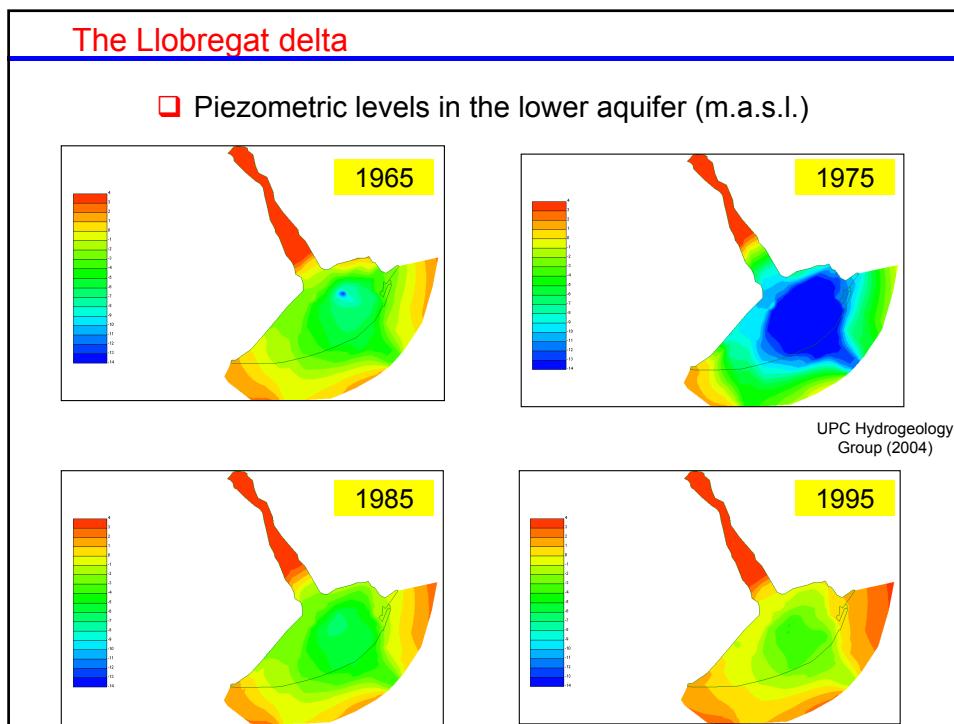
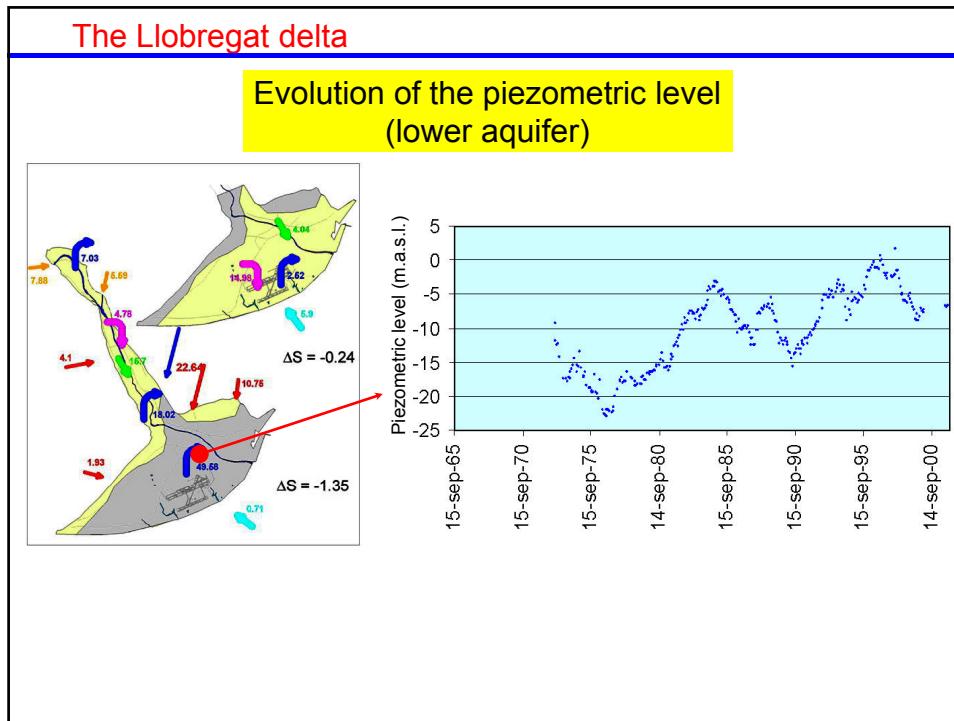
P: Pro-deltaic sediments deposited below the storm wave base  
Clayey silts and silty clays (+ interbedded sand)

### The Llobregat delta

#### Llobregat delta: aquifers







## The Llobregat delta: summary

- ❑ The history and mechanisms of delta formation control and explain the succession and structure of the different deposition units  
*L'histoire et les mécanismes de formation du delta contrôlent et expliquent la succession et la structure des différents ensembles de dépôts sédimentaires*
- ❑ An approach based on an understanding of the mechanisms of delta formation provides a richer geological picture than pure lithological correlations  
*Une approche basée sur la compréhension les mécanismes de formation du delta donne une image plus riche de la géologie du site que des corrélations purement lithologiques.*
- ❑ The flood plain and pro-delta deposits exhibit a high degree of lateral uniformity. Alluvial and beach front deposits are much more dependent on the vagaries of the river flow channels  
*La vallée sédimentaire et les dépôts pro-deltaïques présentent un fort degré d'uniformité latérale. Les alluvions et les dépôts en front de mer sont beaucoup plus dépendants du caractère erratique des chemins d'écoulement dans le lit du fleuve*

## The Llobregat delta: summary

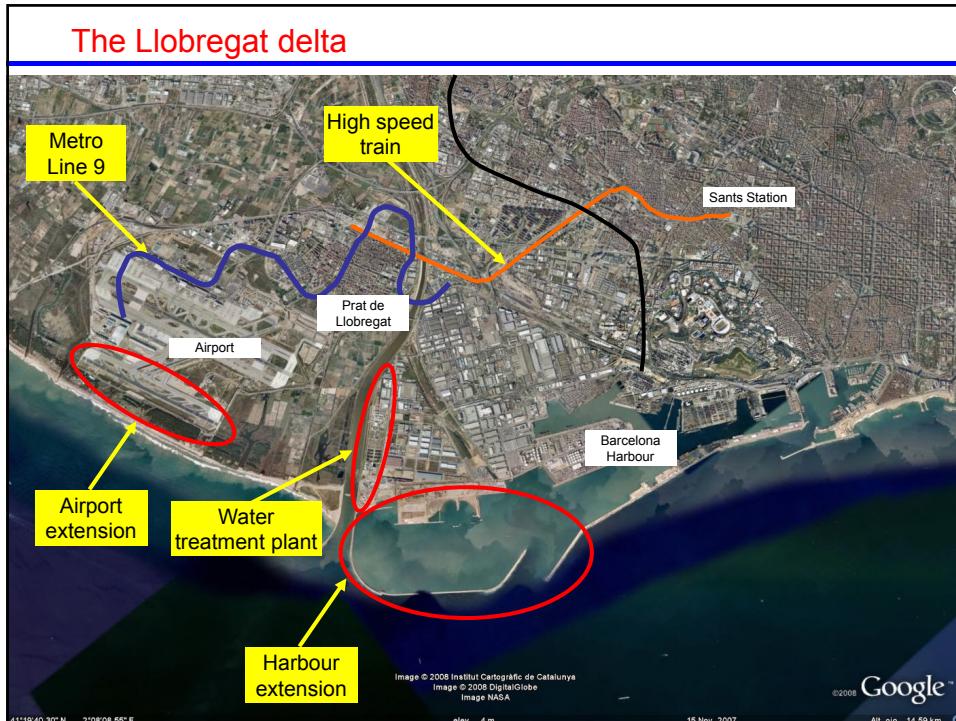
- ❑ The various aquifers play a key role in the geotechnical appraisal of the area:
  - The upper aquifer ensures a high water table throughout
  - The exploitable lower aquifer require protection measures and may constraint some construction procedures
  - The variation of the piezometric levels of the lower aquifer may affect the consolidation state of the intermediate pro-delta deposits.

*Les différentes aquifères jouent un rôle-clé dans l'examen géotechnique:*

*L'aquifère supérieure assure partout un niveau élevé de la nappe phréatique.*

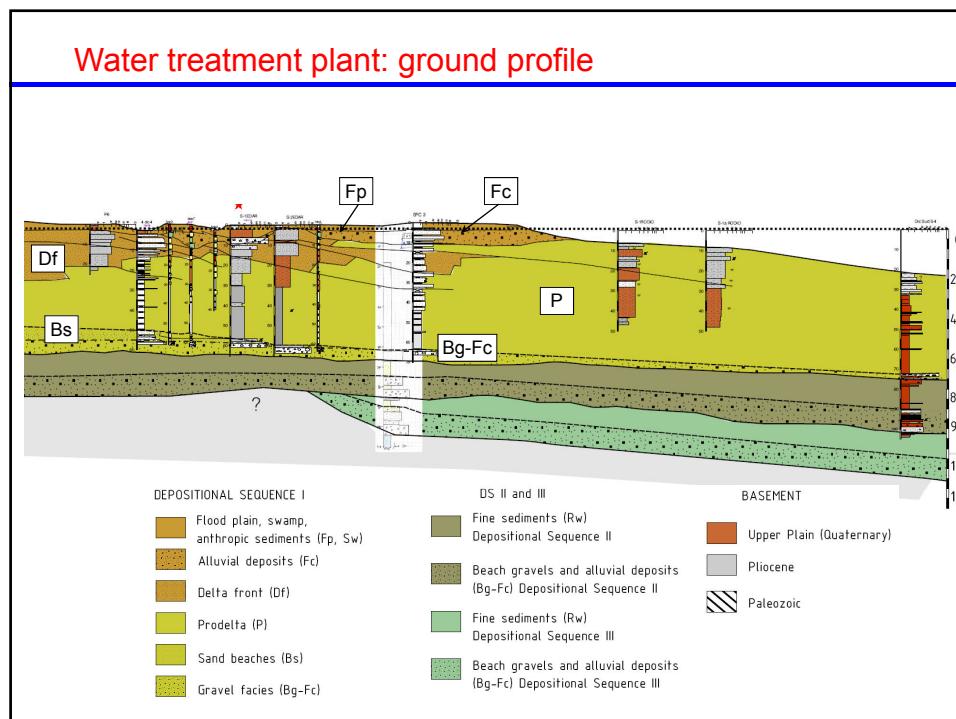
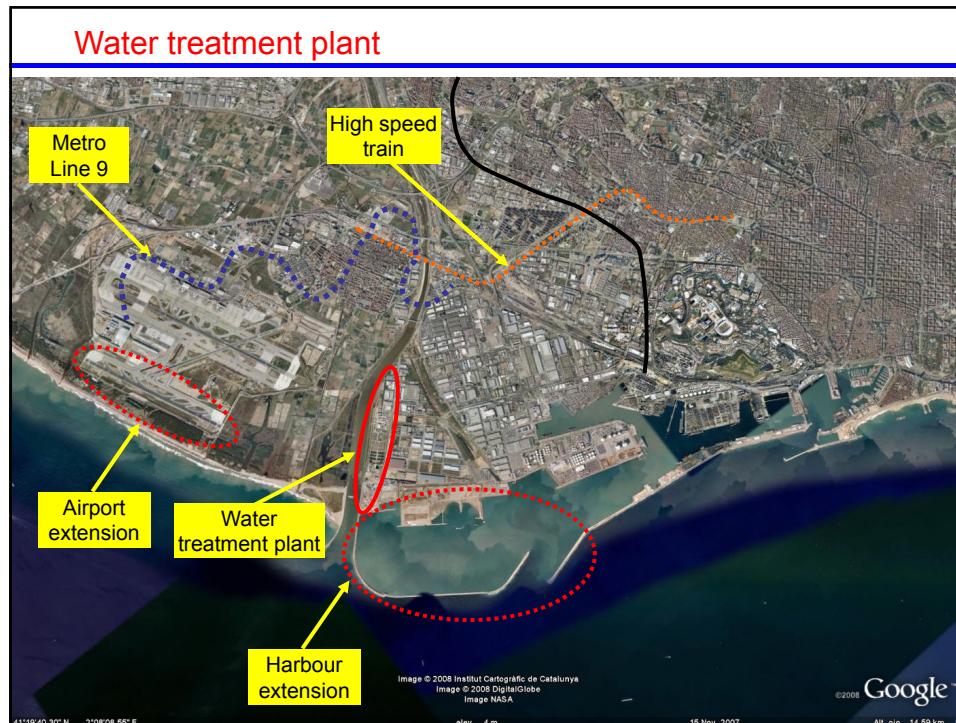
*La partie exploitante de l'aquifère inférieure requiert des mesures de protection et peut contraindre les procédures de construction.*

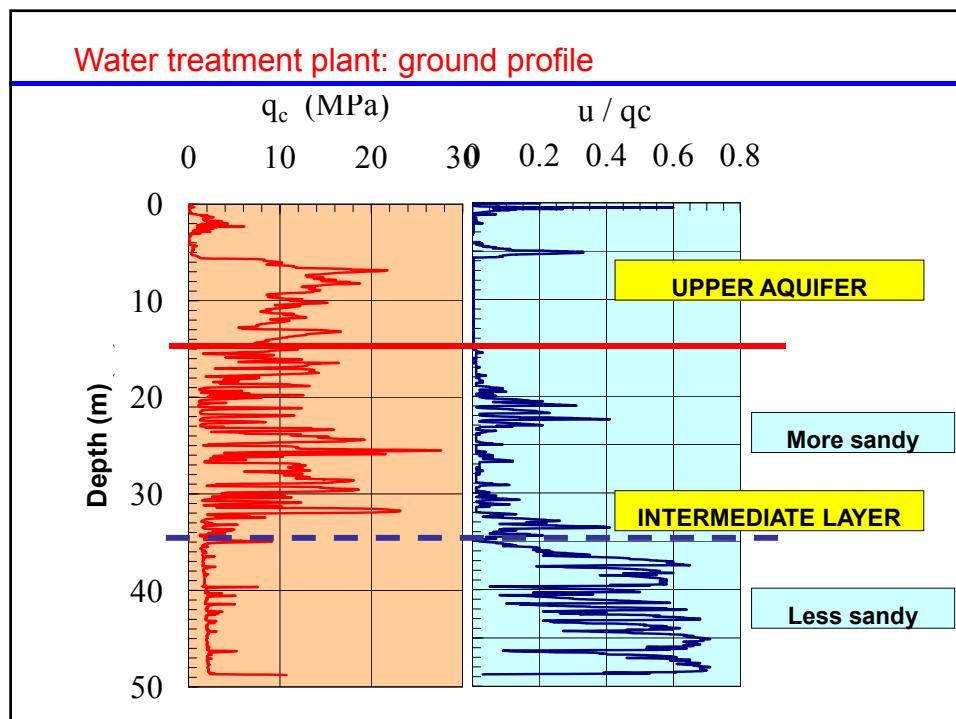
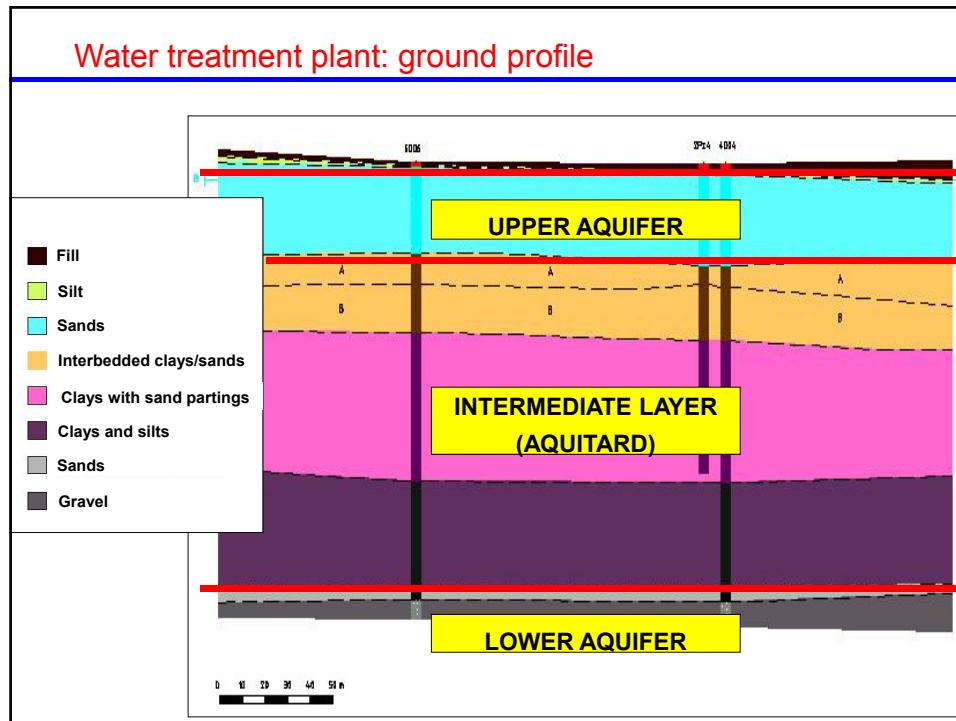
*Les variations des niveaux piézométriques de l'aquifère inférieure peuvent affecter l'état de consolidation des dépôts pro-deltaïques intermédiaires.*



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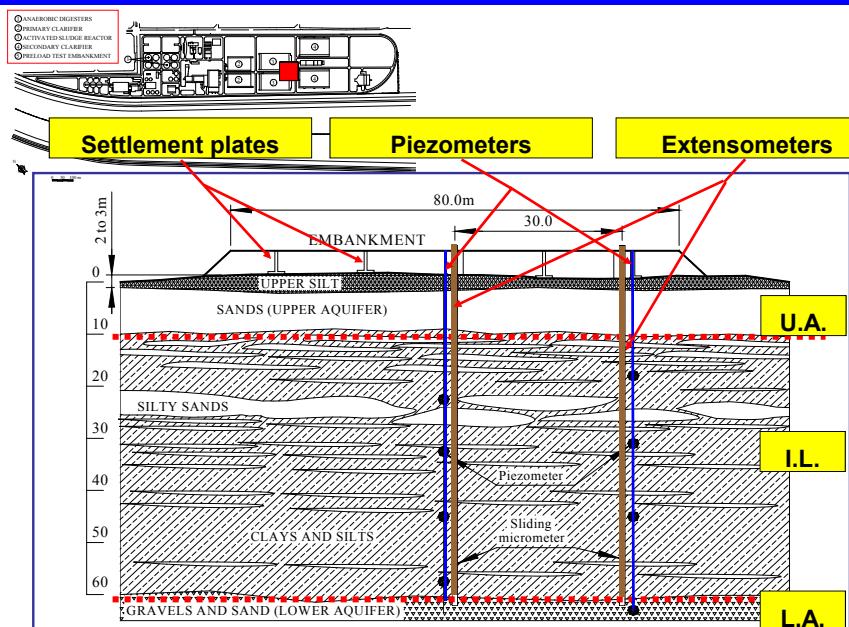


### Preload test of water treatment plant

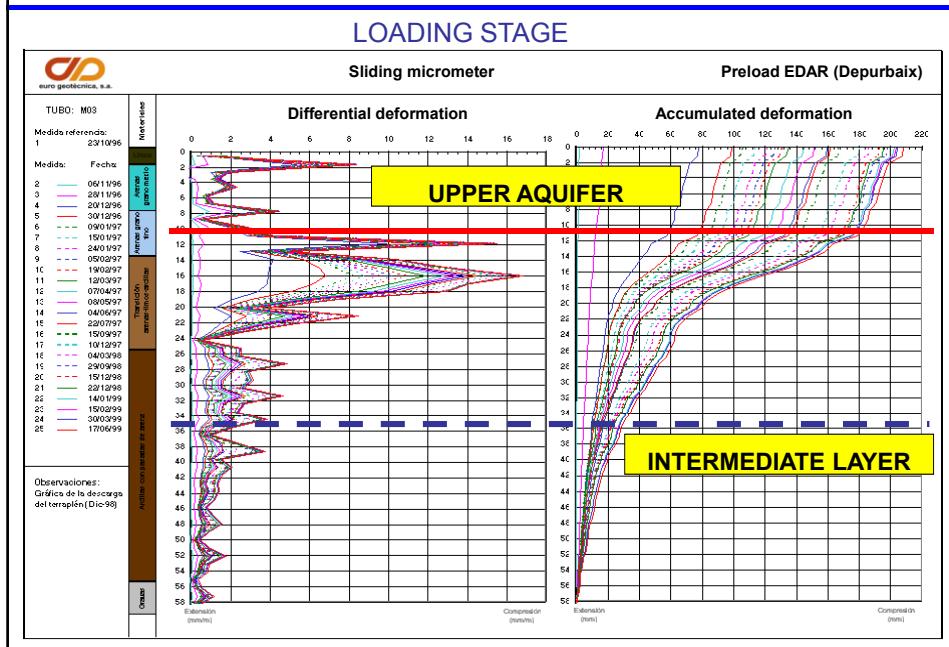


*Géotechnique* (2000), **50**, No 6, 645-656 (Precompression design for secondary settlement reduction)

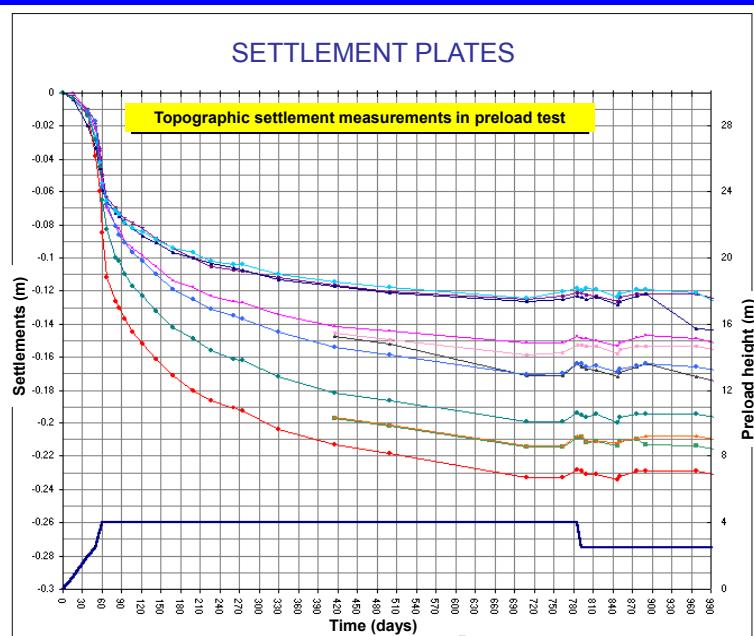
### Preload test of water treatment plant

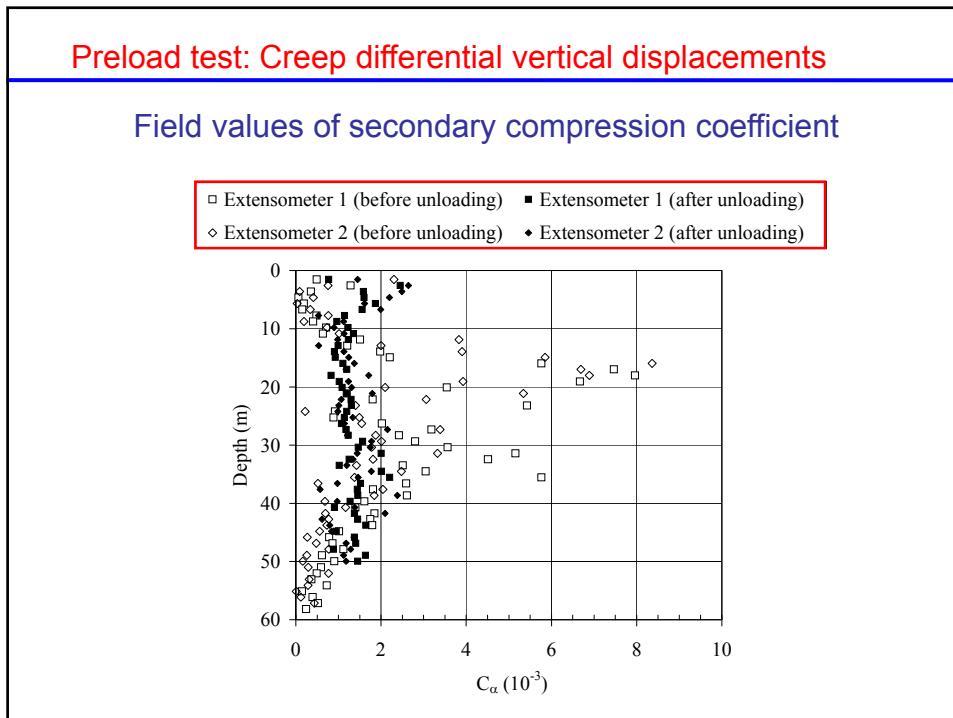
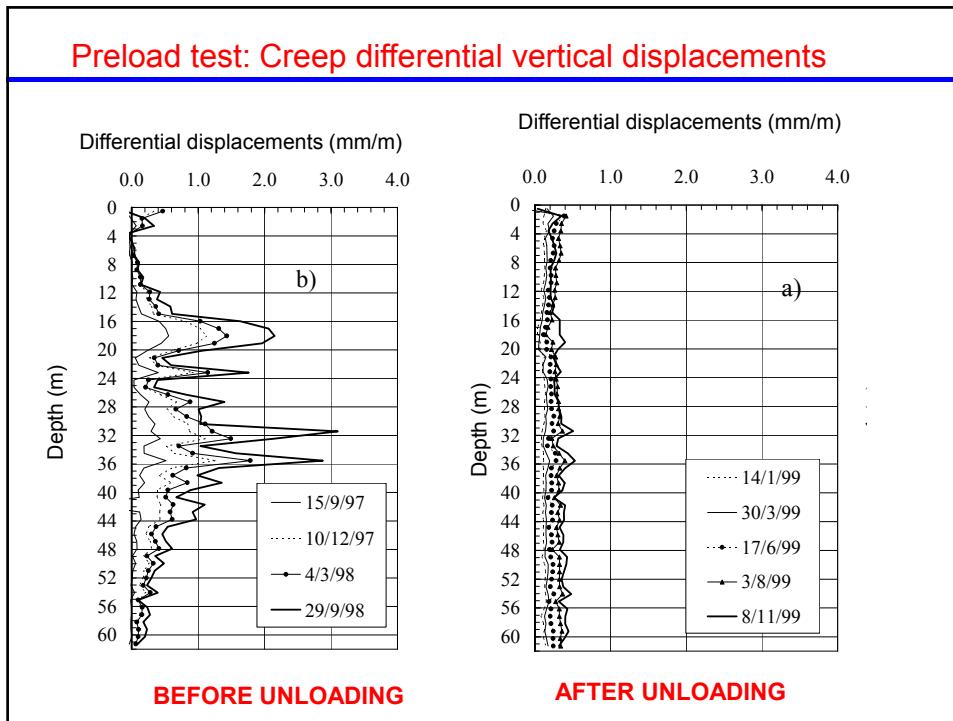


### Preload test: Distribution of vertical movements



### Preload test: Evolution of vertical movements with time

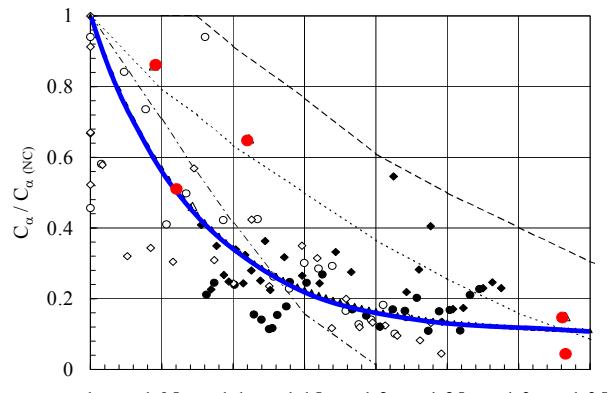




### Preload test: Ground deformation model

$$\Delta\varepsilon_{vs}(z) = C_a(p_c(z, t_i) / \sigma'_v(z, t_i)) \log(t_i / t_{i-1})$$

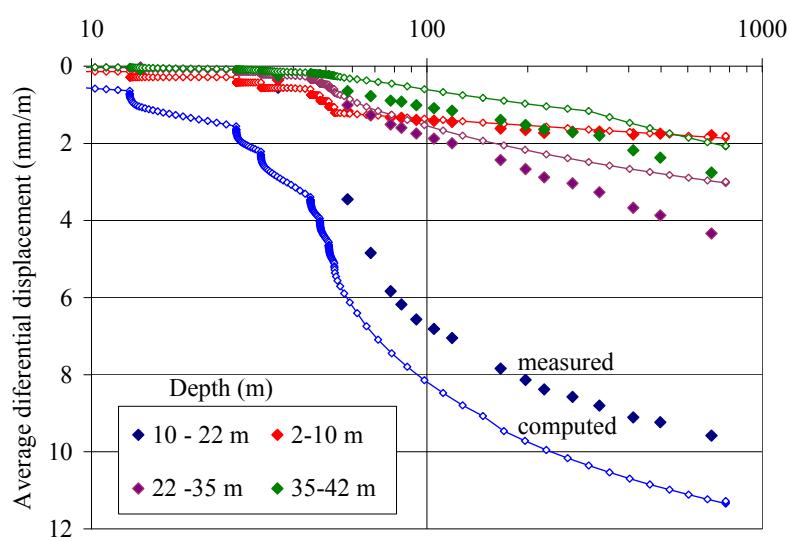
$$(p_c(t_i) / p_c(t_{i-1})) = (t_i / t_{i-1})^{C_a/(C_c - C_s)}$$



$$C_\alpha = 0.008[0.1 + 0.9 \exp(-13(OCR - 1))] \quad \text{Ladd (1971)}$$

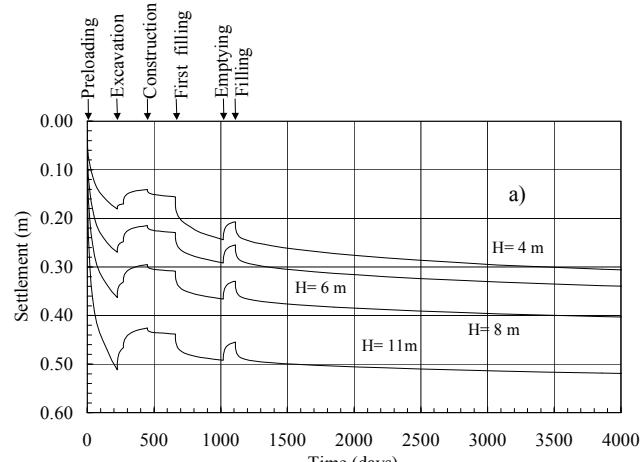
### Preload test: Ground deformation model

#### Validation and calibration



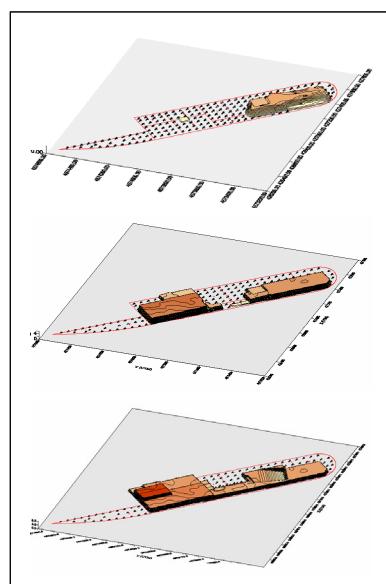
## Preload of water treatment plant: design

### Computed settlement histories



Anaerobic digesters

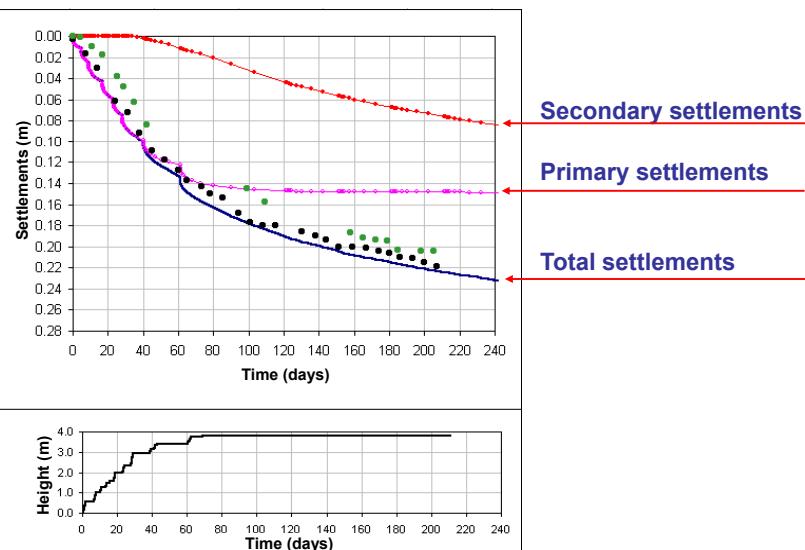
## Water treatment plant: preload prior to construction



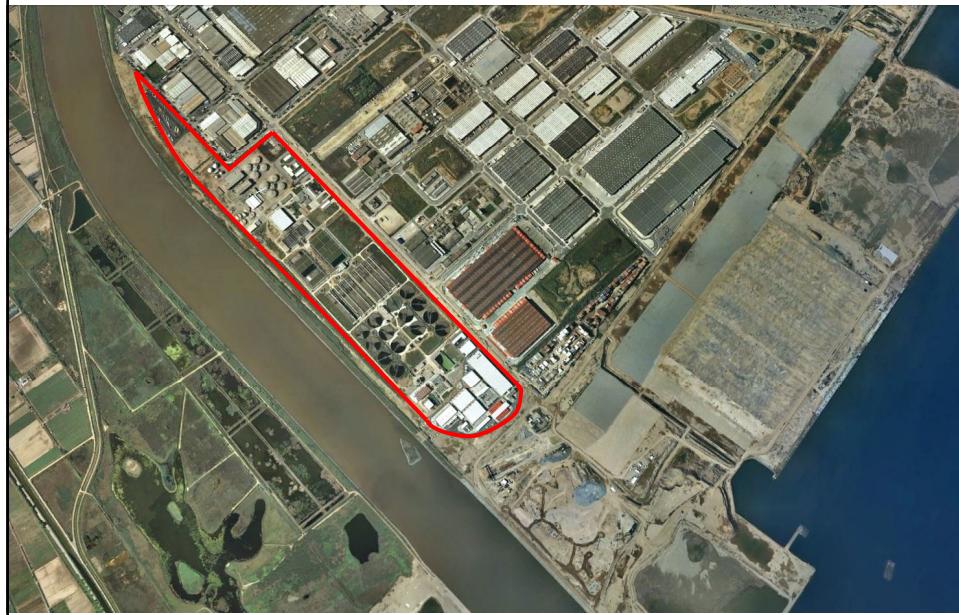
### Water treatment plant: construction



### Water treatment plant: construction



### Water treatment plant



### Barcelona airport extension



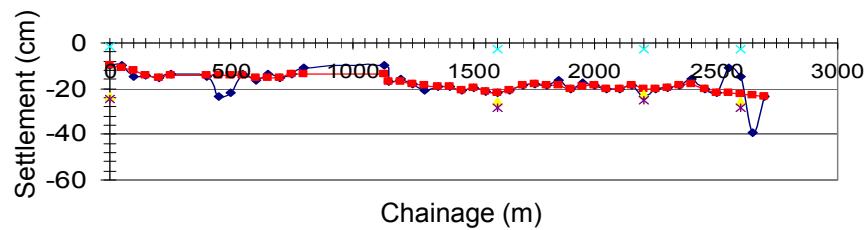
Airport extension: third runway)

Construction



Preload in airport (third runway)

Preload settlements



### Airport extension: third runway)



### Mitigation of long term settlements: summary

- ❑ A well-instrumented **preload test** provides key information on the deformation characteristics of the ground  
*Un essai de préchargement bien instrumenté permet d'avoir des informations clés sur les caractéristiques de déformation du terrain*
- ❑ The pattern of **overconsolidation** (due to the reduction of piezometric levels in the lower aquifer) explains the distributions of vertical movements with depth  
*Le patron de surconsolidation des dépôts, résultant de la réduction des niveaux piézométriques dans l'aquifère inférieur, explique les distributions en profondeur des mouvements verticaux.*
- ❑ A relatively high permeability is exhibited by the upper part of the prodelta deposits due to inter-layering with thin granular horizons. **Primary consolidation settlements can be overcome by preloading** acting during a reasonable length of time  
*La perméabilité de la partie supérieure des dépôts pro-deltaïques est relativement forte en raison de l'intercalation d'horizons granulaires. Il est en conséquence possible de limiter les tassements de consolidation primaire en préchargeant le terrain pendant un temps raisonnable.*

## Mitigation of long term settlements: summary

- ❑ Mitigation of **secondary settlements** requires achieving a certain degree of **overconsolidation** in the compressible material. A calibrated ground deformation model allows the evaluation of different load-time options

*La réduction des **tassements secondaires** demande l'atteinte d'un certain niveau de **surconsolidation**. Un modèle calibré de prédiction des déformations du terrain permet d'évaluer différentes options de chargement en fonction du temps.*

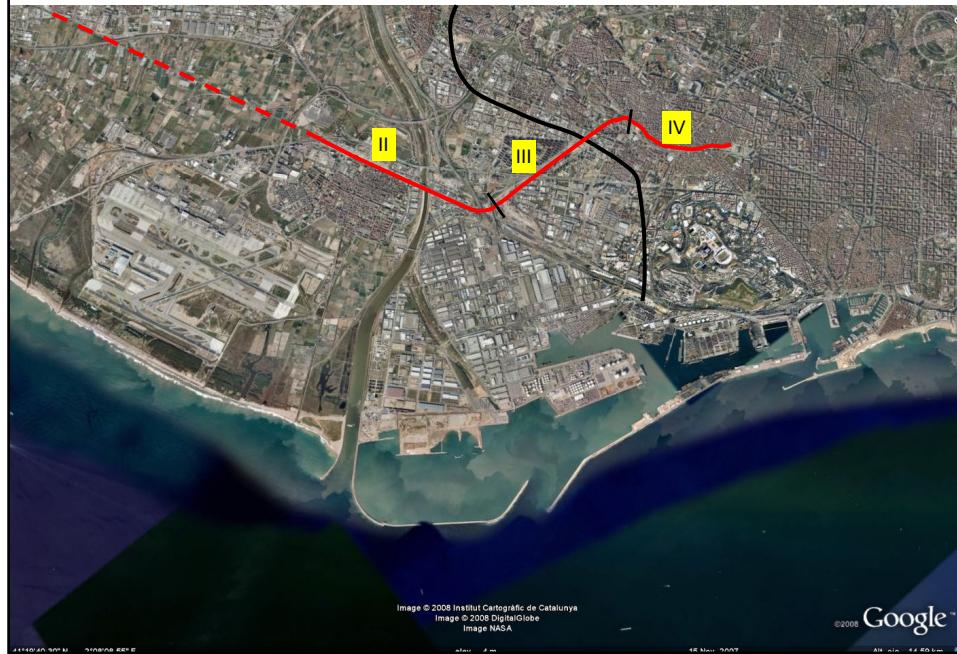
- ❑ The deformation **response** of the ground is **remarkable homogenous** over significant distances. This observation attests the homogeneity of the prodelta deposits.

*Les **déformations du terrain** mettent en évidence une réponse **remarquablement homogène** sur des distances importantes. Cette observation atteste de l'**homogénéité** des dépôts pro-deltaïques*

## Outline

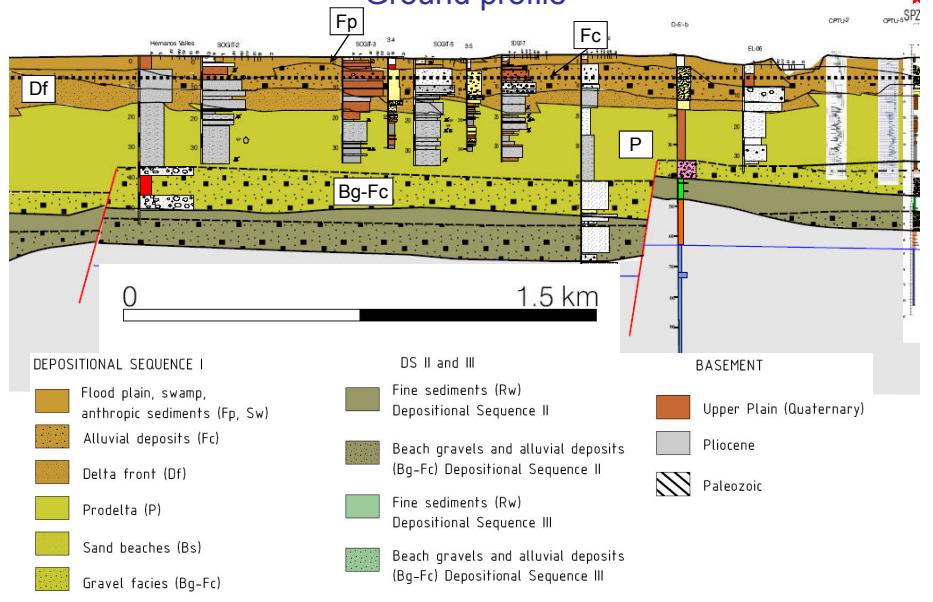
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### High speed train link Madrid - Barcelona

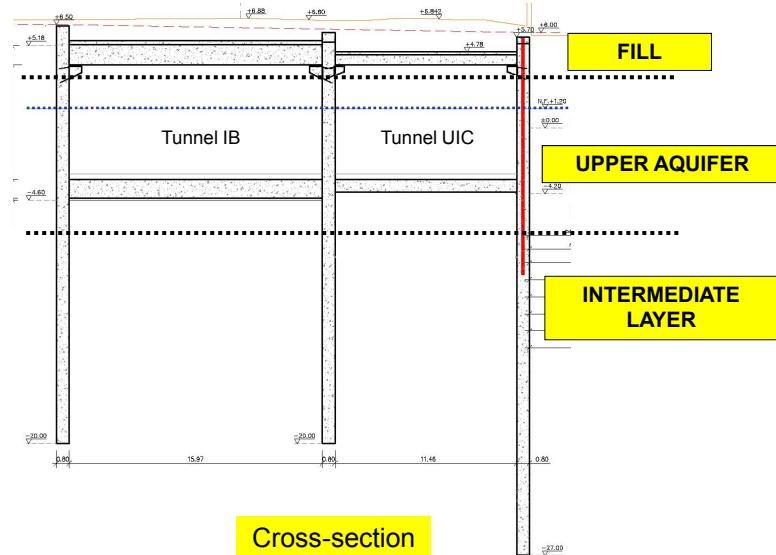


### High speed train link

#### Ground profile



### High speed train link

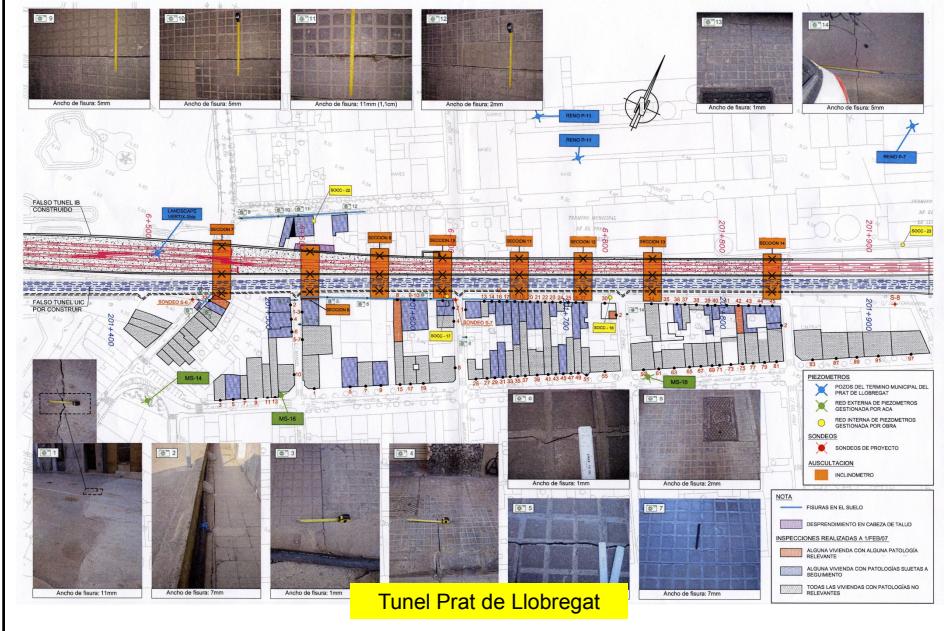


Cross-section

### High speed train link



## High speed train link: observations

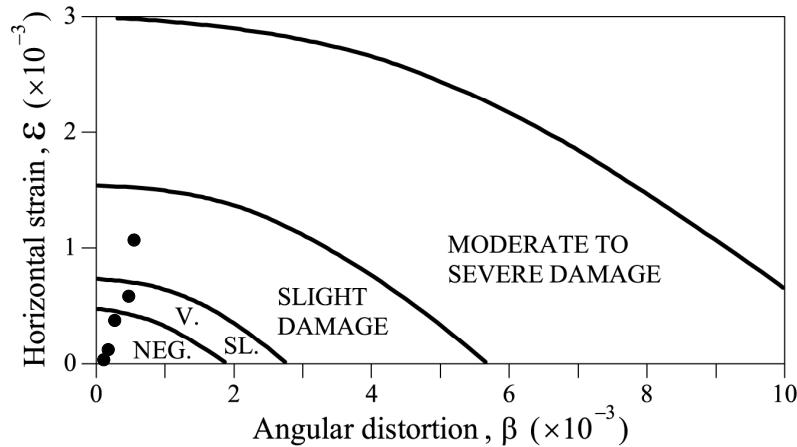


## High speed train link

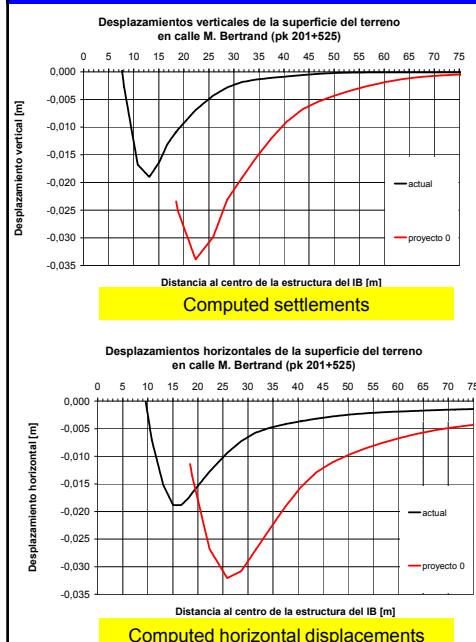




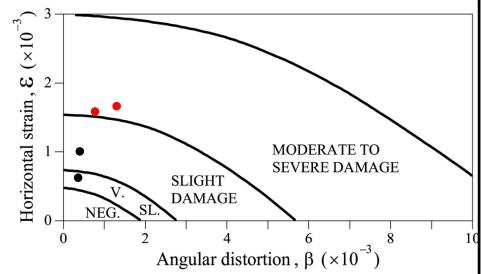
### High speed train link: damage assessment



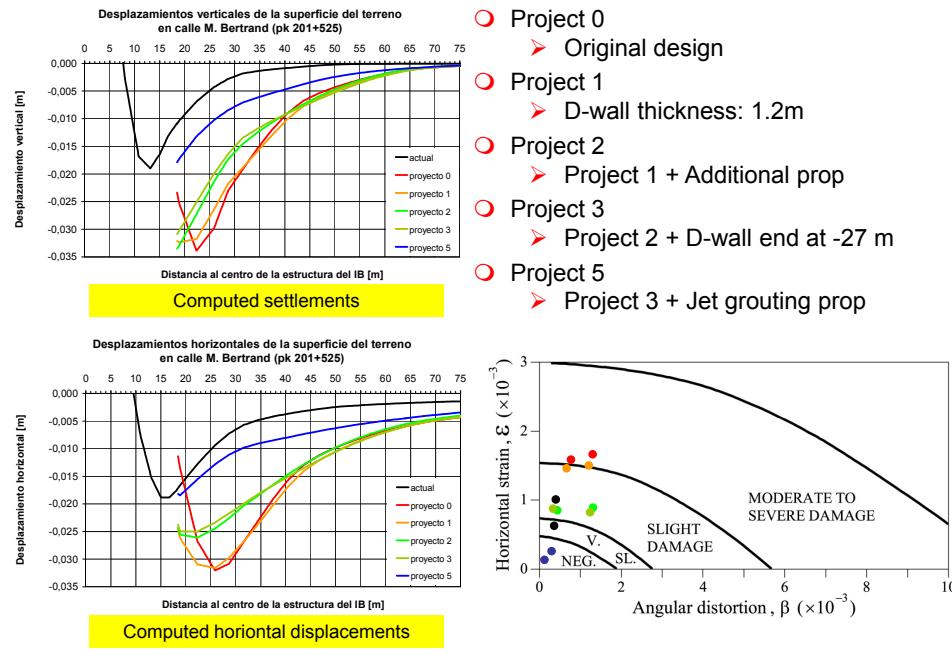
### High speed train link: modelling



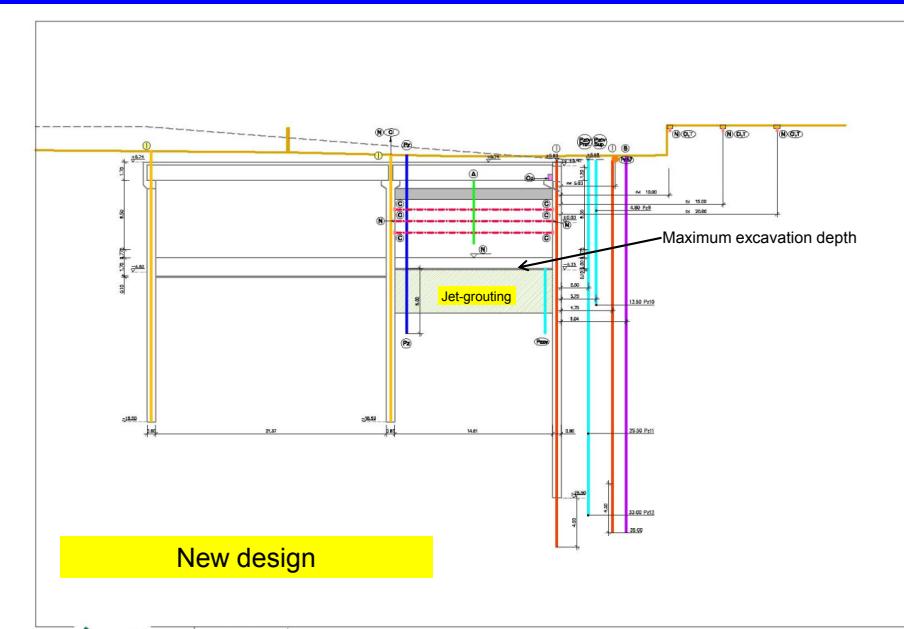
### Predicted future movements



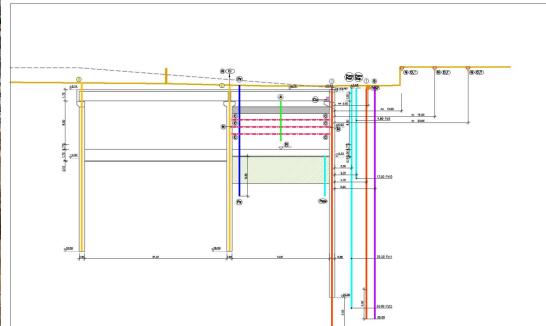
## High speed train link: modelling



## High speed train link

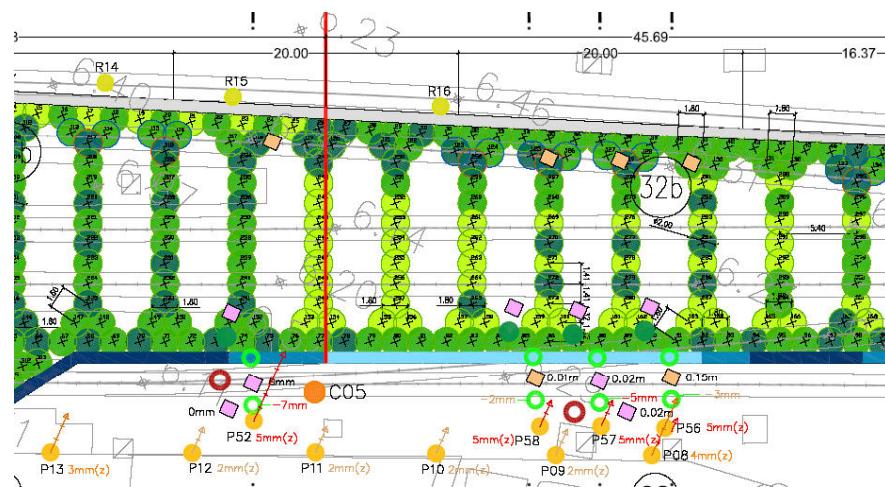


## High speed train link



## Test sections

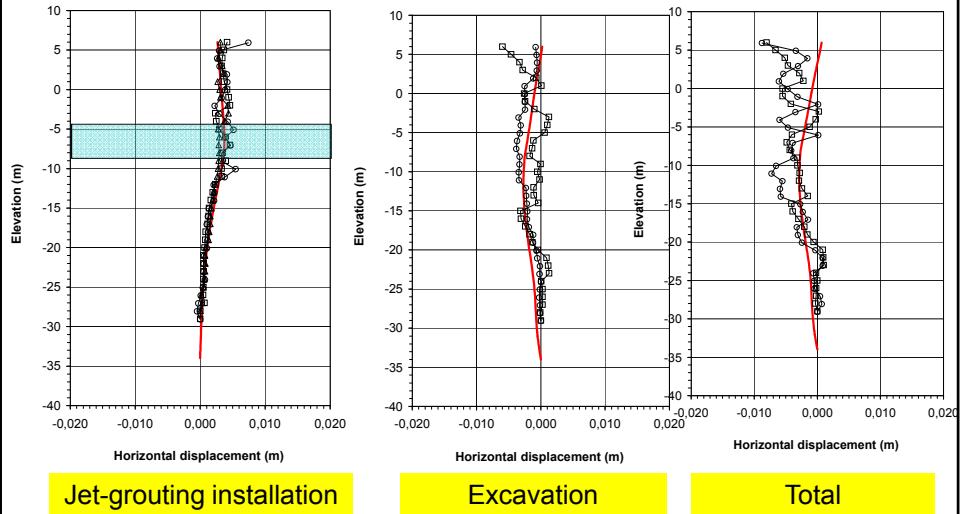
High speed train link



## Jet grouting prop below floor slab elevation

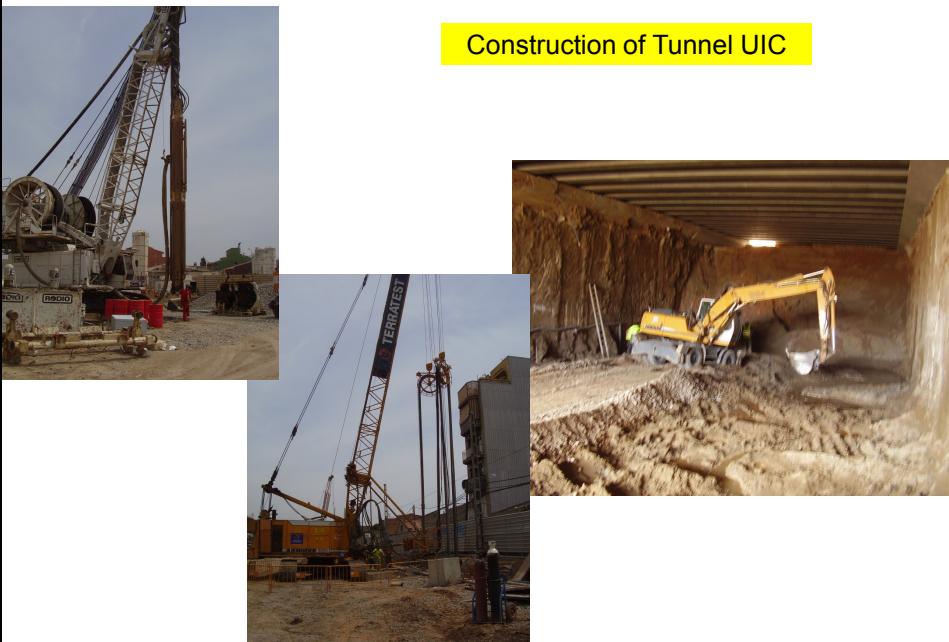
## High speed train link

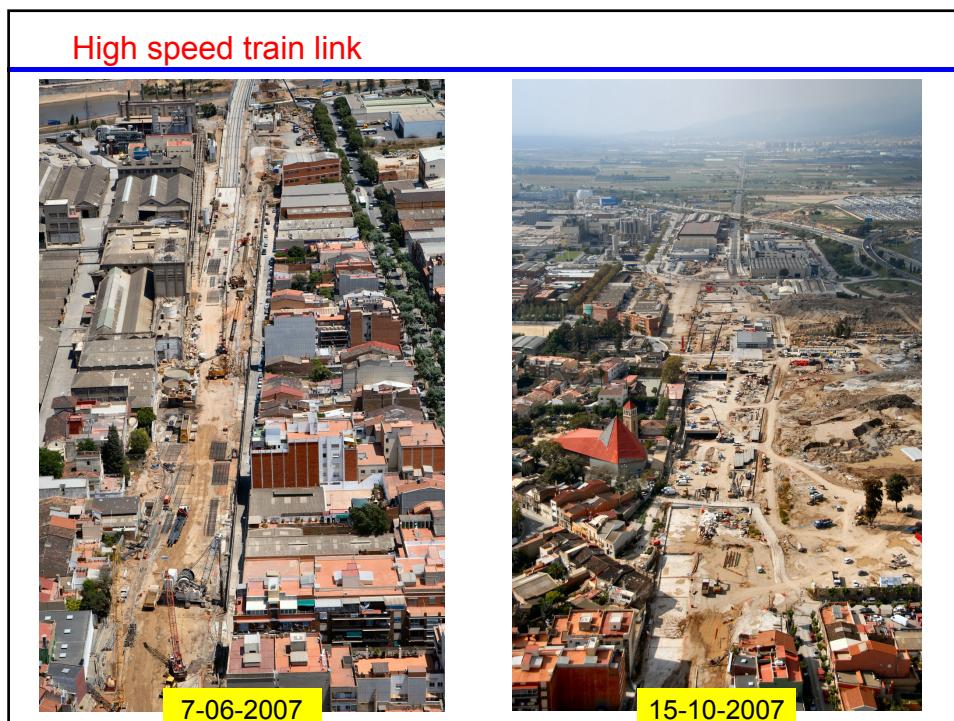
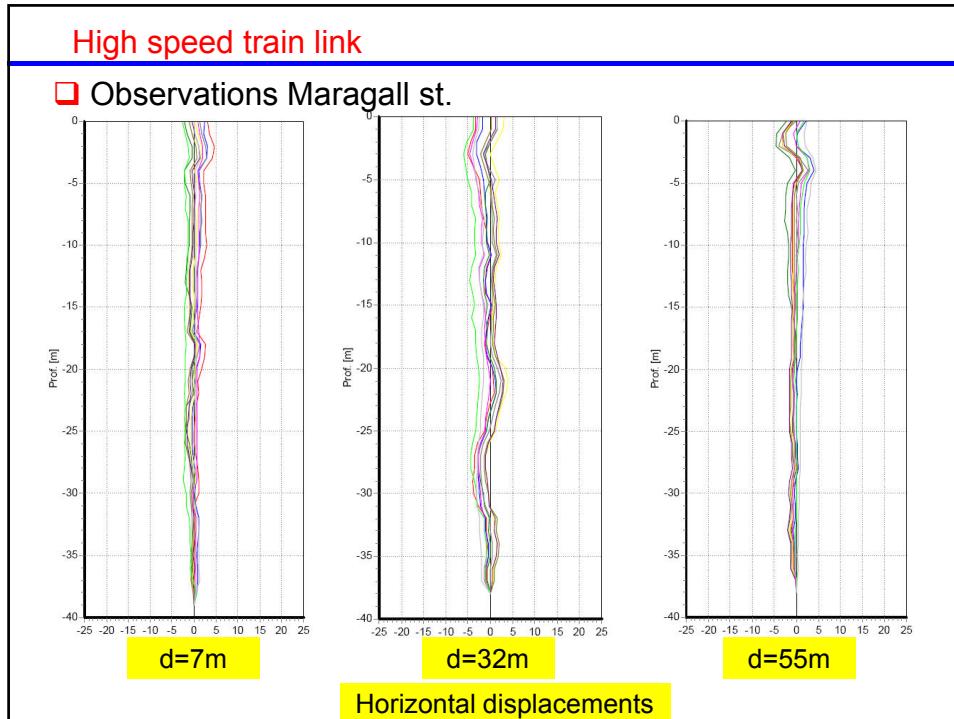
Observations and model calibration. Inclinometers in the ground

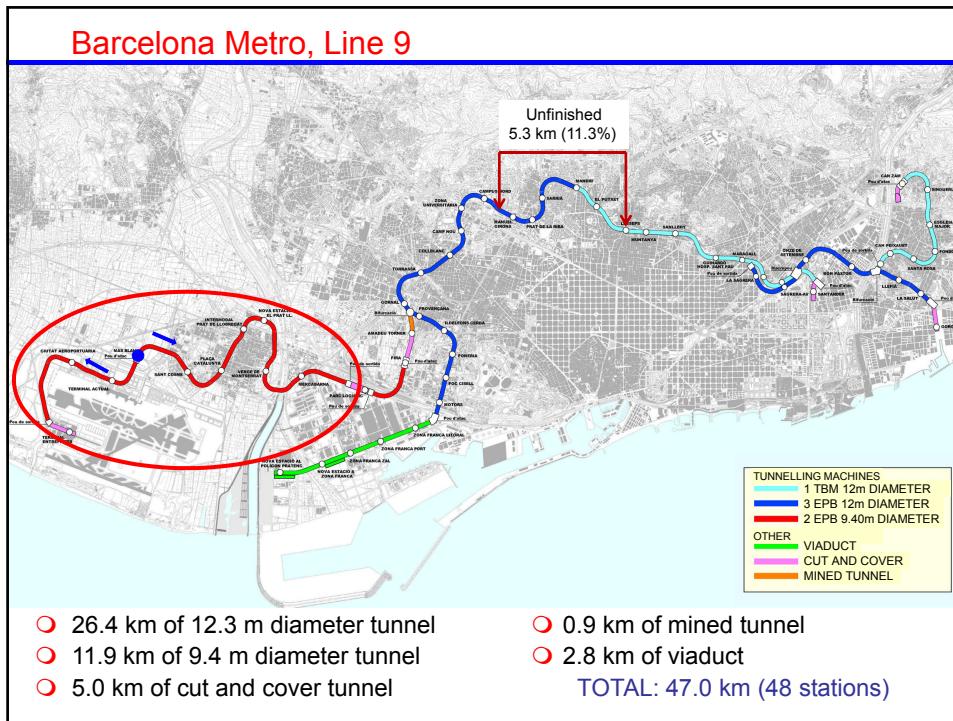


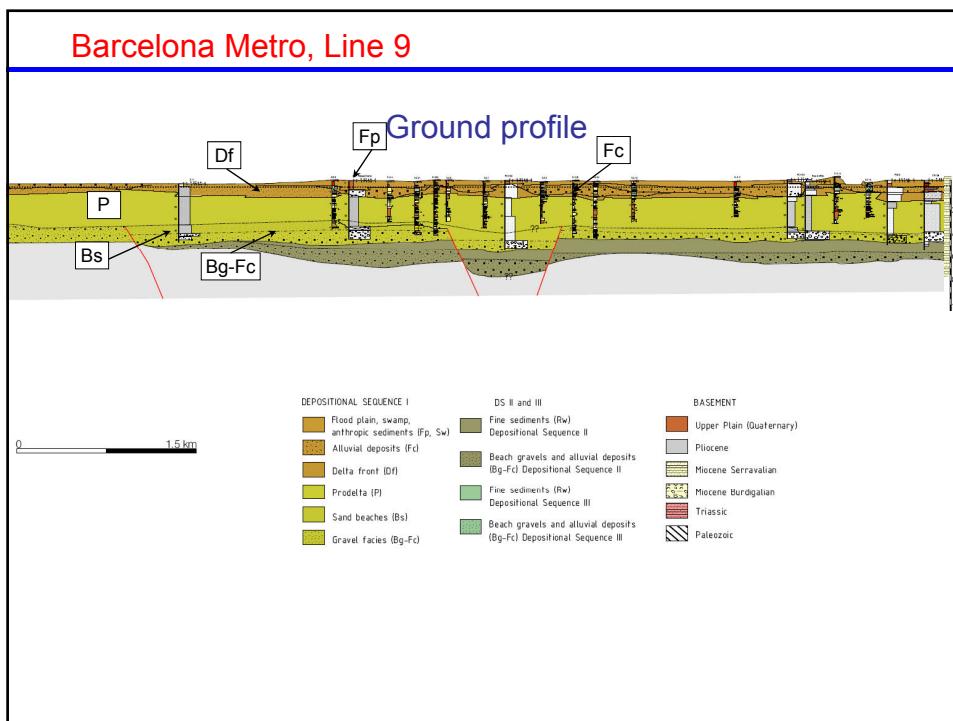
## High speed train link

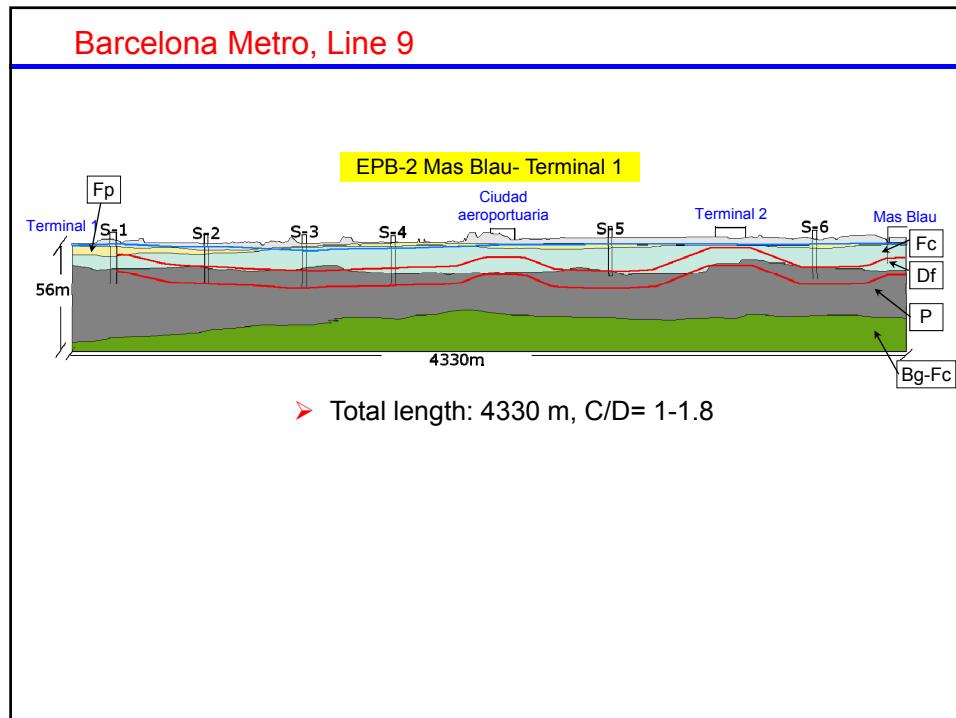
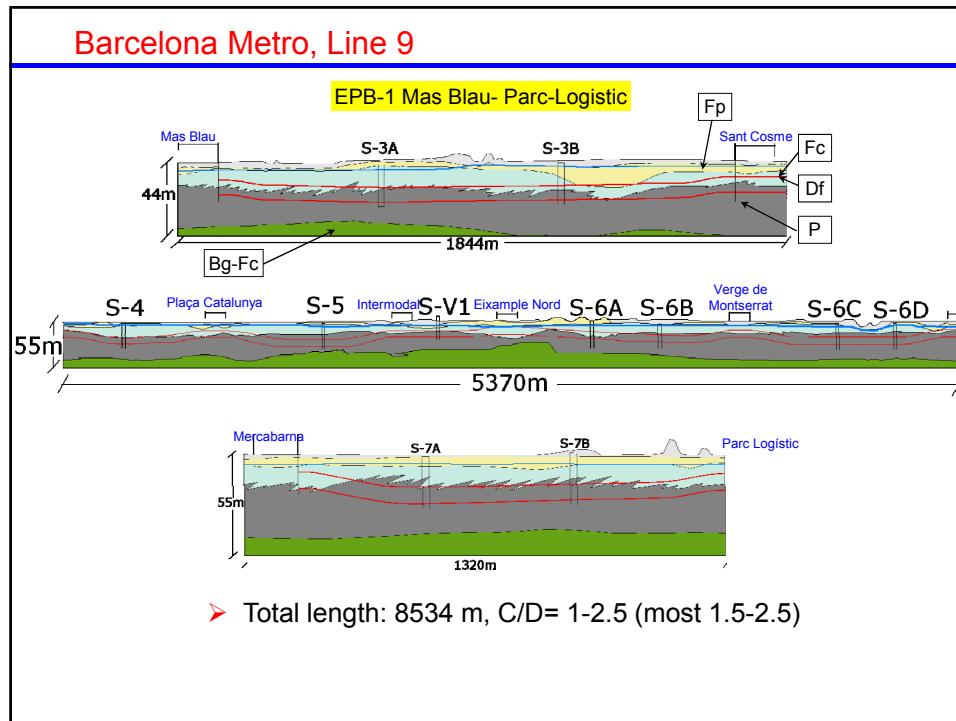
Construction of Tunnel UIC



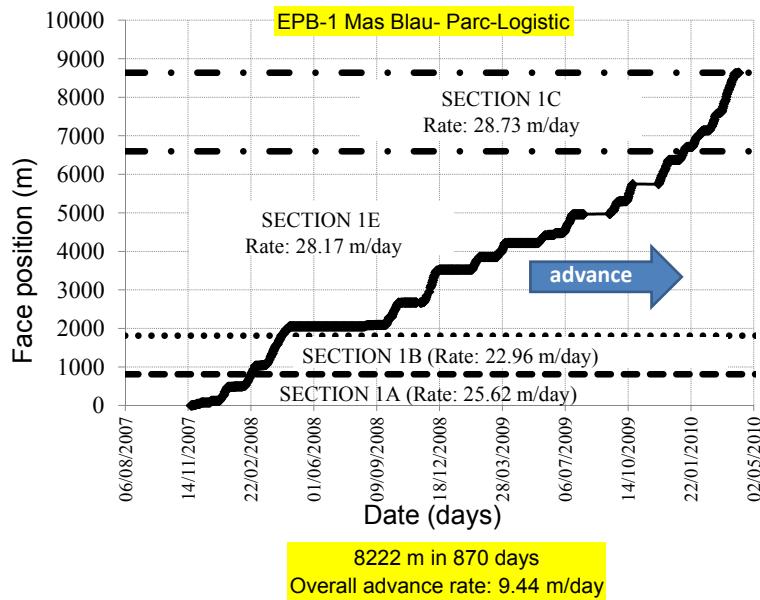




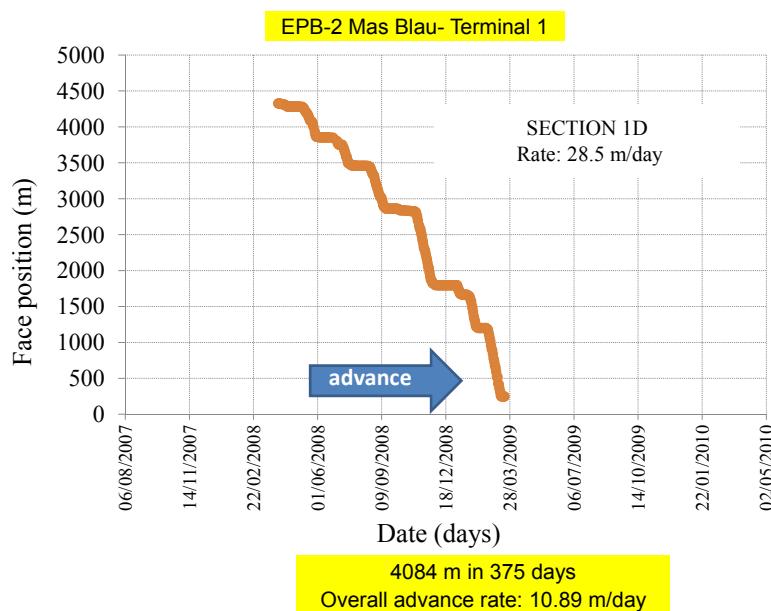




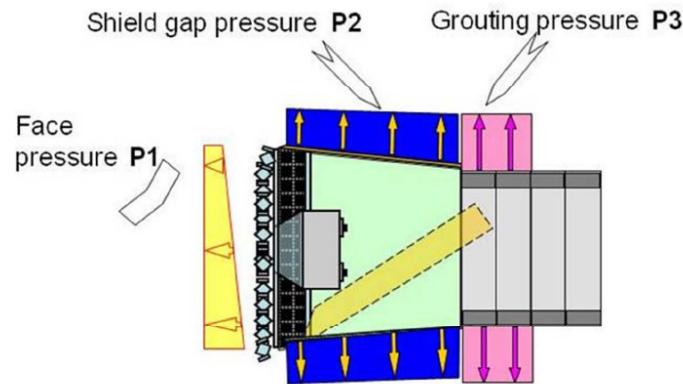
### Barcelona Metro, Line 9: tunnelling advance



### Barcelona Metro, Line 9: tunnelling advance



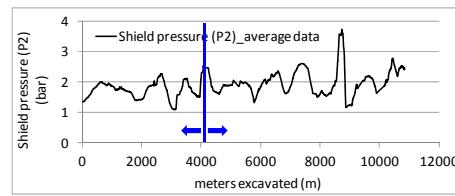
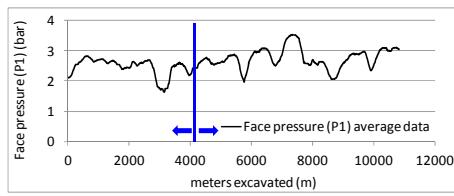
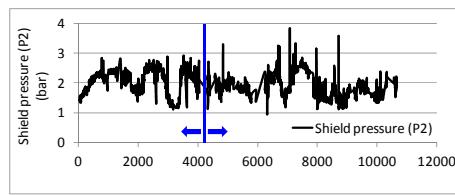
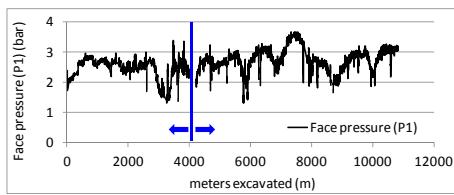
## Barcelona Metro, Line 9: EPB parameters



Closed shield machine. Earth pressure balance TBM (EPB)

## Barcelona Metro, Line 9: EPB parameters

### Tunnelling parameters

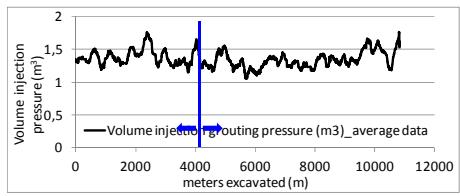
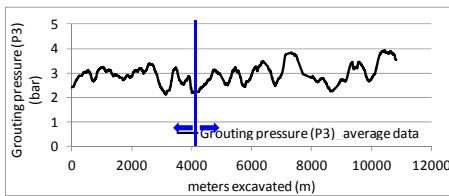
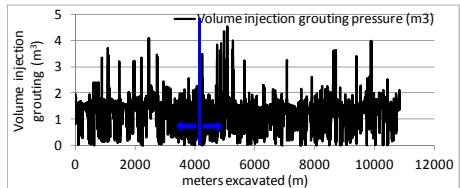
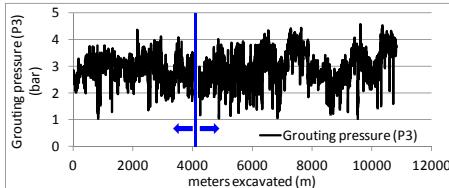


Face pressure (bar)

Shield grouting pressure (bar)

## Barcelona Metro, Line 9: EPB parameters

### □ Tunnelling parameters

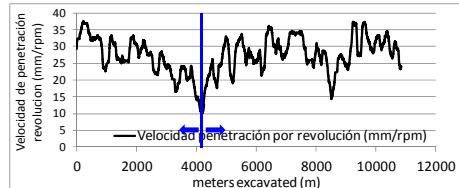
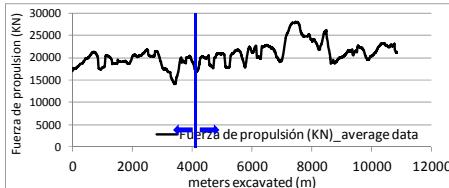
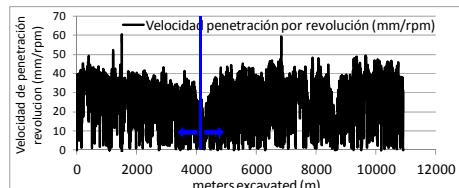
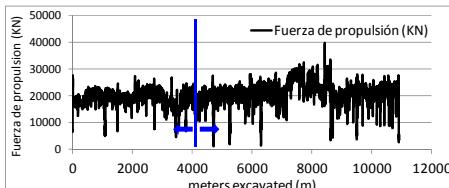


Tail grouting pressure (bar)

Tail grouting volume (m³)

## Barcelona Metro, Line 9: EPB parameters

### □ Tunnelling parameters

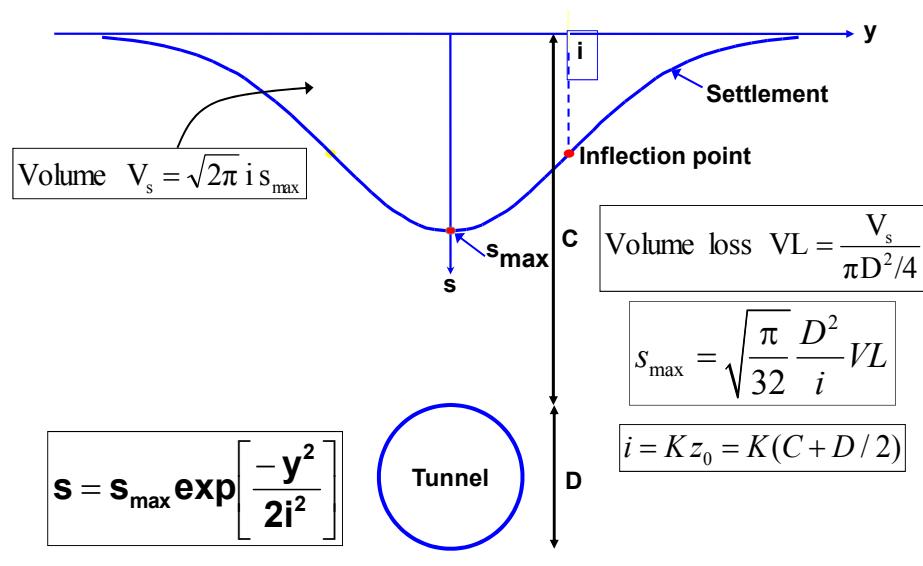


Total thrust (kN)

Penetration rate (mm/rev.)

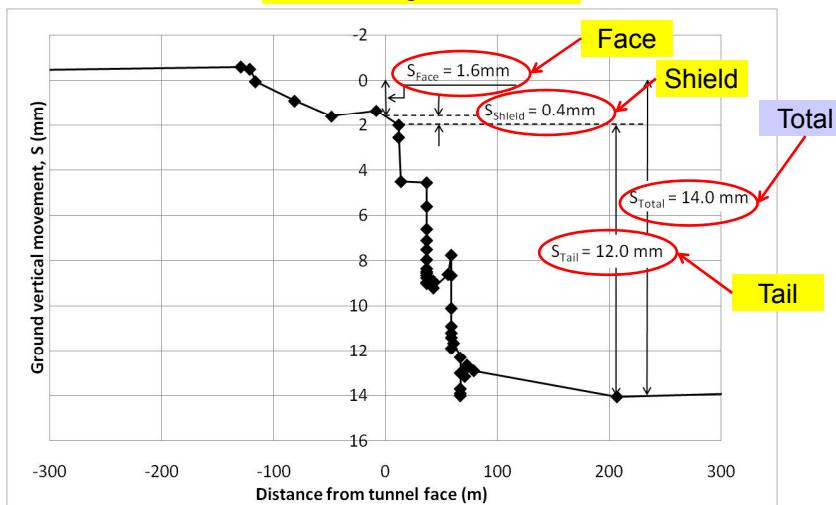
### Barcelona Metro, Line 9: ground movements

- Surface settlement trough and: volume loss

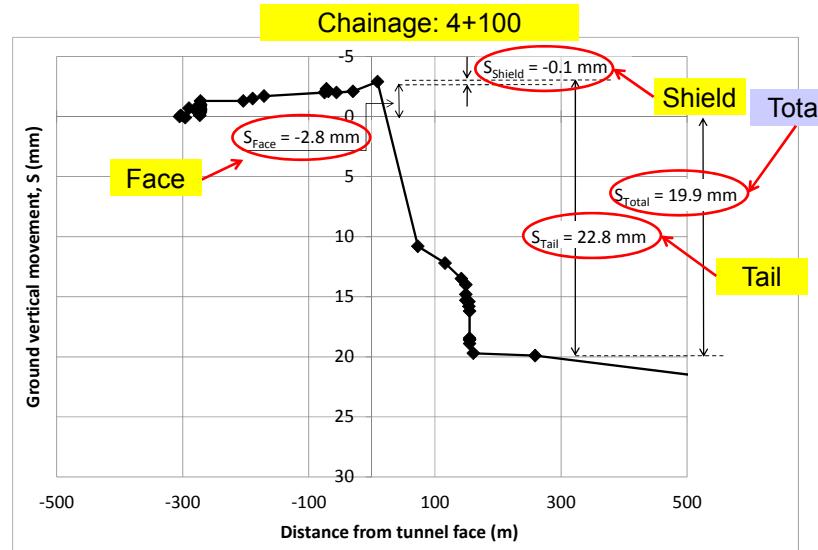


### Barcelona Metro, Line 9: ground movements

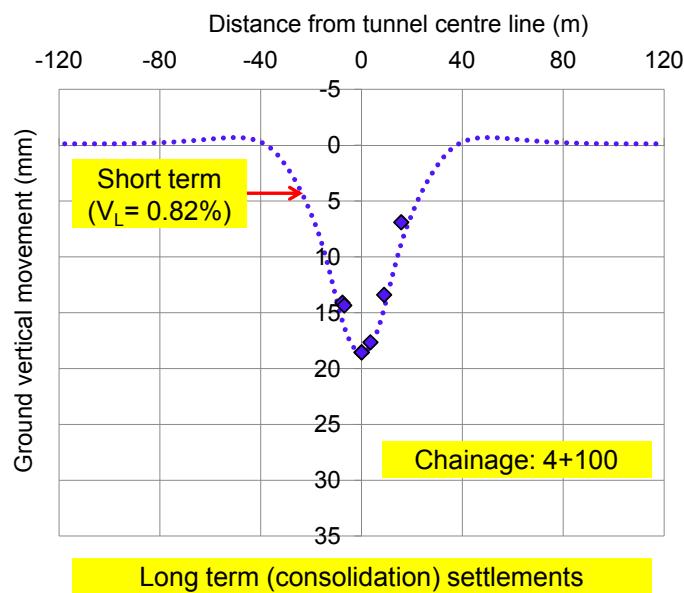
Chainage: 2+225



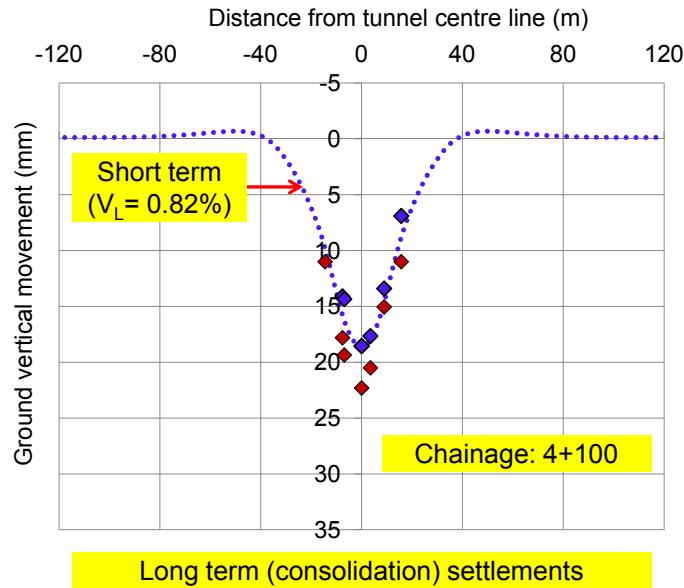
### Barcelona Metro, Line 9: ground movements



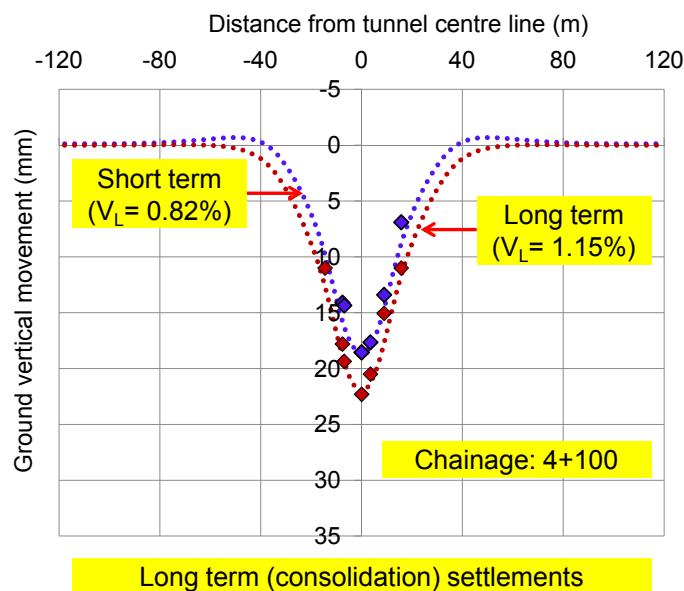
### Barcelona Metro, Line 9: ground movements

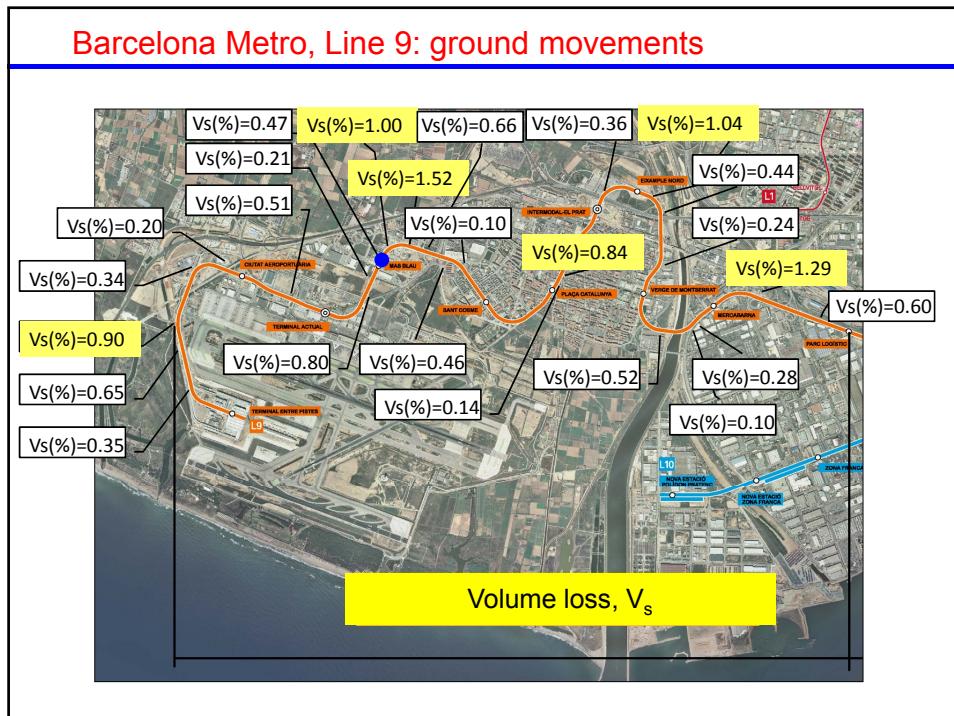
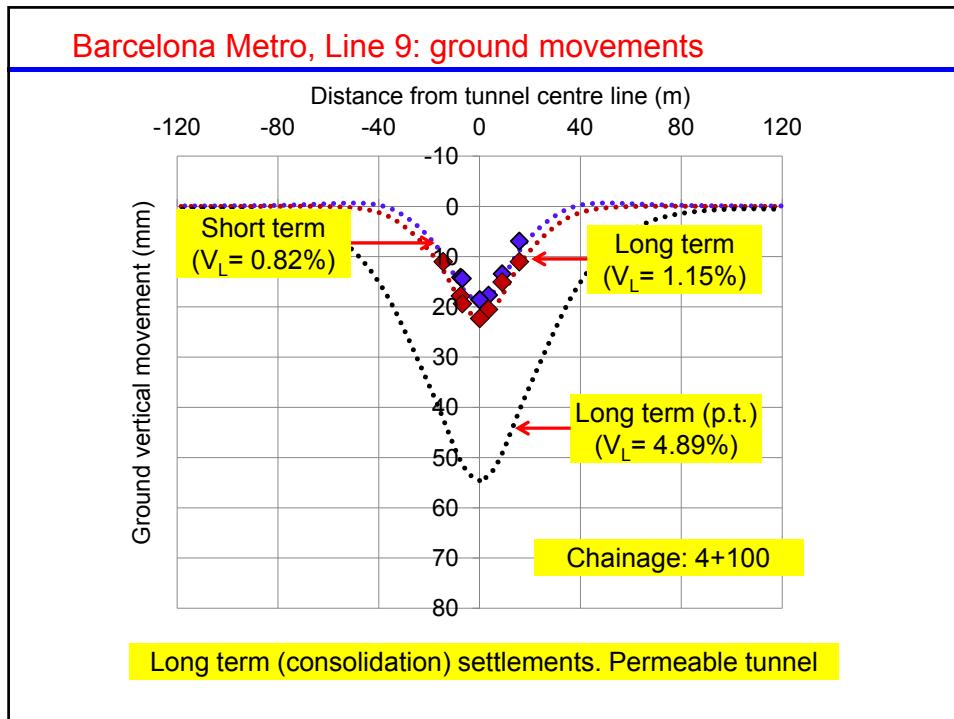


### Barcelona Metro, Line 9: ground movements

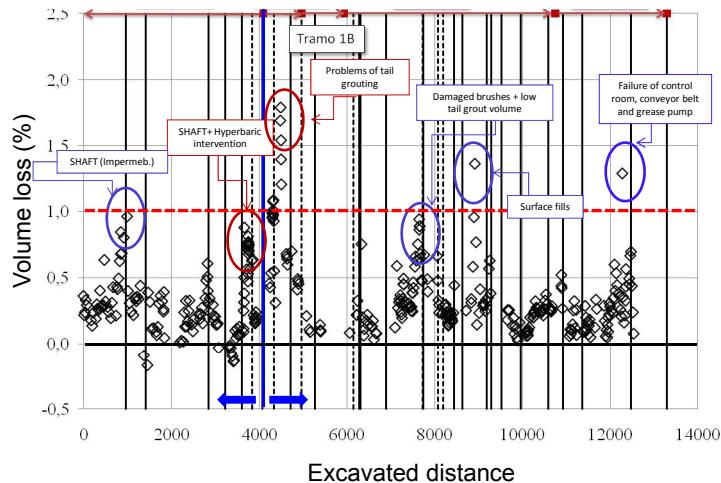


### Barcelona Metro, Line 9: ground movements



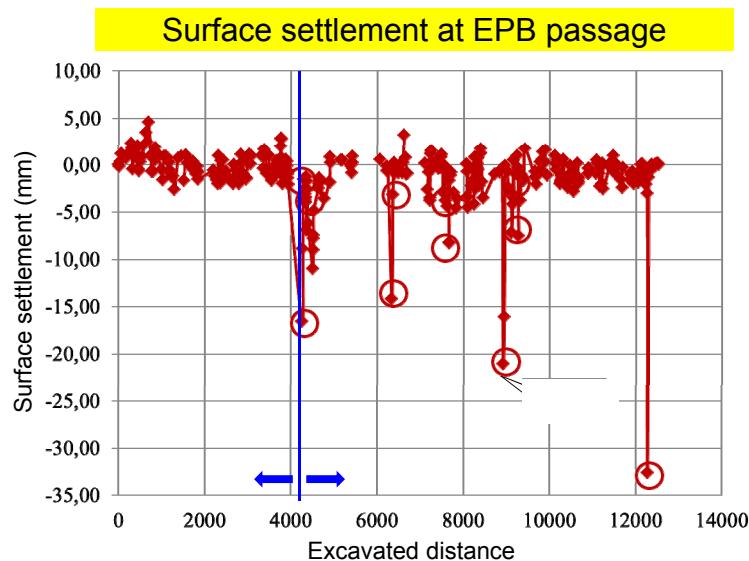


### Barcelona Metro, Line 9: ground movements

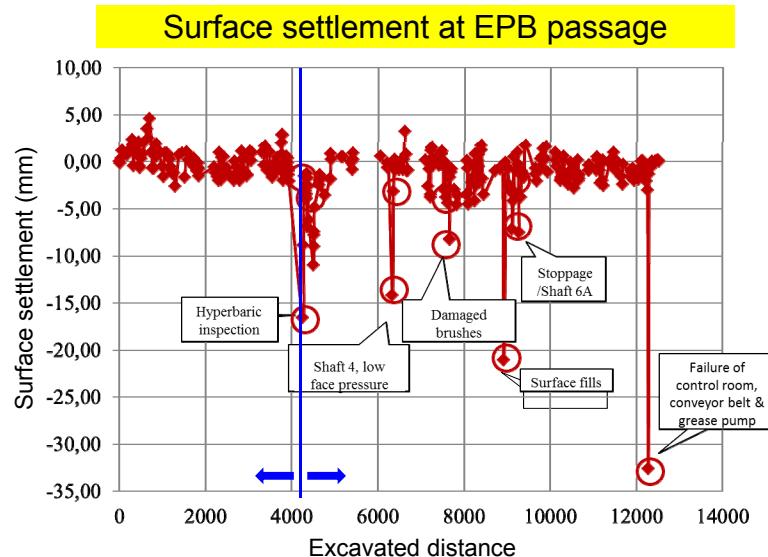


### Volume loss

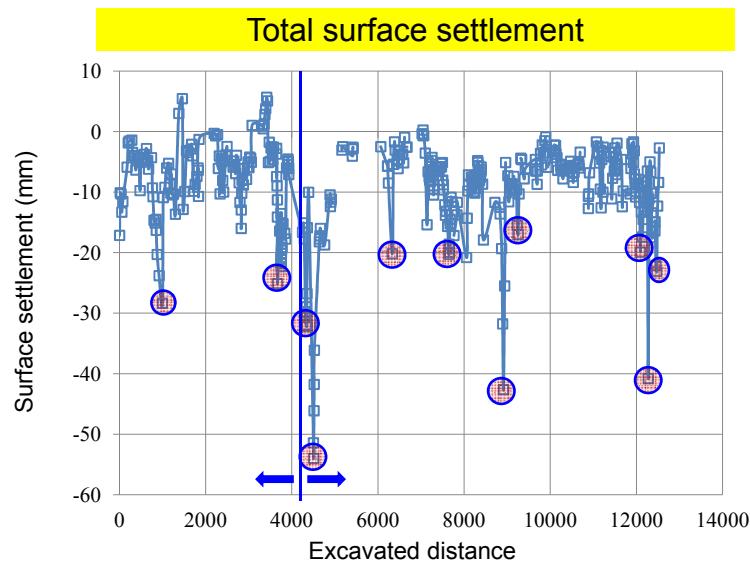
### Barcelona Metro, Line 9: ground movements



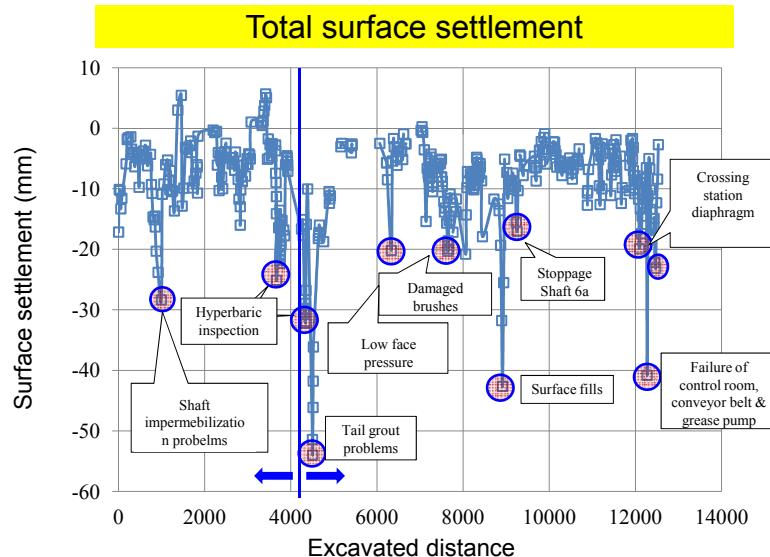
### Barcelona Metro, Line 9: ground movements



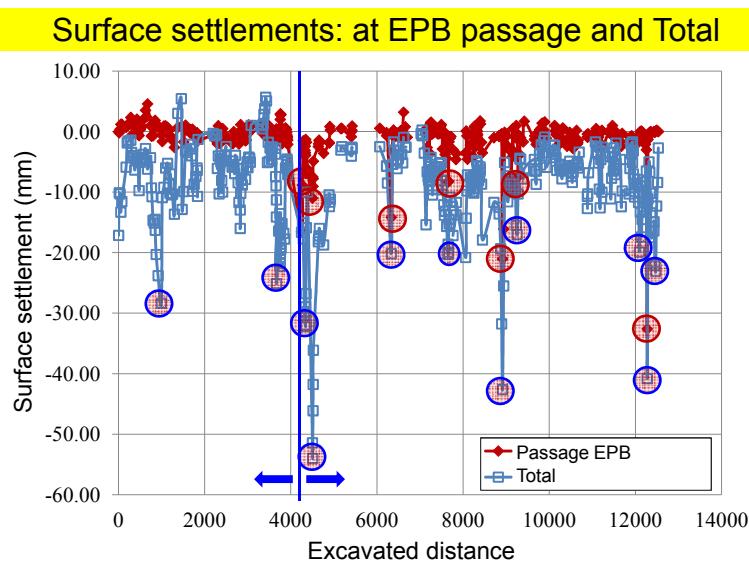
### Barcelona Metro, Line 9: ground movements



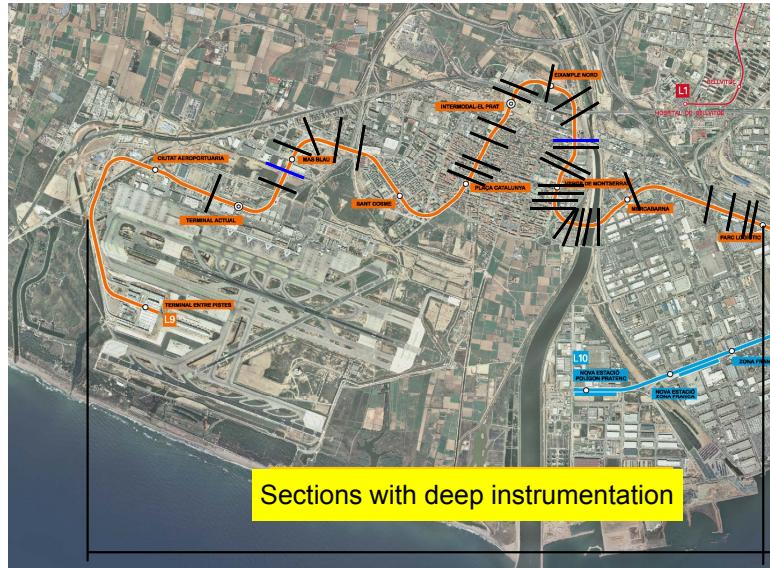
### Barcelona Metro, Line 9: ground movements



### Barcelona Metro, Line 9: ground movements

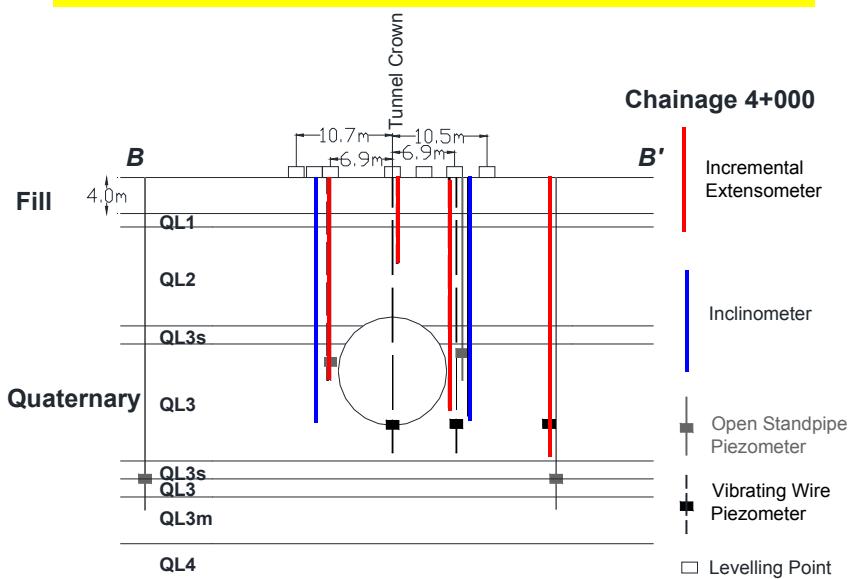


### Barcelona Metro, Line 9: ground movements at depth



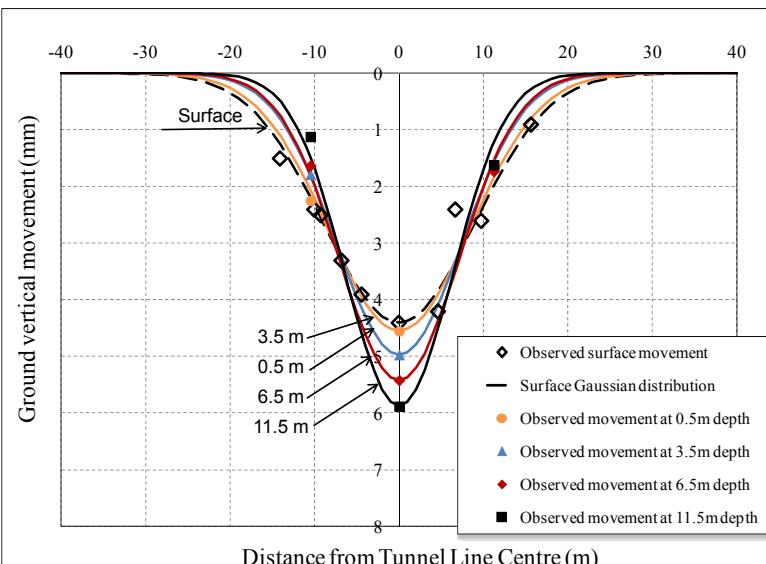
### Barcelona Metro, Line 9: ground movements at depth

Layout of section with deep instrumentation

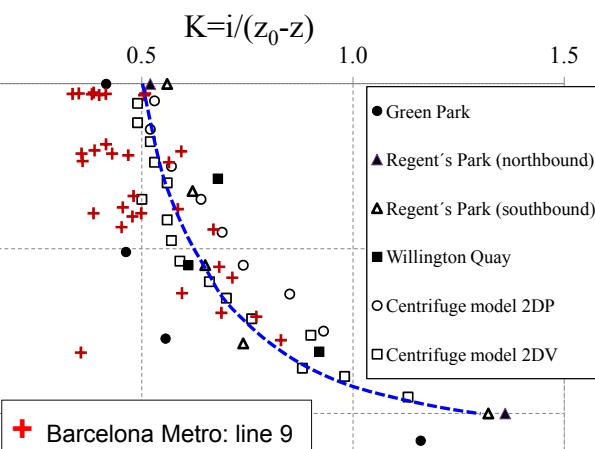


### Barcelona Metro, Line 9: ground movements at depth

Chainage 8+813



### Barcelona Metro, Line 9: ground movements at depth



Mair et al. (1993)

## Control of excavation movements: summary

- ❑ Soft low-stiffness deltaic deposits have the potential to generate undesirable movements during excavations.  
*La faible rigidité des dépôts deltaïques nous peut potentiellement être à la source de mouvements indésirables pendant la réalisation d'excavations.*
- ❑ Ground movement control in cut-and cover excavations may require especial measures. It has been found that **propping below excavation** level is an especially effective action.  
*Le contrôle des mouvements du terrain dans les tranchées couvertes peut exiger l'application de mesures spéciales. La mise en place d'étais en dessous du fond d'excavation est apparu être une mesure particulièrement efficace.*

## Control of excavation movements: summary

- ❑ EPB excavation can be a very successful tunnelling procedure in soft deltaic deposits under the water table leading to **very limited volume losses**. Occasional larger ground movements generally arise from the learning process, operational errors or crossing singular points.  
*Les méthodes qui utilisent des tunneliers à pression de terres (technologie EPB) peuvent fournir d'excellents résultats lors de creusements sous la nappe phréatique dans des dépôts mous car elles donnent lieu à de très faibles pertes de volume. Des mouvements plus importants peuvent toutefois être occasionnellement observés. Ils sont généralement le résultat du procédé d'ajustement des paramètres du tunnelier, d'erreurs opérationnelles ou du passage de points singuliers.*
- ❑ It is important to ensure a sufficient degree of tunnel impermeability to avoid **large consolidation movements**.  
*Il est important d'assurer un degré de imperméabilité suffisant dans le tunnel afin d'éviter de grands mouvements de consolidation.*

## Control of excavation movements: summary

- ❑ Although, instrumentation and well-calibrated models are a key aspect of a successful practice in this geotechnical problems, some of the sources of significant ground movement (for instance, in EPB tunnelling) may be beyond computations

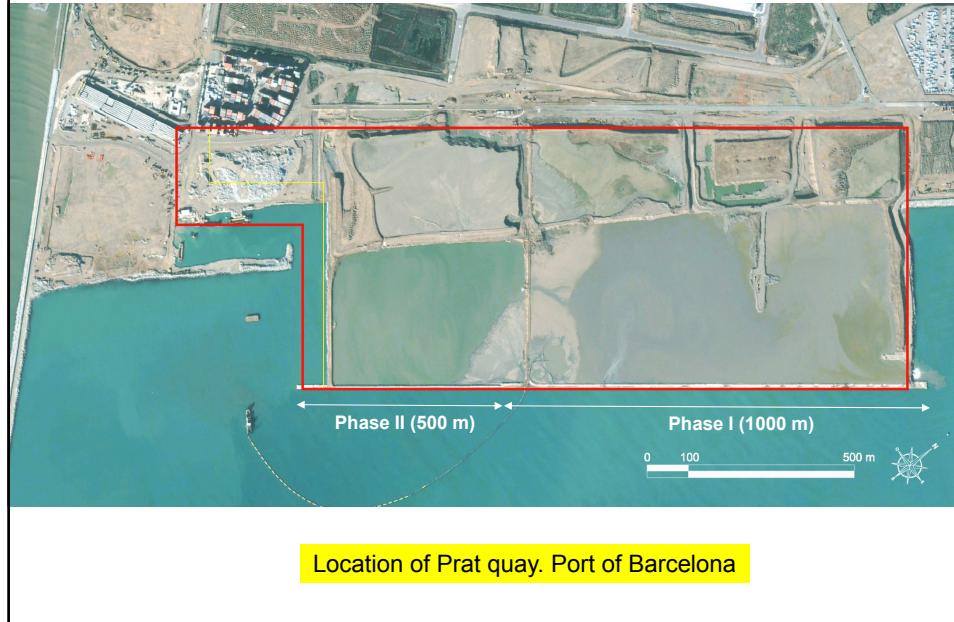
*L'utilisation d'une instrumentation de qualité en parallèle avec des modèles bien calibrés est un aspect important pour une pratique réussie dans ce type de problèmes géotechniques. Toutefois, certaines causes de grands mouvements peuvent se situer au-delà de la capacité prédictive des modèles, particulièrement dans le cas de creusement par tunneliers EPB.*

## Outline

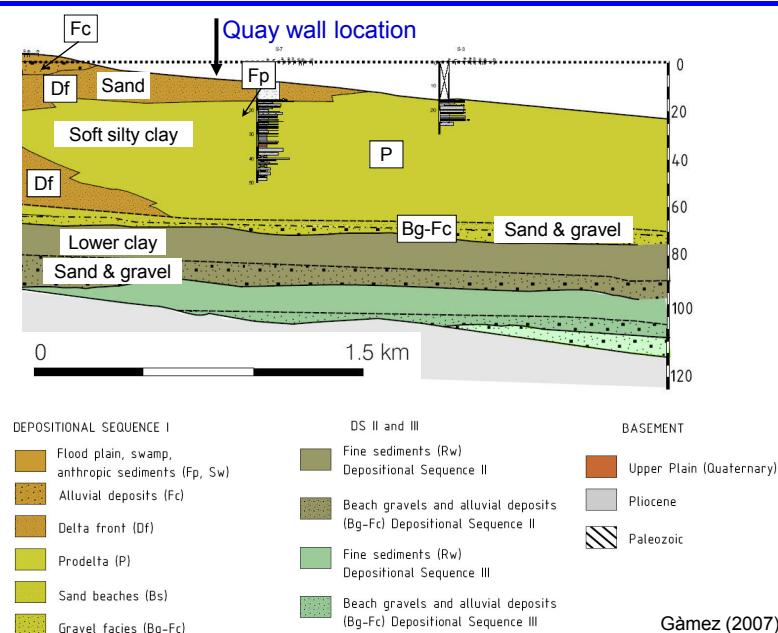
- ❑ Introduction
- ❑ The Llobregat delta
- ❑ Civil Engineering works in the Llobregat delta
  - Mitigation of long term settlements
    - Water treatment plant
    - Third runway at Barcelona airport
  - Control of excavation movements
    - High speed train Madrid-Barcelona
    - Barcelona Line 9 Metro
  - Stability on soft ground
    - New Breakwaters in Barcelona Harbour
    - New container terminal in Barcelona Harbour
- ❑ Closure



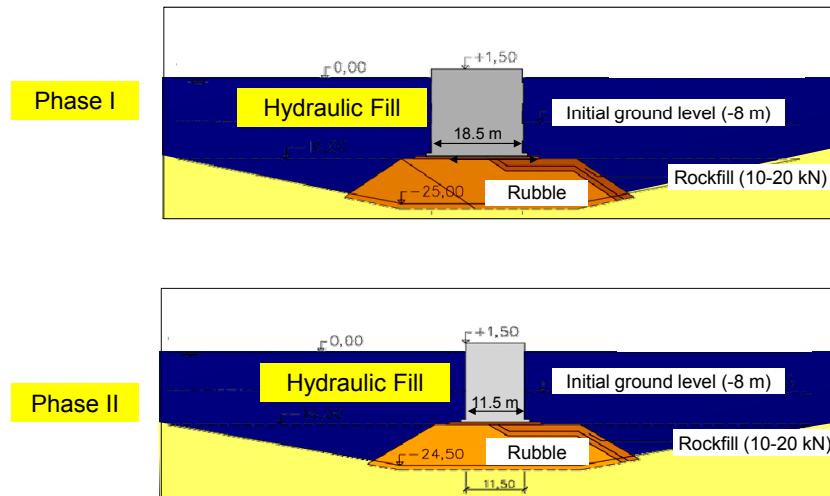
### Barcelona harbour extension: Prat quay



### Barcelona harbour extension: Prat quay



### Barcelona harbour extension: Prat quay



Prat quay section. Port of Barcelona

### Barcelona harbour extension: Prat quay



- Material dredged from the upper unit, known to contain varying amount of fines
- Hydraulic fill discharged from the caissons, it would flow long distances; some segregation unavoidable
- Rainbowing involved soil and water travelling through air, possibility of air entrapped

Hydraulic fill: rainbowing deposition

### Barcelona harbour extension: Prat quay



Failure occurred on 01-01-2007

### Barcelona harbour extension: Prat quay



Failure view

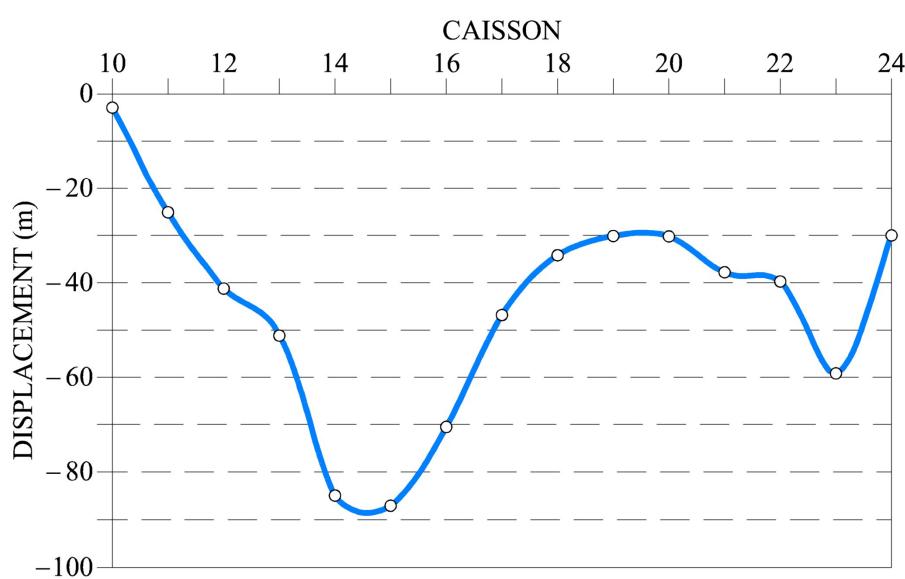
### Barcelona harbour extension: Prat quay

As a result of the failure a significant length of Mota Sur, estimated to be 60m, disappeared

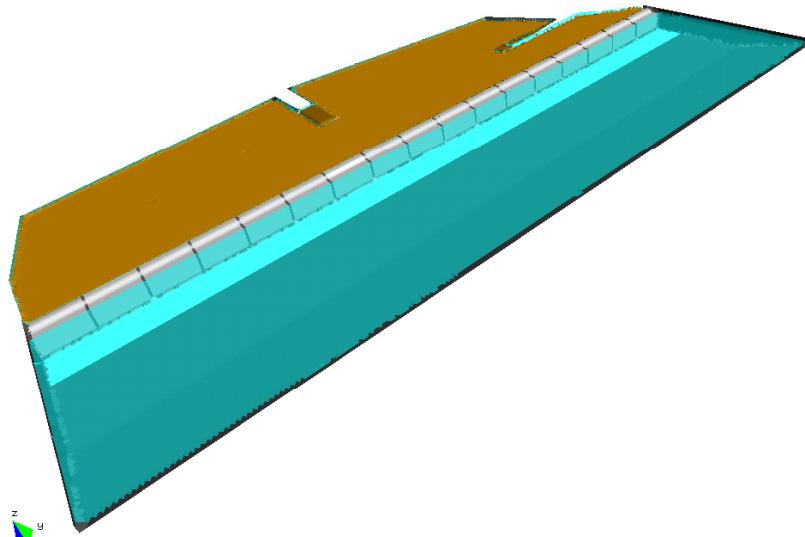


Failure viewed from the sea

### Barcelona harbour extension: Prat quay



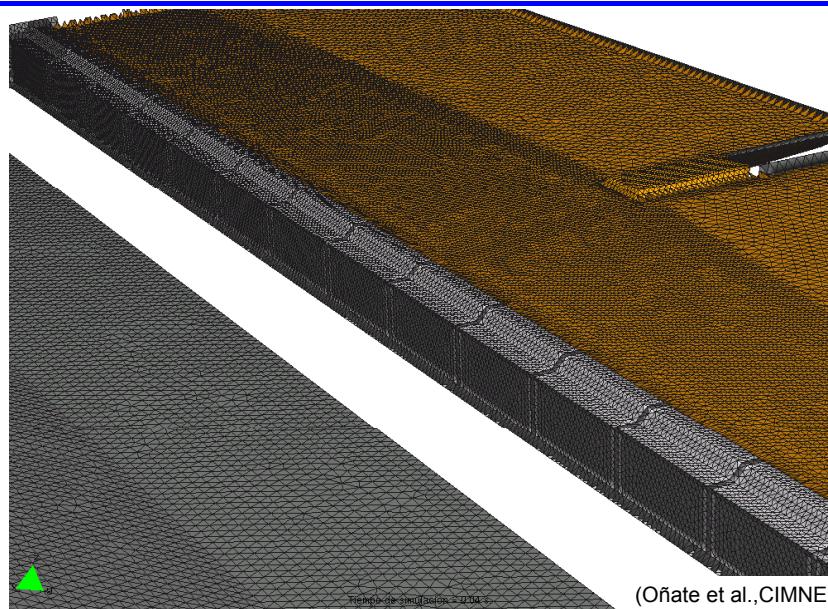
The failure of Prat quay



(Oñate et al., CIMNE 2007)

Failure modelling by Particle Finite Element Method (PFEM)

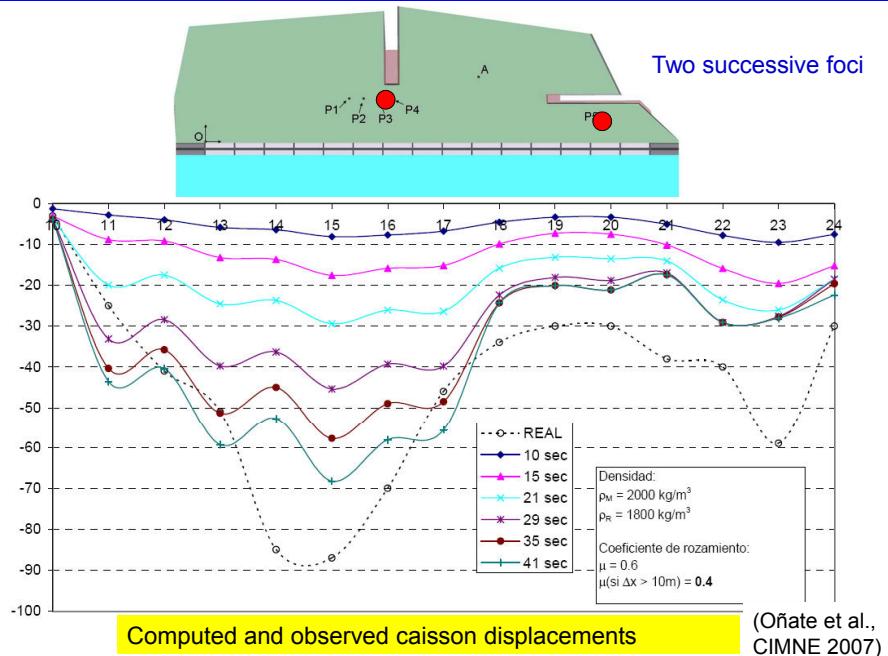
The failure of Prat quay



(Oñate et al., CIMNE 2007)

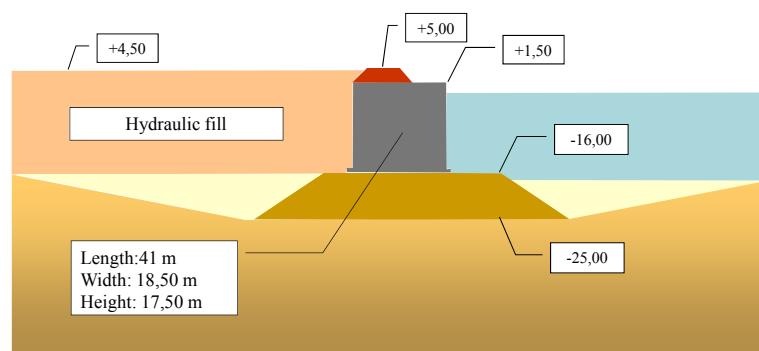
Failure modelling by Particle Finite Element Method (PFEM)

### The failure of Prat quay



### Barcelona harbour extension: Prat quay

#### Situation just before failure



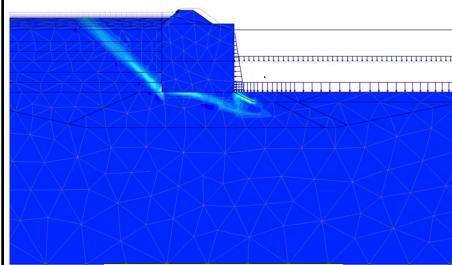
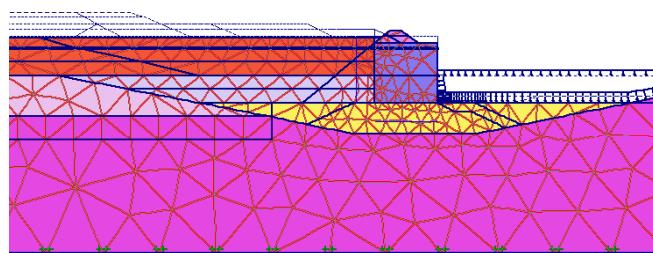
Prat quay section. Port of Barcelona

### Barcelona harbour extension: Prat quay

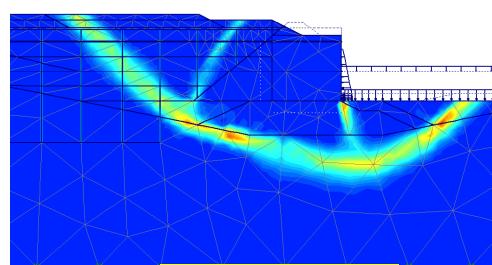


### Barcelona harbour extension: Prat quay

#### Possible failure mechanisms

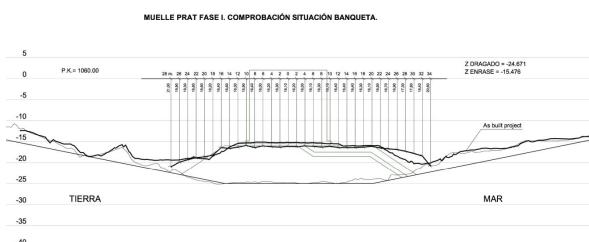
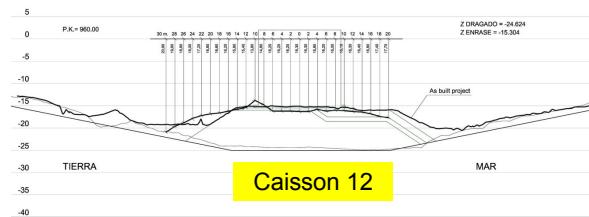


Sliding failure



Deep failure

## Barcelona harbour extension: Prat quay



Investigation of surviving rubble bench

## The failure of Prat quay

- Prat Quay (Phase I) failed by horizontal sliding due to the thrust of liquefied hydraulic fill raised to a large height
- It is likely that the method of construction of the separation embankments and the method of fill placement (rainbowing) contributed to the liquefaction of the fill
- Liquefaction provided the excess thrust required to drag the quay caissons to a considerable distance. The distribution of caisson movement is better reproduced assuming two successive liquefaction foci
- Obviously, the safety of Phase II and reconstructed Phase I had to be re-assessed!!

They were found to be precarious

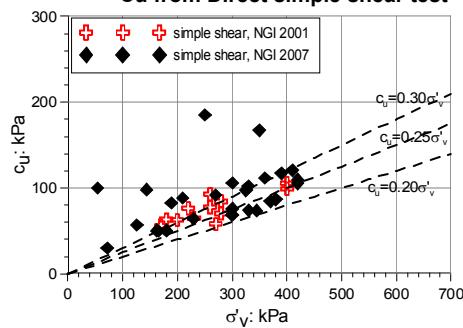
### Barcelona harbour extension: Prat quay



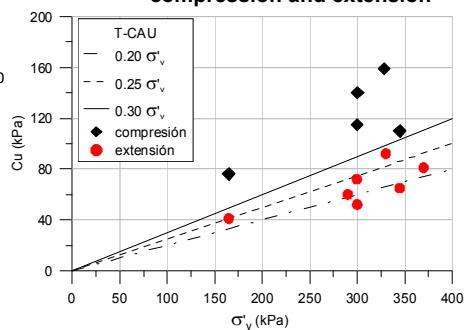
### Barcelona harbour extension: Prat quay

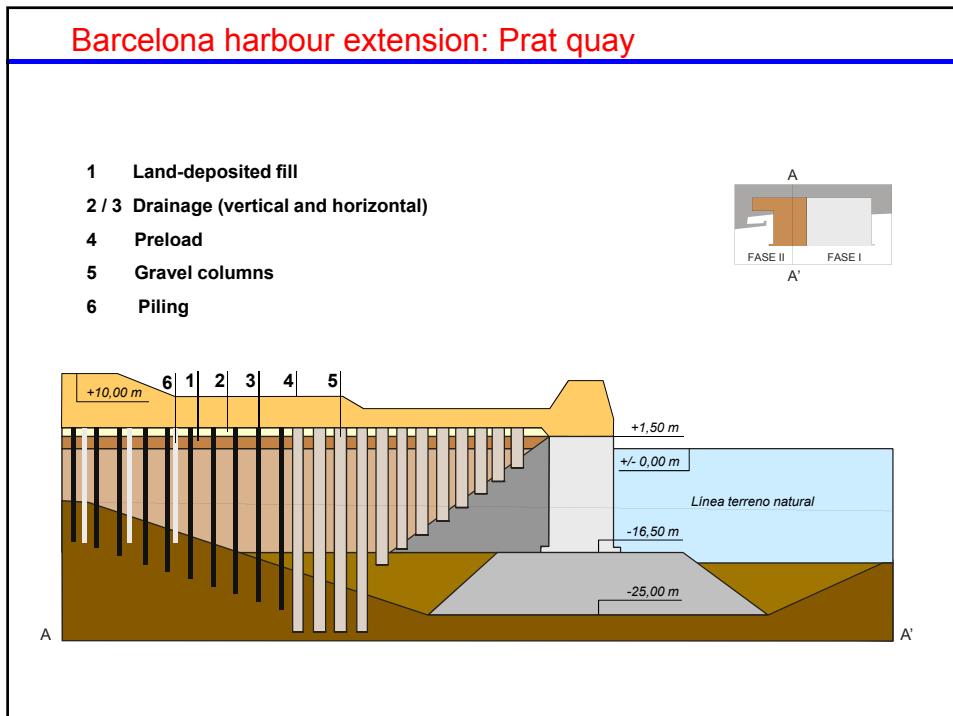
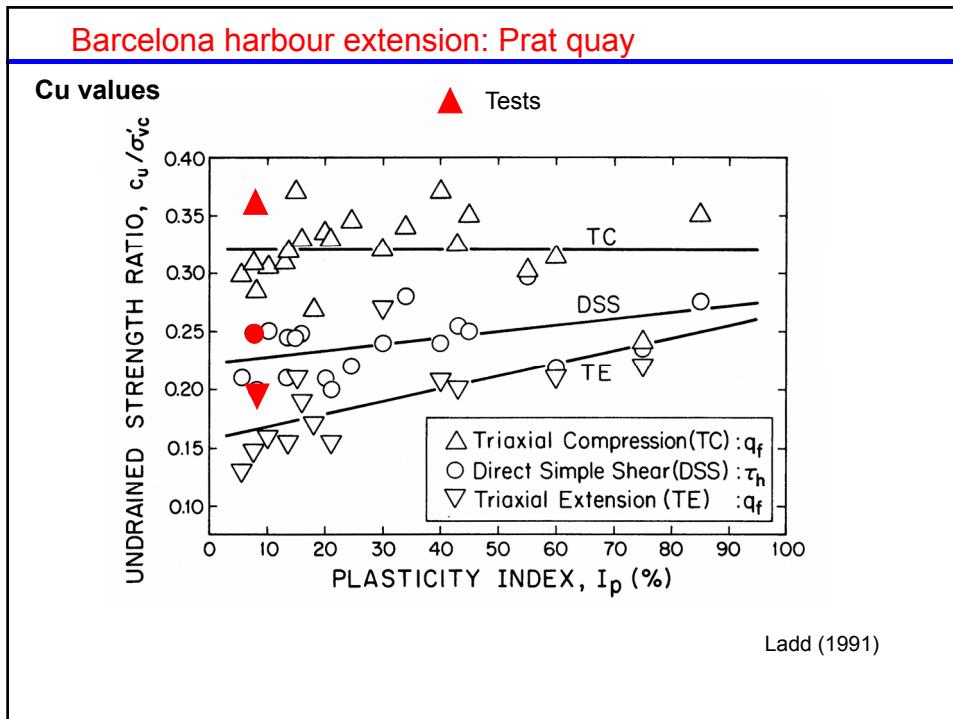
#### Pro-deltaic deposits: undrained shear strength

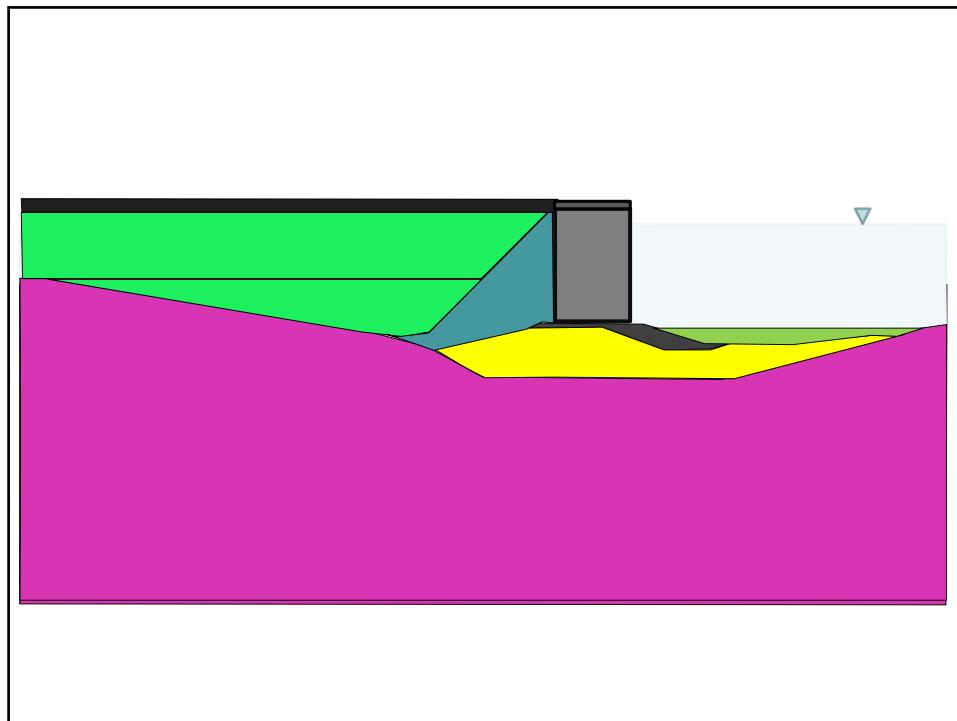
Cu from Direct simple shear test



Cu from Triaxial compression and extension



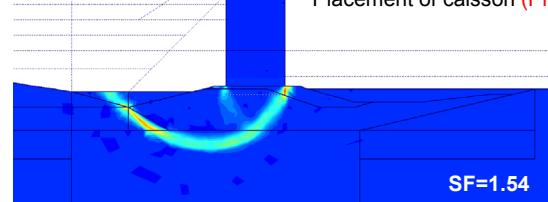




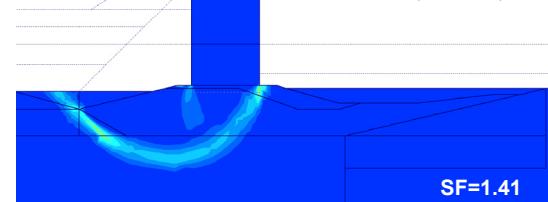
### Barcelona harbour extension: Prat quay

#### Factors of safety

Placement of caisson (Phase 3)

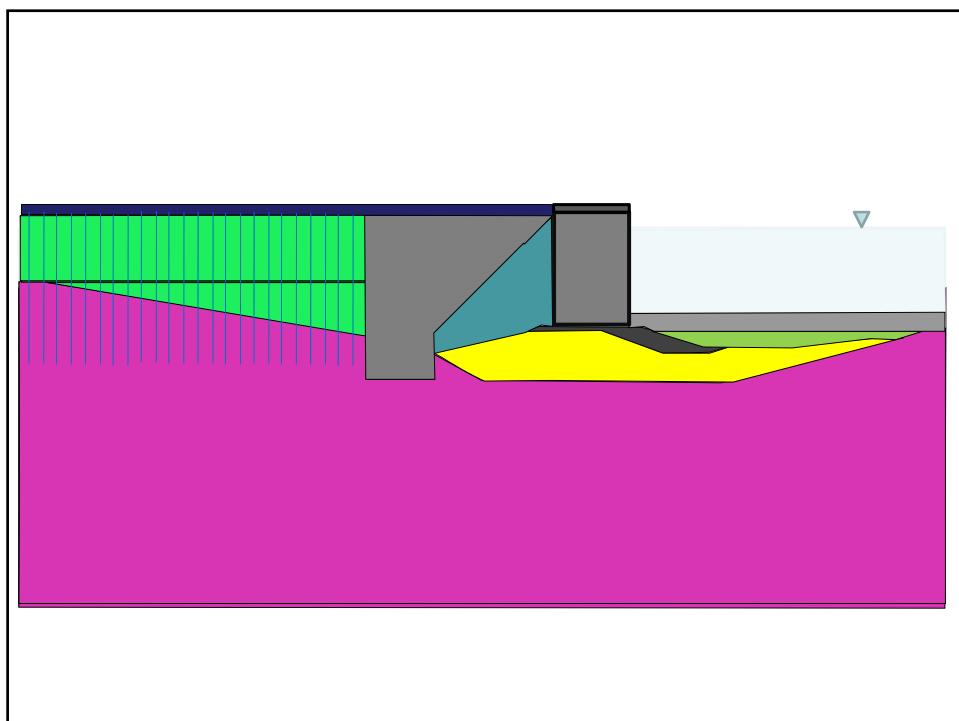
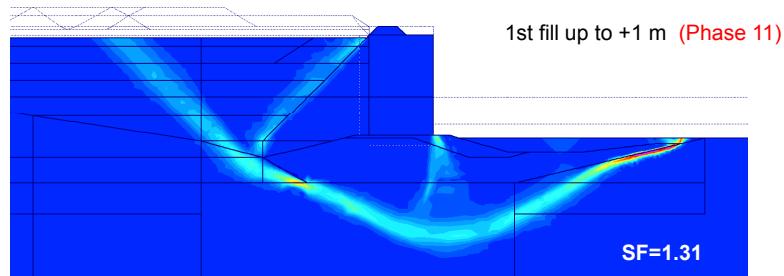


Filled caisson (Phase 4)



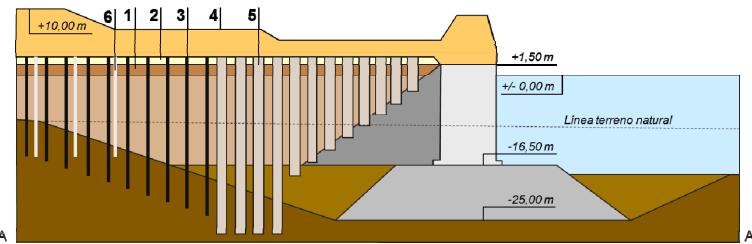
## Barcelona harbour extension: Prat quay

### Factors of safety



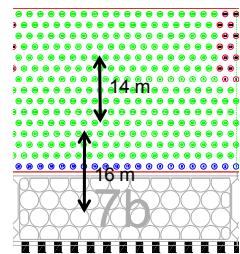
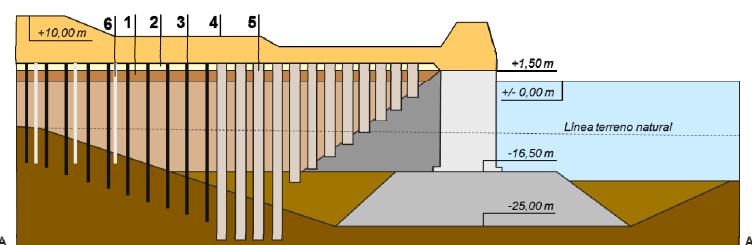
### Barcelona harbour extension: Prat quay

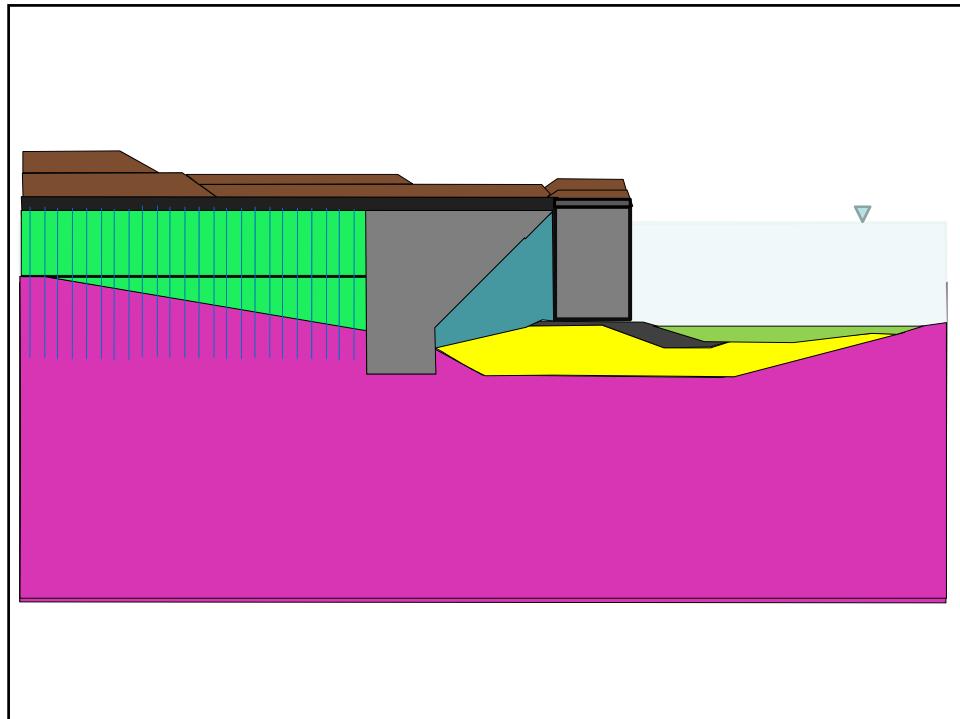
Installation of vertical drains



### Barcelona harbour extension: Prat quay

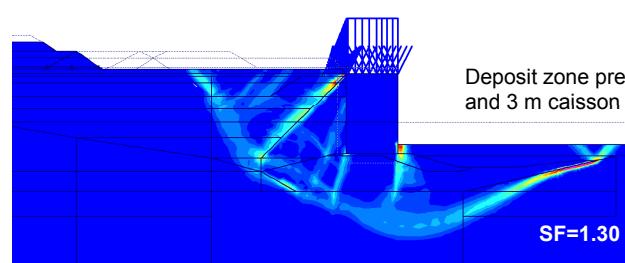
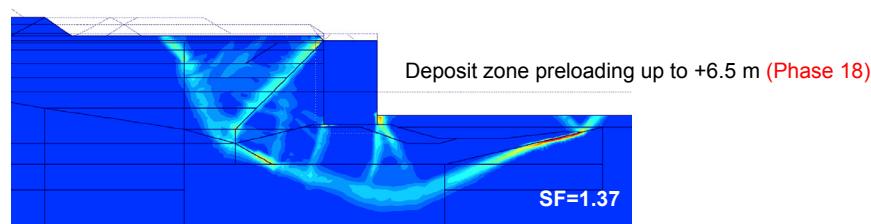
Installation of gravel columns





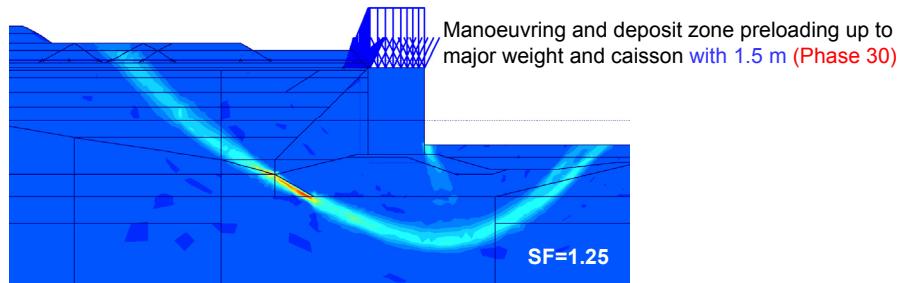
### Barcelona harbour extension: Prat quay

#### Factors of safety



## Barcelona harbour extension: Prat quay

### Factors of safety

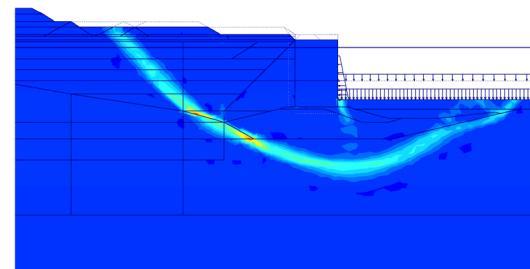


## Barcelona harbour extension: Prat quay

### Effect of gravel columns

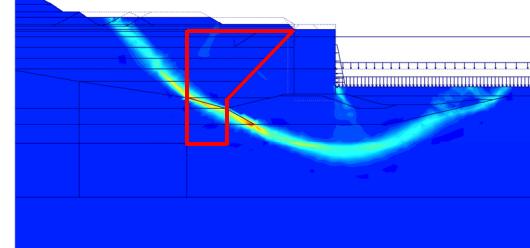
NO GRAVEL COLUMNS

FS= 1.17



WITH GRAVEL COLUMNS

FS= 1.25

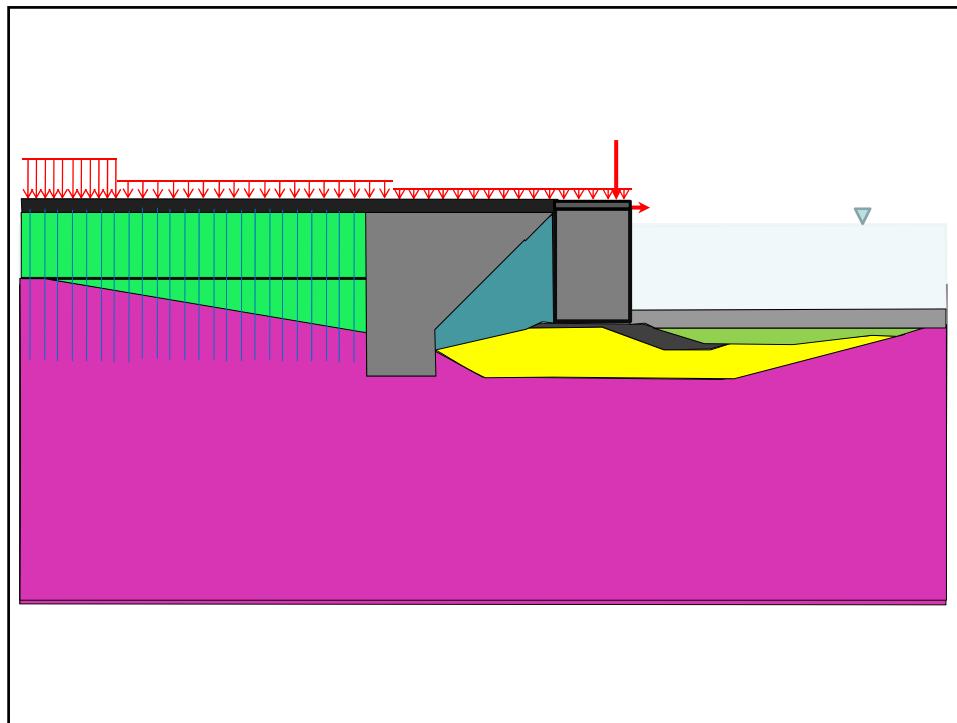


Barcelona harbour extension: Prat quay



Barcelona harbour extension: Prat quay





### Barcelona harbour extension: Prat quay

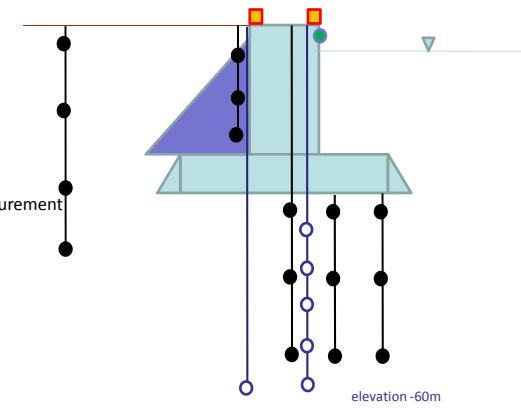
#### Field instrumentation

○ inclinometer

● piezometer

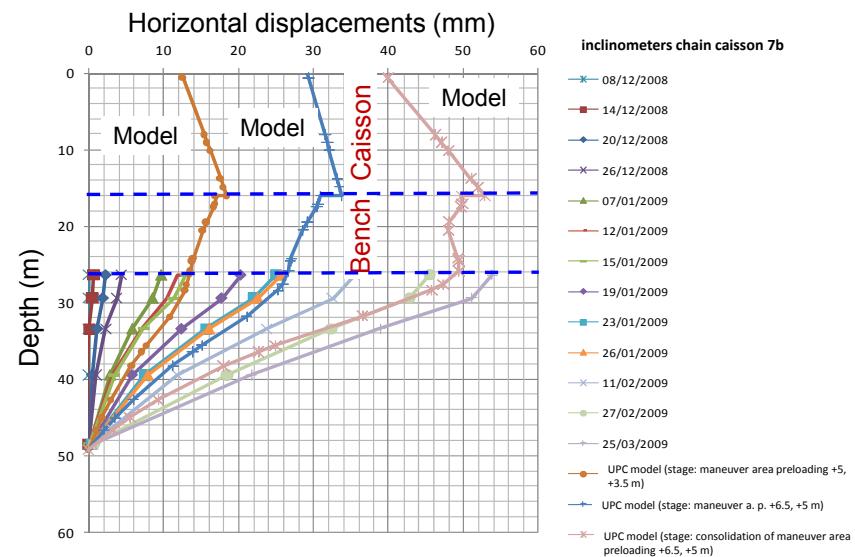
■ geodetic measurement

● clinometer



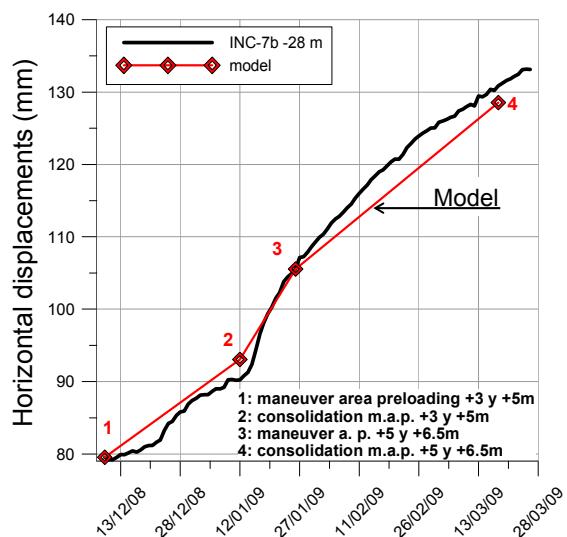
### Barcelona harbour extension: Prat quay

#### Horizontal displacements



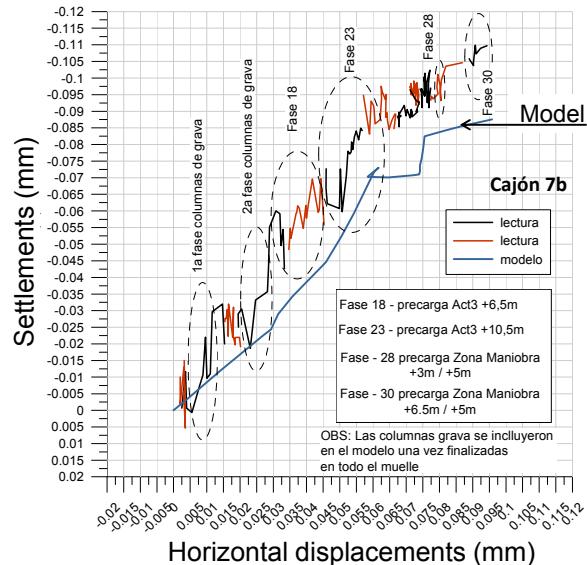
### Barcelona harbour extension: Prat quay

#### Horizontal displacements



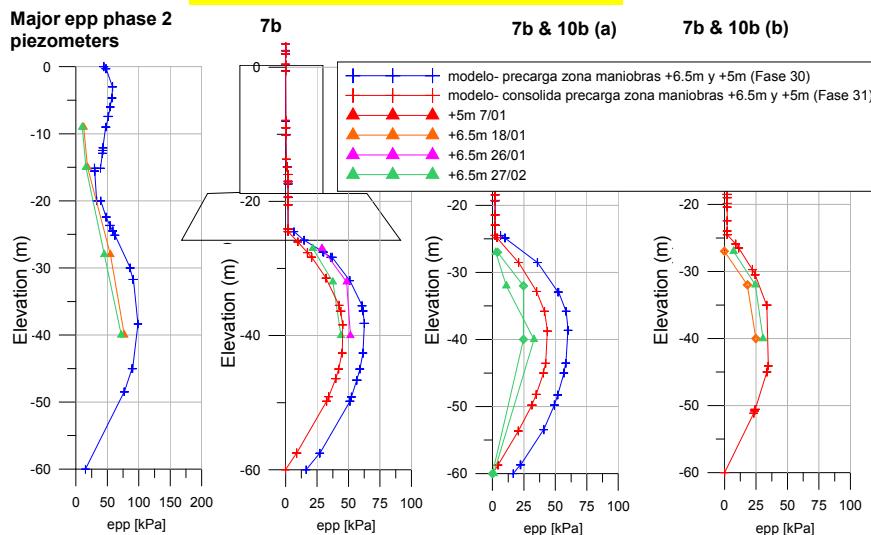
### Barcelona harbour extension: Prat quay

#### Horizontal displacements vs. settlements



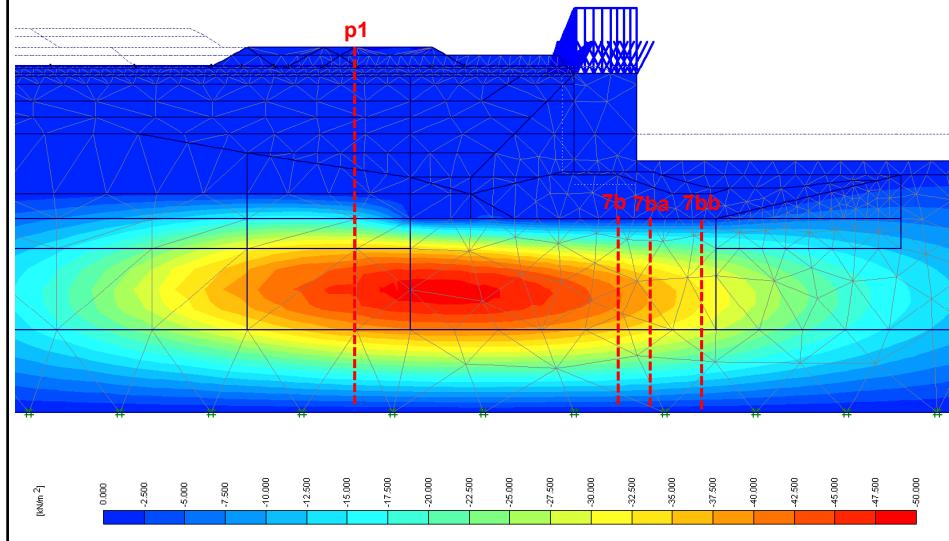
### Barcelona harbour extension: Prat quay

#### Excess pore pressures



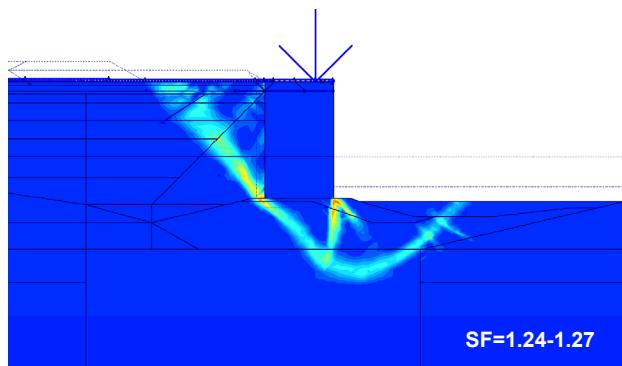
### Barcelona harbour extension: Prat quay

Excess pore pressures at the end of preloading

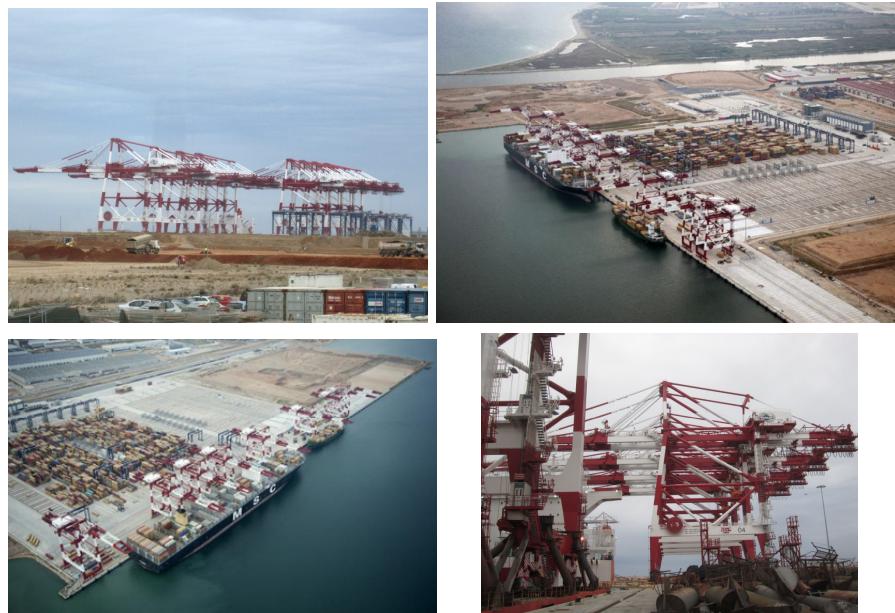


### Construction of Prat Quay (Phase II)

Factors of safety under service loads: 1.24-1.27



### Final situation



### Stability on soft ground: summary

- ❑ Heavy maritime structures may exhibit potential instability problems when founded on soft deltaic deposits. Stability is always controlled by undrained conditions.

*Les structures maritimes gravitaires peuvent potentiellement connaître des problèmes d'instabilité quand elles sont fondées sur des dépôts deltaïques mous. La stabilité est toujours contrôlée par les conditions non drainées.*

- ❑ Staged construction and/or preloading may be effective measures to ensure stability. On occasion, additional ground improvement procedures may be required

*La construction par étapes et/ou le préchargement peuvent être des mesures efficaces pour assurer la stabilité. Dans certaines occasions, elles doivent s'accompagner de procédures additionnelles d'amélioration du sol.*

## Stability on soft ground: summary

- ❑ **Instrumentation has a critical role** in this type of stability problems; in particular by monitoring the degree of pore water dissipation and by providing early warning of potential failure.

*L'instrumentation fournit des informations fondamentales pour l'analyse des conditions critiques dans ce type de problèmes de stabilité. Il est en particulier essentiel d'effectuer un suivi du degré de dissipation des pressions interstitielles et des facteurs prémonitoires d'une rupture potentielle.*

- ❑ **All construction phases** must receive the same level of attention. Often, intermediate stages are the most critical ones regarding stability.

*Toutes les étapes de construction doivent être suivies avec la même attention. Les étapes intermédiaires sont souvent celles dont la stabilité est la plus critique.*

## Concluding remarks / Closure

- ❑ A good understanding of the Llobregat delta formation and structure has provided the **necessary geological background** to undertake a variety of geotechnical engineering projects in the area

*La bonne compréhension de la formation du delta du Llobregat et de sa structure a permis de définir le cadre géologique de base nécessaire à l'entreprise de différents projets dans la zone.*

- ❑ **Intense and careful monitoring coupled to well-calibrated numerical models** have proved very effective as support of engineering decisions. Their main role, however, is **not prediction but understanding**. In addition, some important issues may be beyond computational capabilities.

*Une instrumentation intense et de qualité, couplée avec des modèles bien calibrés, montré fournir un outil efficace d'aide aux décisions d'ingénierie. Son rôle n'a pas été de prédire mais de comprendre les mécanismes en jeu. De plus, certaines questions d'importance apparaissent être au-delà des capacités actuelles de modélisation.*

- ❑ Long term settlements can be due to **secondary consolidation (creep)** phenomena. They can be successfully controlled via **soil overconsolidation by preloading**

*Les tassements à long terme peuvent être causés par des phénomènes de consolidation secondaire (fluage). Ils ont été contrôlés avec succès en augmentant la préconsolidation du sol par précharge.*

## Concluding remarks / Closure

- ❑ Deltaic deposits often have low stiffness and may cause **significant movements during excavations**. Those movements can be reduced to very small values adopting adequate displacement control measures  
*Les dépôts deltaïques sont souvent pourvus d'une faible rigidité, ce qui peut entraîner **d'importants mouvements pendant la réalisation d'excavations**. Ces mouvements peuvent être réduits à de très faibles valeurs si des mesures adéquates de contrôle des déplacements sont prises.*
- ❑ Tunnel excavation by EPB in deltaic deposits can be performed with very **small values of volume losses**. However, displacements can be large if appropriate operational procedures are not followed.  
*Il est possible d'obtenir de **très faibles pertes de volumes** lors du creusement de tunnels dans des dépôts deltaïques, si des tunneliers avec technologie EPB sont employés. La production de grands déplacements continue toutefois d'exister quand les procédures opérationnelles ne sont pas suivies.*
- ❑ The soft nature of many deltaic deposits leads to **potential stability problems** for heavy structures founded on them. They can be overcome by **staged construction/preloading** supported by adequate **instrumentation** systems  
*En raison du caractère **mou** des dépôts deltaïques, les structures gravitaires fondées dans ces matériaux sont **susceptibles de connaître des problèmes de stabilité**. Ces problèmes peuvent être surmontés par une **construction en étapes**, précédée ou non par un **préchargement** et accompagnée par des systèmes **d'instrumentation**.*

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# Géotechnique dans un environnement deltaïque

## Geotechnics in a deltaic environment

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