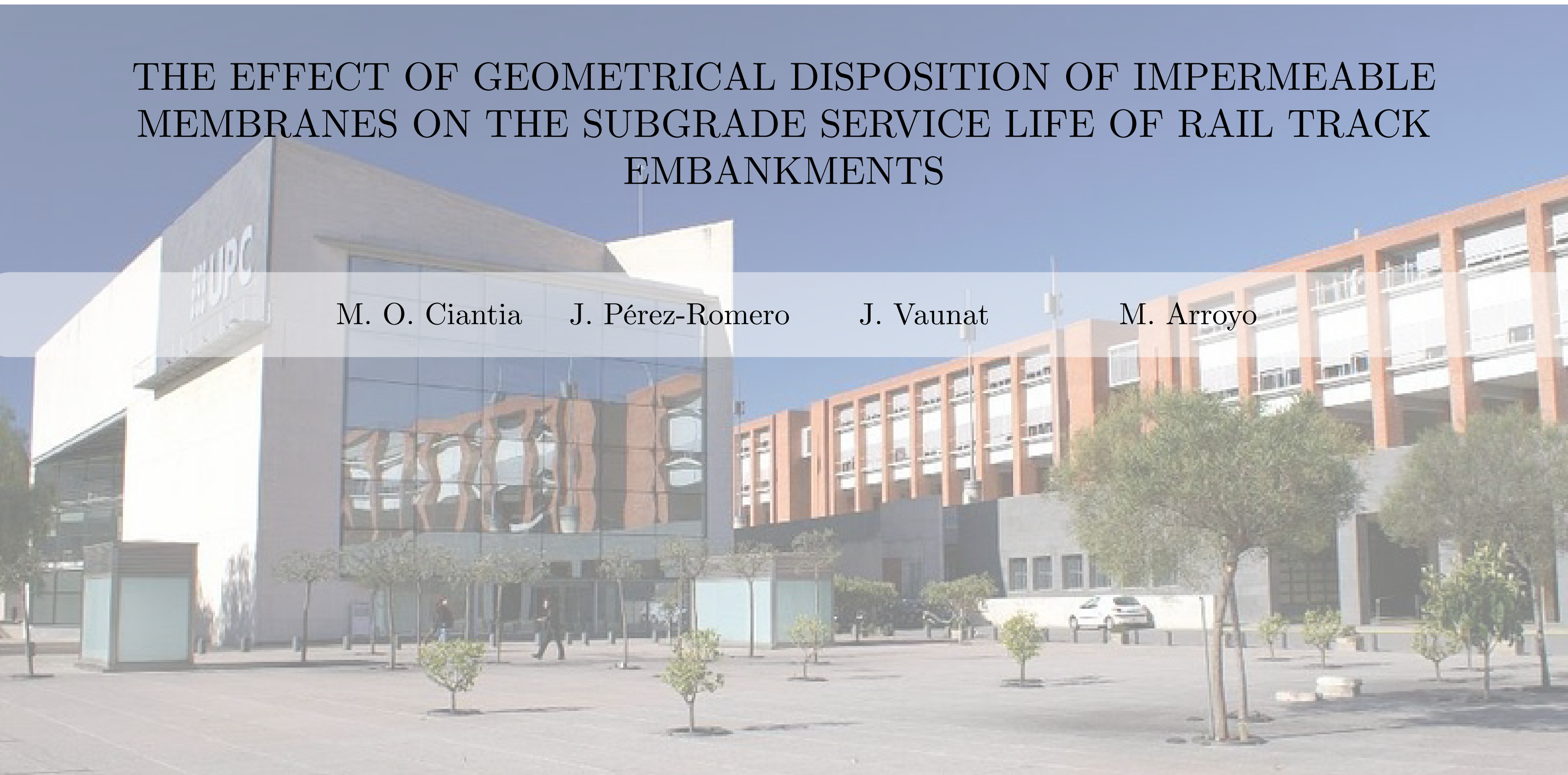
Universitat Politècnica de Catalunya · BarcelonaTech

Department of Geotechnical Engineering and Geosciences
(ETCG)

THE EFFECT OF GEOMETRICAL DISPOSITION OF IMPERMEABLE MEMBRANES ON THE SUBGRADE SERVICE LIFE OF RAIL TRACK EMBANKMENTS

M. O. Ciantia   J. Pérez-Romero   J. Vaunat   M. Arroyo



FASTRACK

eco-Friendly And Sustainable slab TRACK for high-speed lines

GOBIERNO DE ESPANA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD

CDTI

Unión Europea
Fondo Europeo de Desarrollo Regional

OUTLINE

INTRODUCTION

*Overview of the problem and objectives

AASHTO INDICATIONS

American Association of State Highway and Transportation Officials

* Long term, environmental induced traffic irreversible deformations

2D HYDRO-THERMAL ANALYSES

*Geometrical positioning of impermeable membranes

*Embankment dimensions

*Water table depth

*Climate

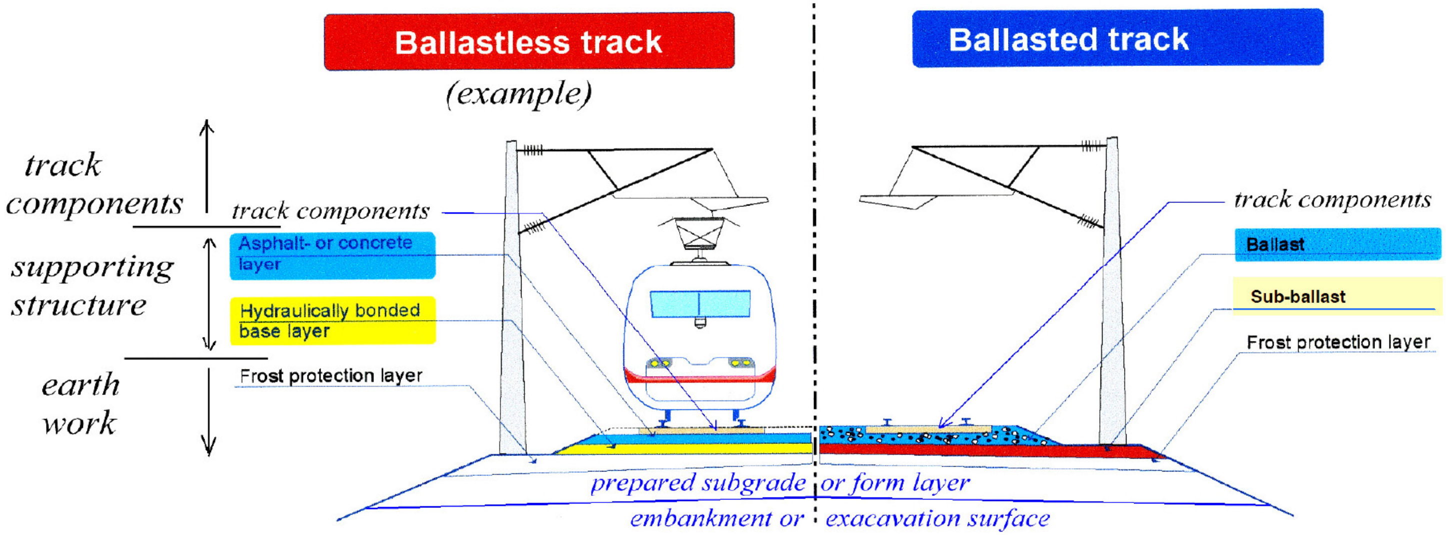
LONG TERM EMBANKMENT DEFORMATION

Fatigue based environmental induced irreversible deformations

CONCLUSIONS

High speed train tracks

Ballastless vs Ballasted track



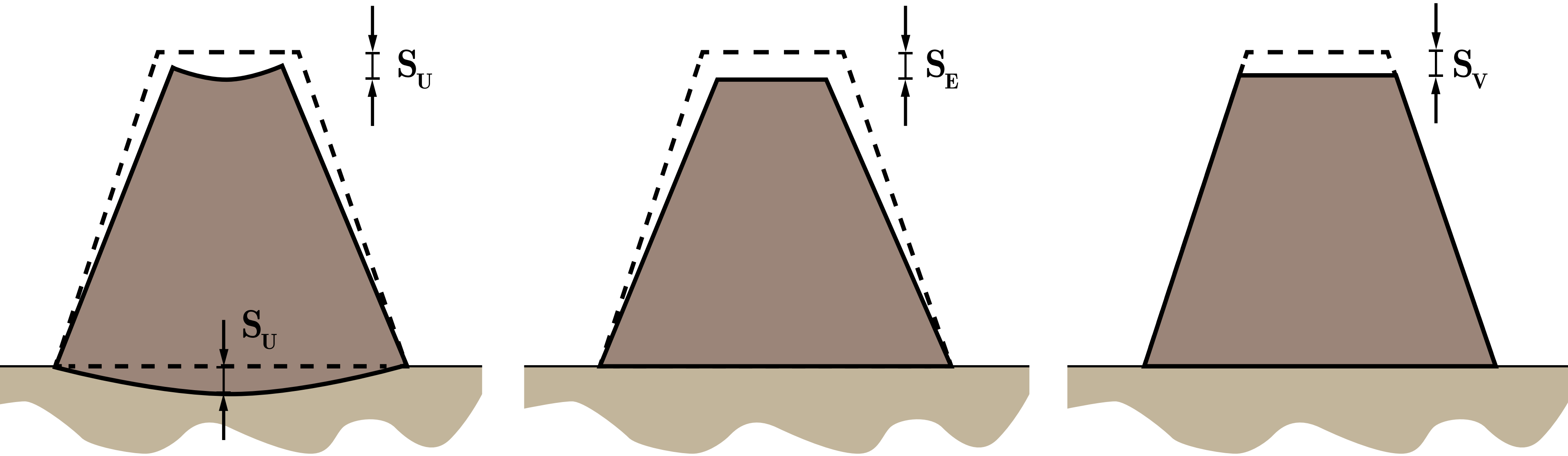
- continuous slab of concrete (like a highway structure) with the rails supported directly on its upper surface (using a resilient pad)

Advantages of Ballastless tracks (Michas, 2012):
- Less maintenance and longer life time
- High stability and efficient load redistribution
- Higher precision during construction
- Good design for high speed trains > 300 km/h
- Reduction of vegetation maintenance costs

Embankment deformation

UIC (2008). Earthworks and Track bed for railway lines. UIC 719R. Febrero 2008.

Lifetime embankment deformation



S_U =Bed settlement

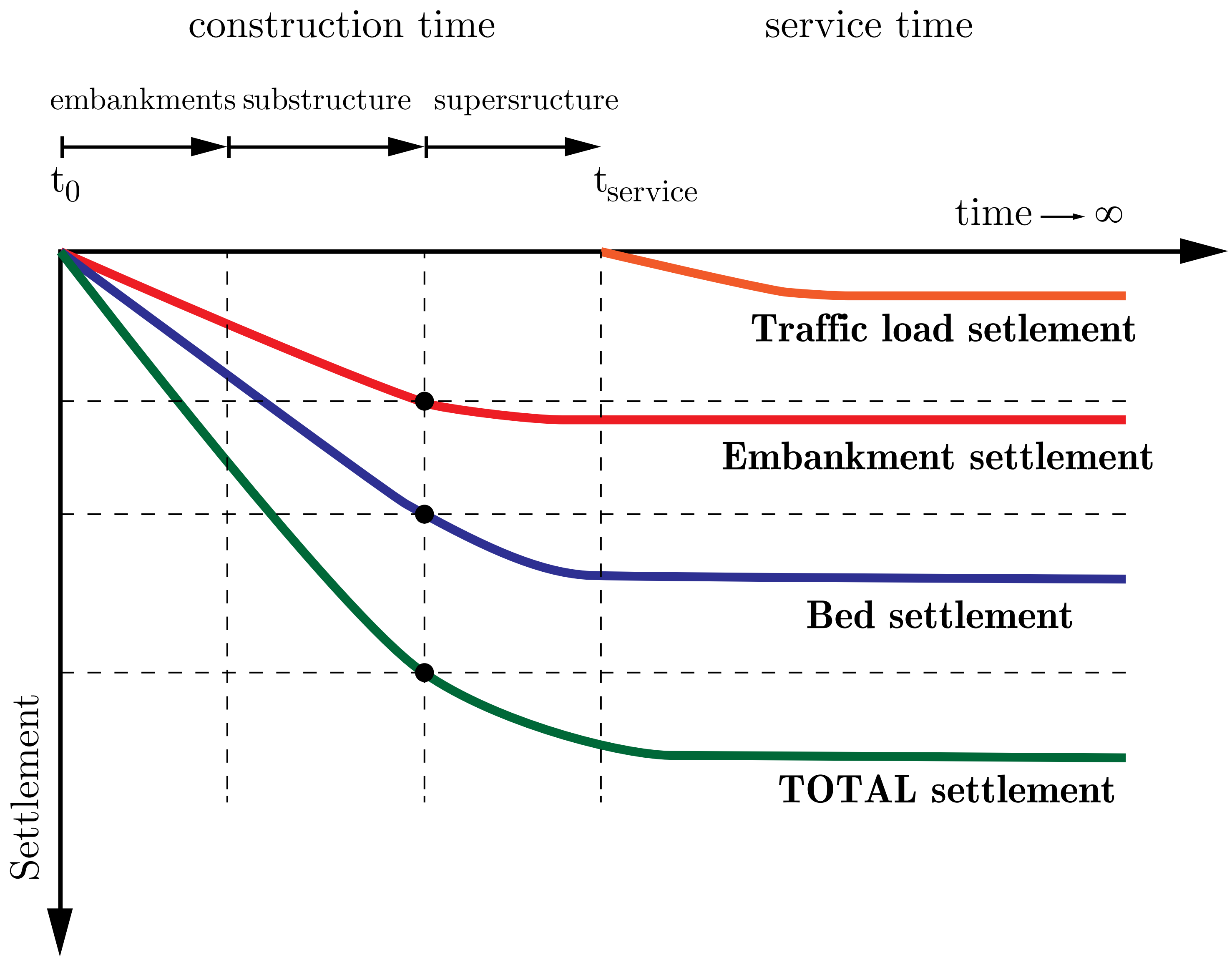
S_E =Embankment settlement

S_V =Traffic load setlement

TOTAL settlement $= S_U + S_E + S_V$

Embankment deformation

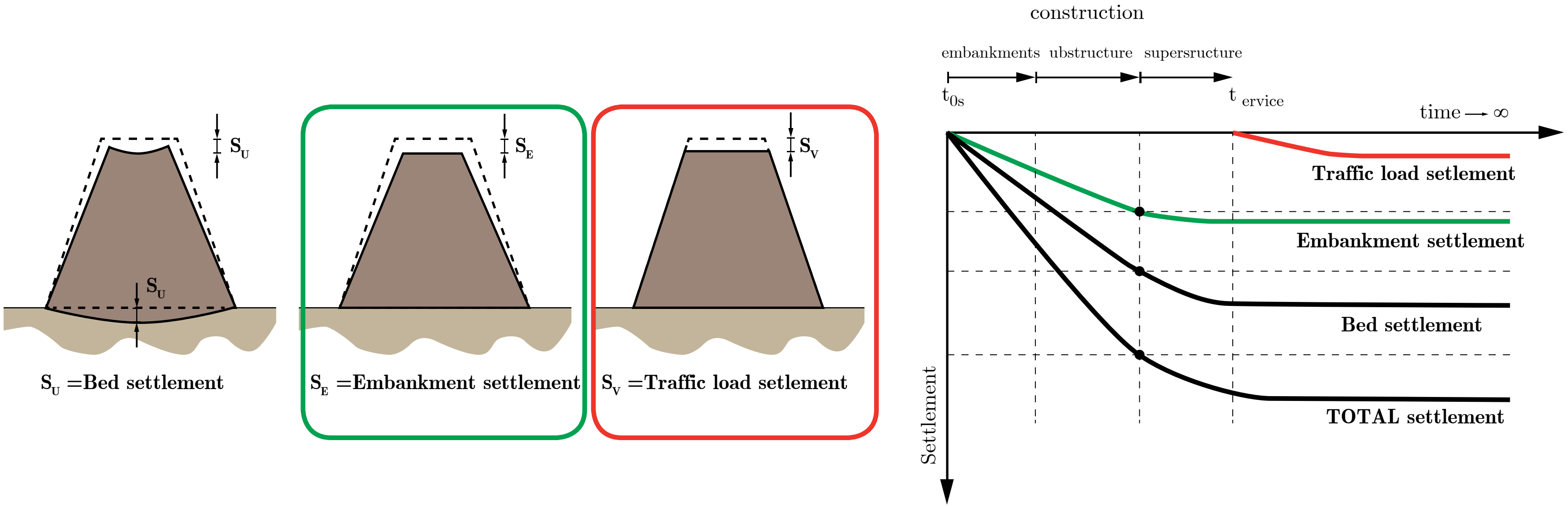
UIC (2008). Earthworks and Track bed for railway lines. UIC 719R. Febrero 2008.



OBJECTIVE:
LONG TERM EMBANKMENT SETTLEMET

1. Embankment settlement due to self weight + environmental loads

2. Embankment settlement due to traffic loads + environmental loads



HOW??
Uncoupled TH - M analyses based on the AASHTO indications

AASHTO: Fatigue based calculation -1

traffic repetitions · vertical deformation · fatigue coefficients · calibration factor

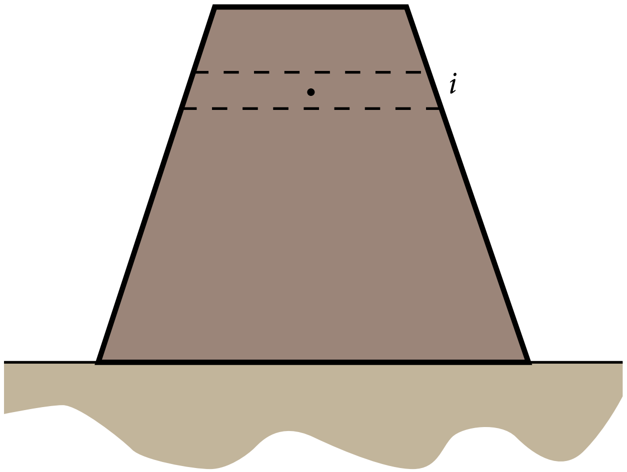
- $$\varepsilon_v(N) = \varepsilon_v^0 \left[\beta_1 \left(\frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$

water content

- $$\log \beta = -0.61119 - 0.017638 W_c$$

- $$\log\left(\frac{\varepsilon_0}{\varepsilon_r}\right) = 0.5\left[e^{(\rho)^{\beta}} a_1 + e^{\left(\rho/10^9\right)^{\beta}} a_9 \right]$$

$$\rho = 10^9 \left(\frac{C_0}{\left(1-\left(10^9\right)^{\beta}\right)} \right)^{\frac{1}{\beta}} \qquad C_0 = \ln\left(\frac{a_1}{a_9}\right)$$



AASHTO: Fatigue based calculation -2

- $$\varepsilon_v(N) = \varepsilon_v^0 \left[\beta_1 \left(\frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$
- $$\log \beta = -0.61119 - 0.017638 W_c$$
- $$\log\left(\frac{\varepsilon_0}{\varepsilon_r} \right) = 0.5 \left[e^{(\rho)^{\beta}} a_1 + e^{\left(\rho/10^9\right)^{\beta}} a_9 \right]$$

$$\rho = 10^9 \left(\frac{C_0}{\left(1-\left(10^9\right)^{\beta}\right)} \right)^{\frac{1}{\beta}} \qquad C_0 = \ln\left(\frac{a_1}{a_9} \right)$$

SEPARATE MECHANICAL ANALYSIS

EMPIRICAL

$$W_c = 51.712 \left[\left(\frac{E_r}{2555} \right)^{\frac{1}{0.64}} \right]^{-0.3586 * GWT^{0.1192}}$$

$$log \frac{M_R}{M_{Ropt}} = a + \frac{b-a}{1 + EXP\left(ln \frac{-b}{a} + k_m \cdot \left(S - S_{opt}\right) \right)}$$

NUMERICAL

HYDRO-THERMAL
NUMERICAL ANALYSES
CODE_BRIGHT
environmental boundary conditions

AASHTO: Fatigue based calculation -3

- $$\varepsilon_v(N) = \varepsilon_v^0 \left[\beta_1 \left(\frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$
- $$\log \beta = -0.61119 - 0.017638 W_c$$
- $$\log\left(\frac{\varepsilon_0}{\varepsilon_r}\right) = 0.5\left[e^{(\rho)^{\beta}} a_1 + e^{\left(\rho/10^9\right)^{\beta}} a_9 \right]$$

$$\rho = 10^9 \left(\frac{C_0}{\left(1-\left(10^9\right)^{\beta}\right)} \right)^{\frac{1}{\beta}} \qquad C_0 = \ln\left(\frac{a_1}{a_9}\right)$$

SEPARATE MECHANICAL ANALYSIS

EMPIRICAL

$$W_c = 51.712 \left[\left(\frac{E_r}{2555} \right)^{\frac{1}{0.64}} \right]^{-0.3586*GWT^{0.1192}}$$

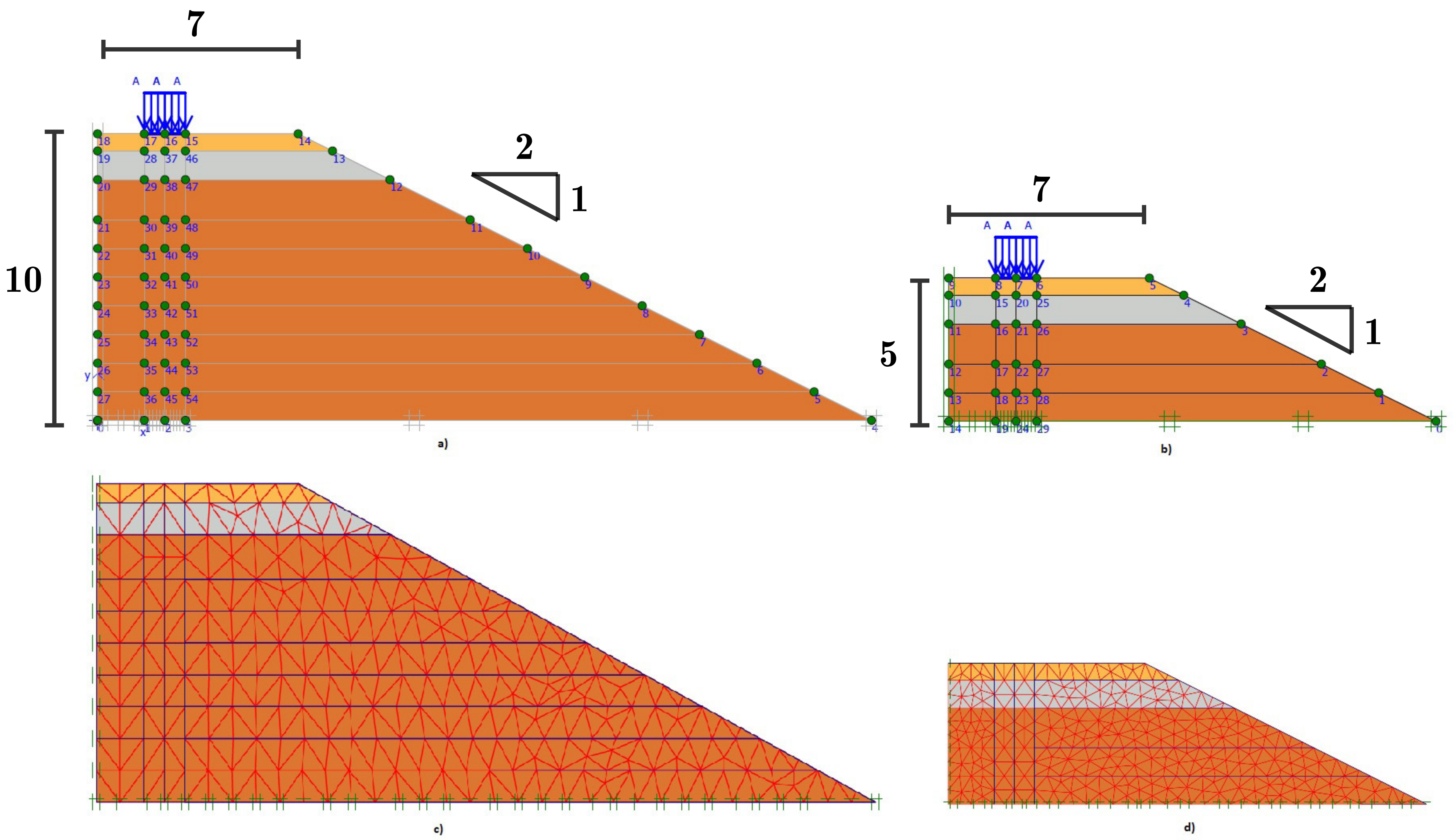
$$log \frac{M_R}{M_{Ropt}} = a + \frac{b-a}{1+EXP\left(ln\frac{-b}{a} + k \cdot \left(S - S_{opt}\right)\right)}$$

Moço FerreiraT. & Fonseca Teixeira (2012)

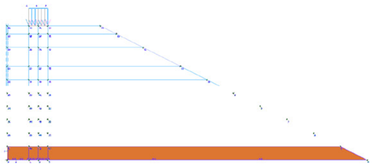
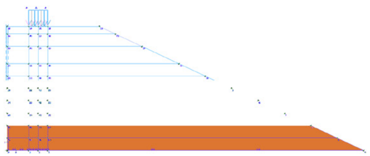
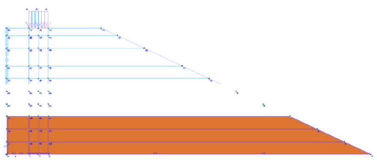
NUMERICAL

HYDRO-THERMAL NUMERICAL ANALYSES
CODE_BRIGHT
environmental boundary conditions

T-H MODEL: Geometrical specifications



M MODEL: Calcultaing ε_v

Numero fase	Visualización
1	
2	
3	
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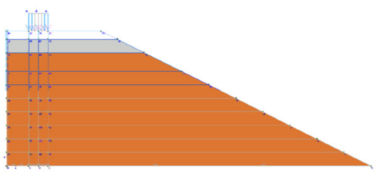
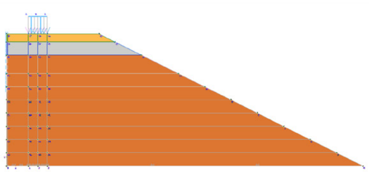
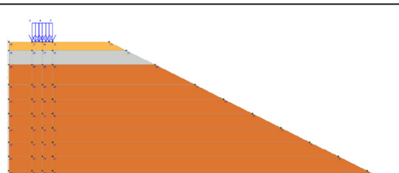
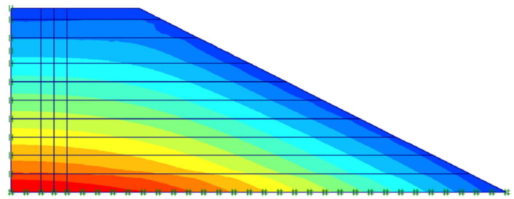
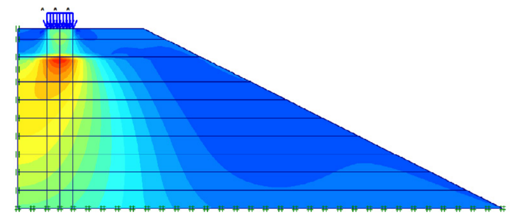
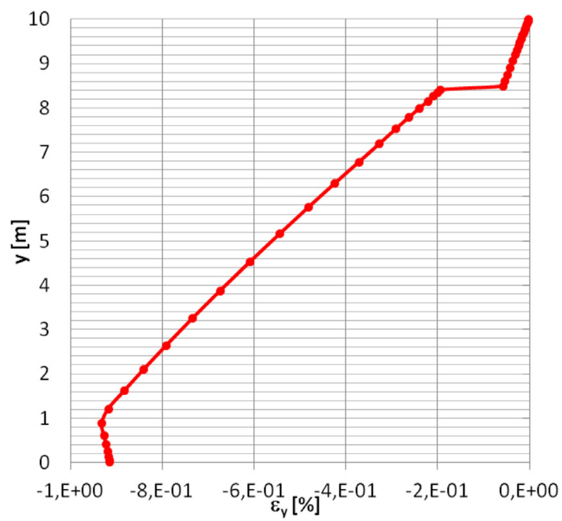
8	
9	
10	

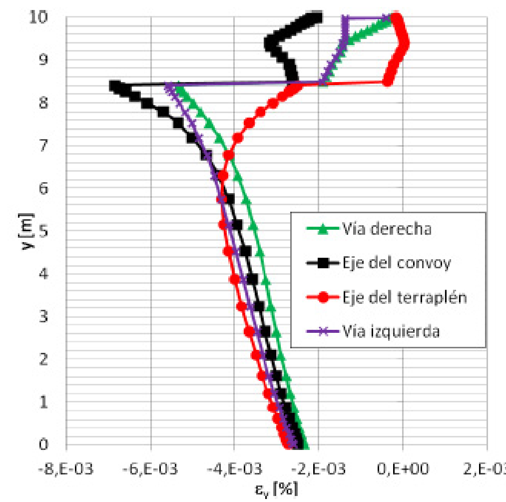
$\varepsilon_v^{\text{self-weight}}$



$\varepsilon_v^{\text{traffic}}$

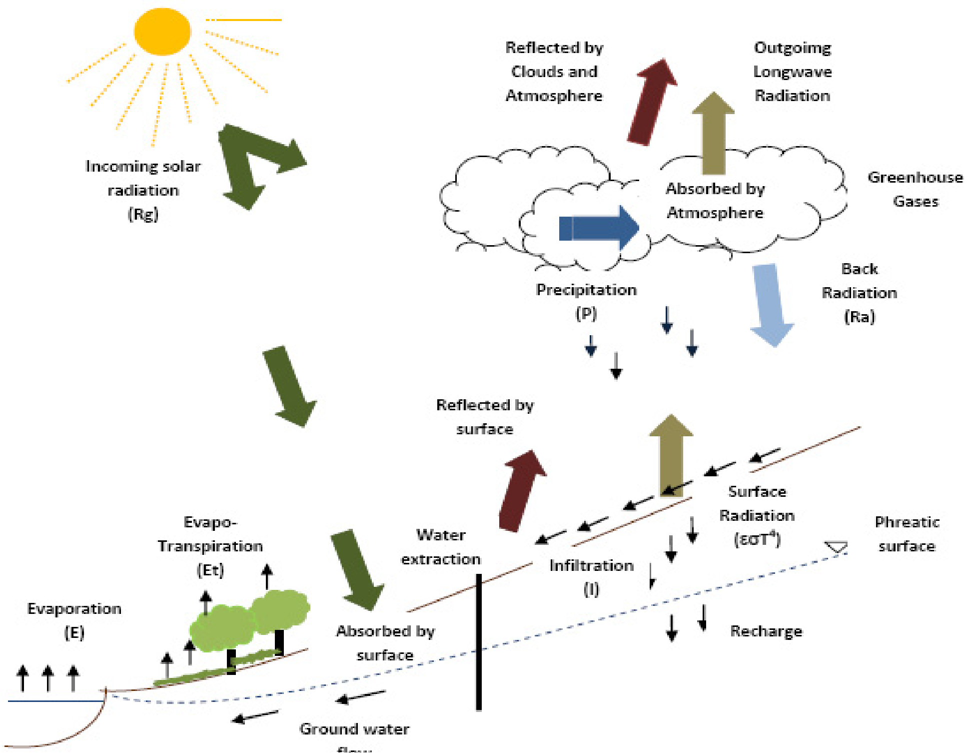






T-H MODEL: CODE_BRIGHT

ATMOSPHERE:



At soil surface:

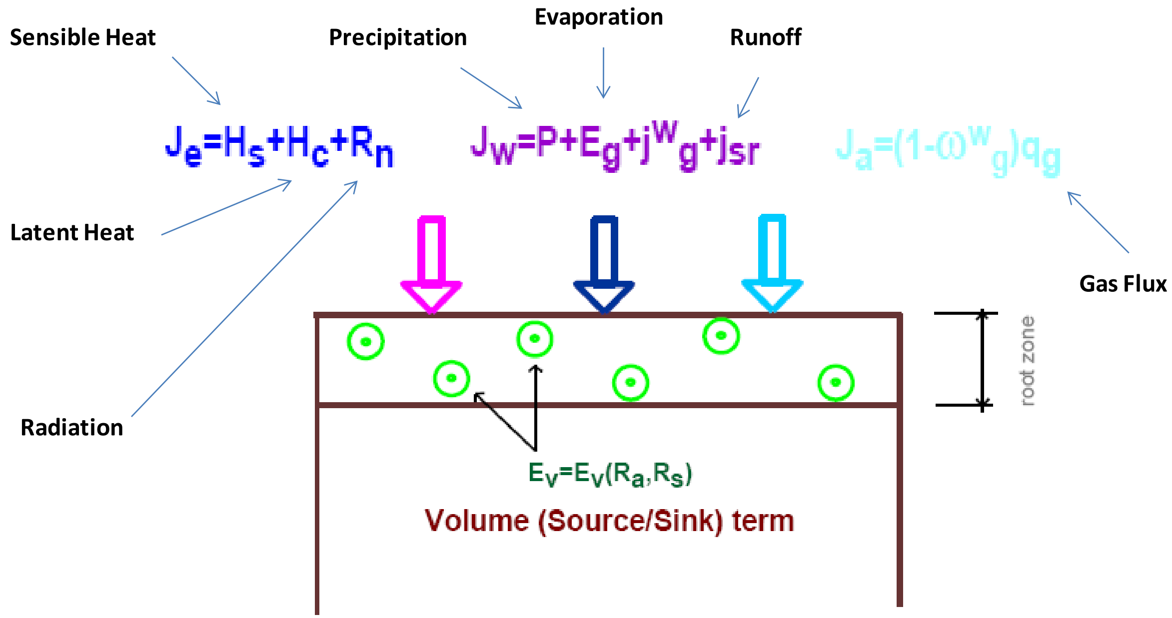
Heat exchange:
Solar radiation (+)
Radiation re-emitted by the atmosphere (+)
Radiation re-emitted by the soil (-)
Heat convected by evapotranspiration (in particular latent heat) (-)
Heat convected by liquid water (+/-)
Heat convected by air

Water exchange:
Precipitation (+)
Runoff (–)
Evapotranspiration (-)

Air exchange:
Flow due to change in atmospheric pressure
Strongly enhanced by aerodynamics effects

T-H MODEL: CODE_BRIGHT

SOIL:



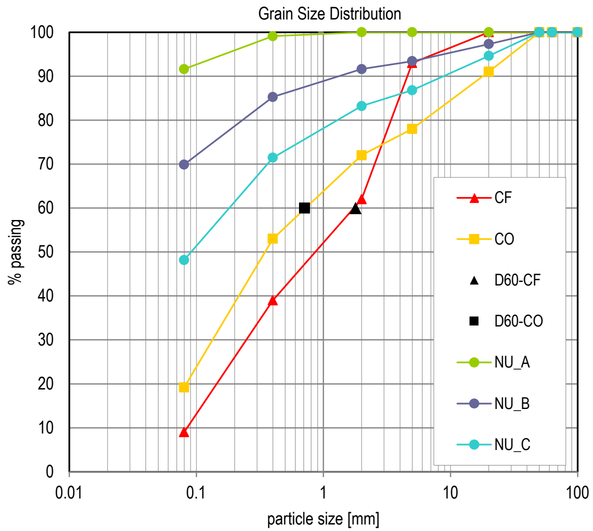
Mass balance of heat (including conductive, diffusive and advective fluxes)

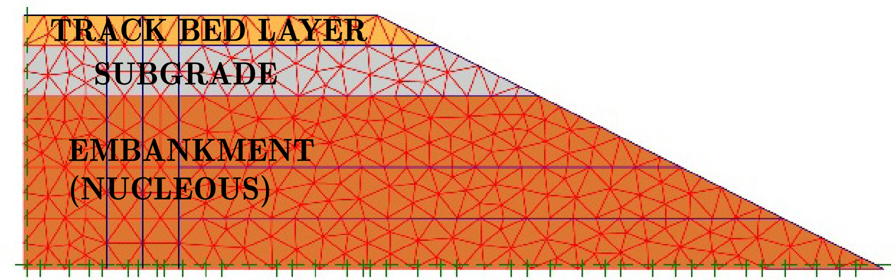
Mass balance of water (including liquid water and vapour)

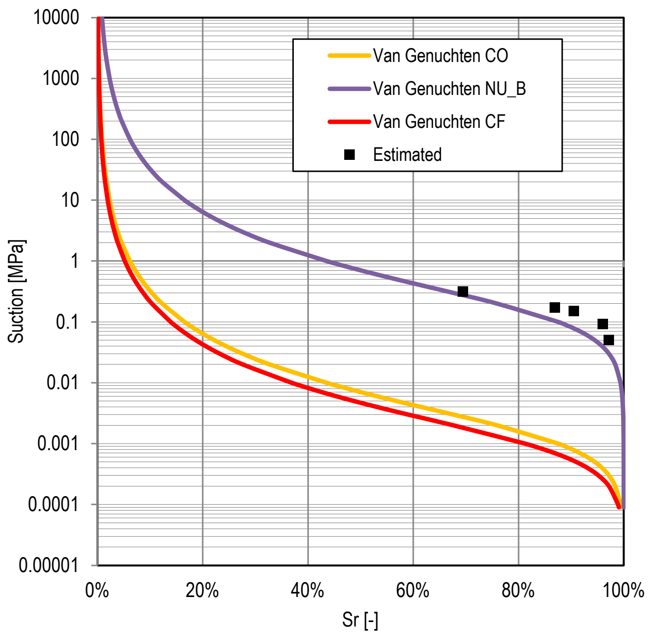
Mass balance of air (including dry air and dissolved air)

Stress equilibrium

T-H MODEL: Materials

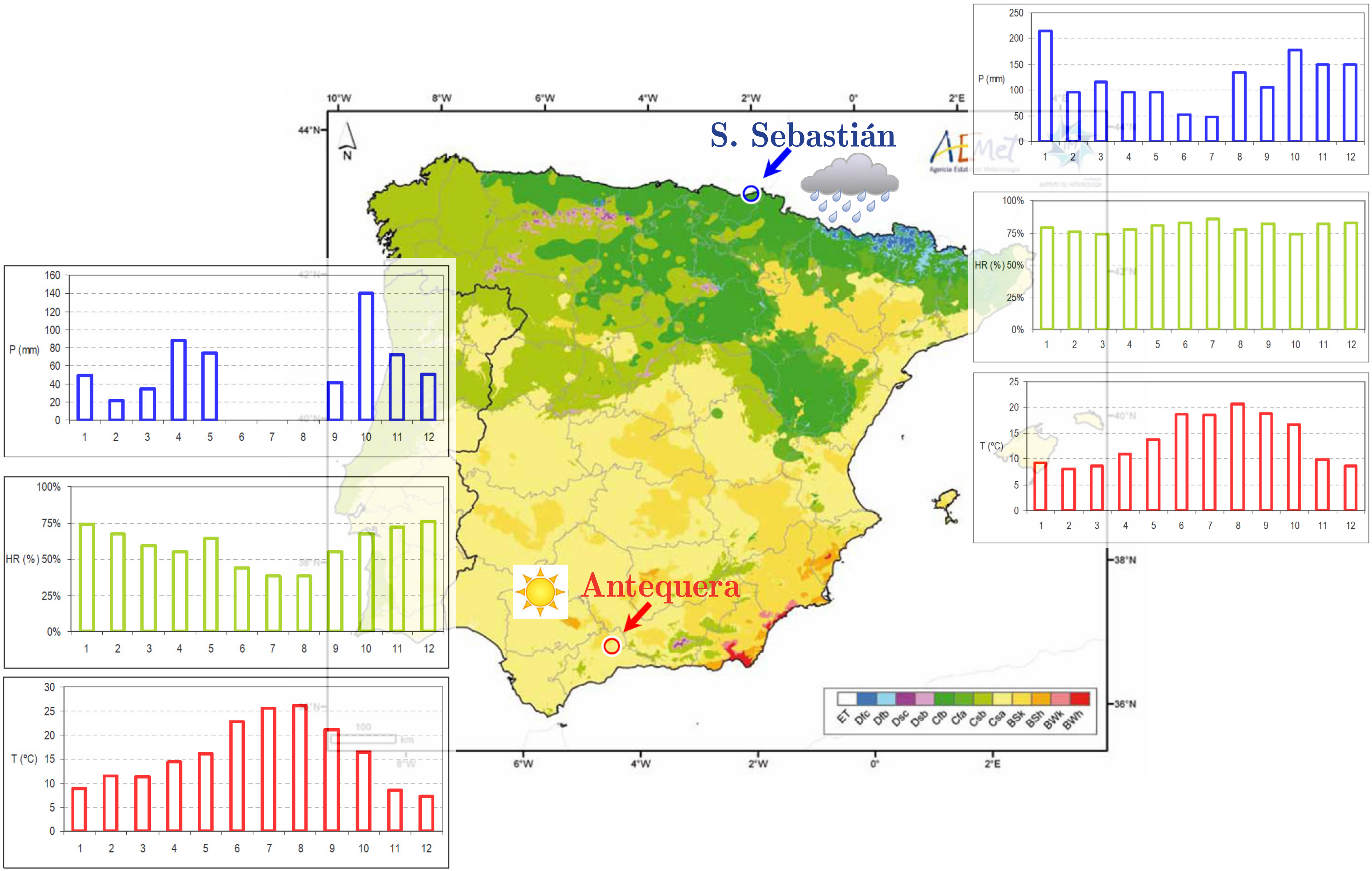






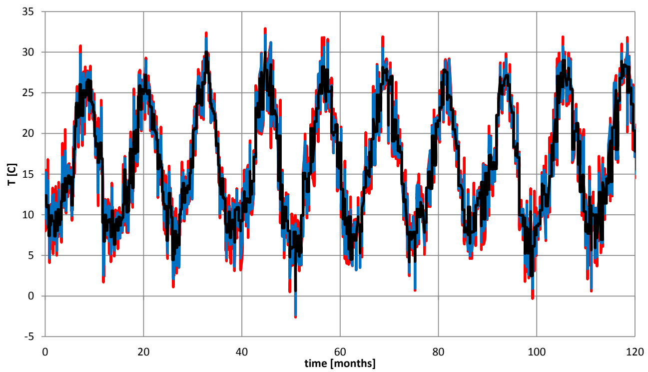
			Track bed layer	*Subgrade*	*Nucleus C*	*Nucleus B*	*Nucleus A*
Strength and stiffness	*E '*	*MPa*	50	50	13	13	13
	ν	-	0.33	0.33	0.33	0.33	0.33
	ϕ '	*º*	33	33	30	30	30
	c '	*kPa*	10	10	10	10	10
Permeability	*K*	*m/s*	2,5 E-04	2,1 E-04	2,0 E-8	2,0 E-9	2,0 E-10
Plasticity Indices	*LL*	*%*	NP	NP	37,6	37,6	37,6
	LP	*%*	NP	NP	23,0	23,0	23,0
	IP	*%*	NP	NP	14,6	14,6	14,6
Modified Proctor	*Gs*	-	2,65	2,65	2,65	2,65	2,65
	γ_{dry} *(PM)*	g/cm^3	2,0	2,0	1,78	1,78	1,78
	w_{opt} *(PM)*	*%*	18,2	18,2	29,9	29,9	29,9
	CBR (PM)	-	25	25	5	5	5
	Sr (PM)	*%*	80,6	80,6	90,6	90,6	90,6
	suction (PM)	*kPa*	20	50	150	150	150

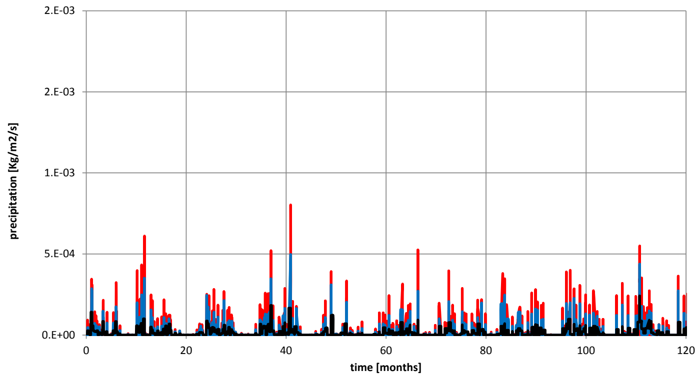
T-H MODEL: Boundary Conditions #1
WEATHER

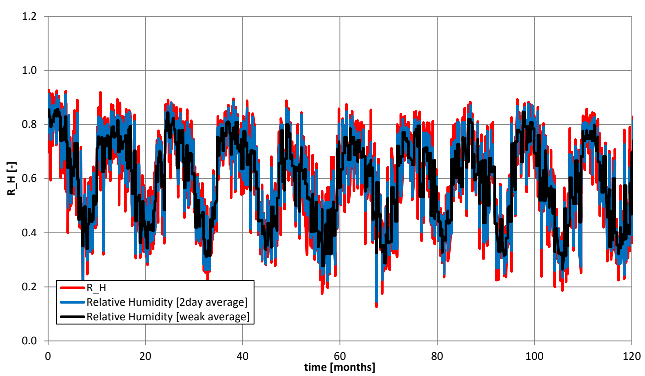


T-H MODEL: Boundary Conditions #1
WEATHER

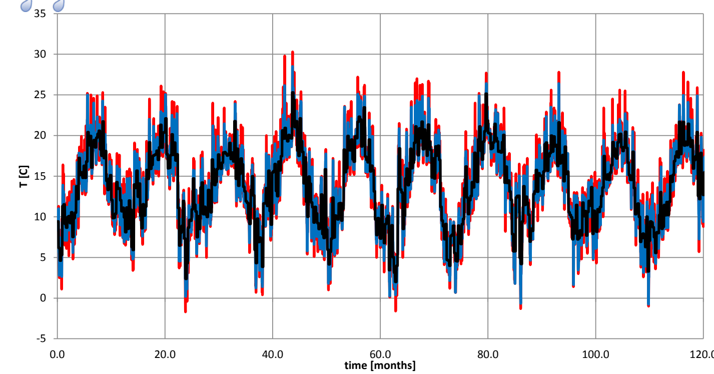
Antequera

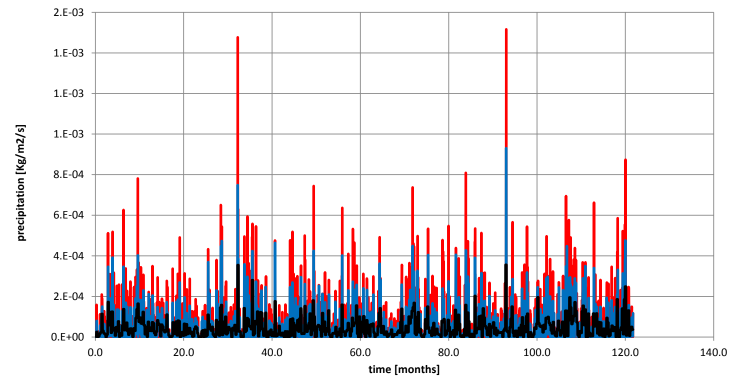


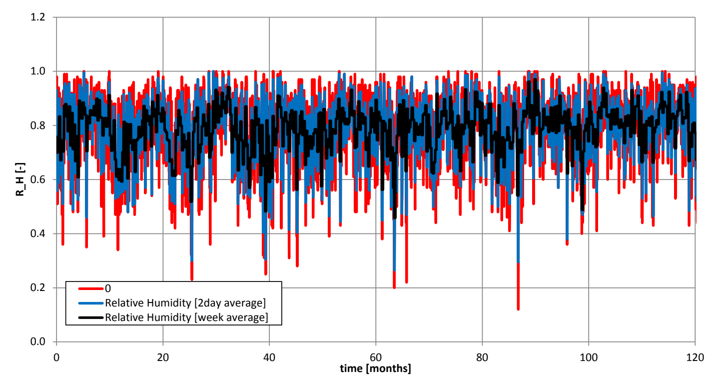




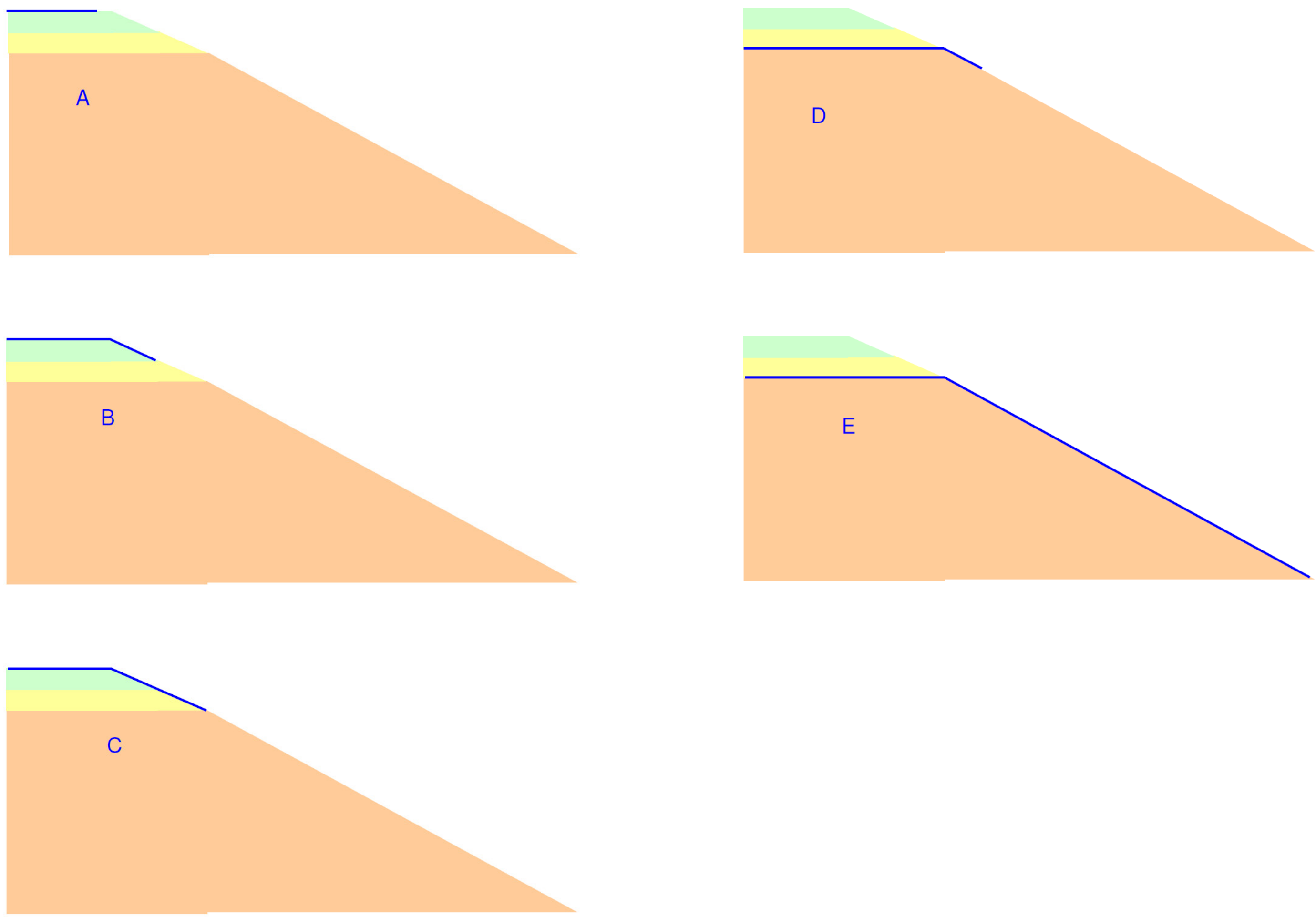
S. Sebastián



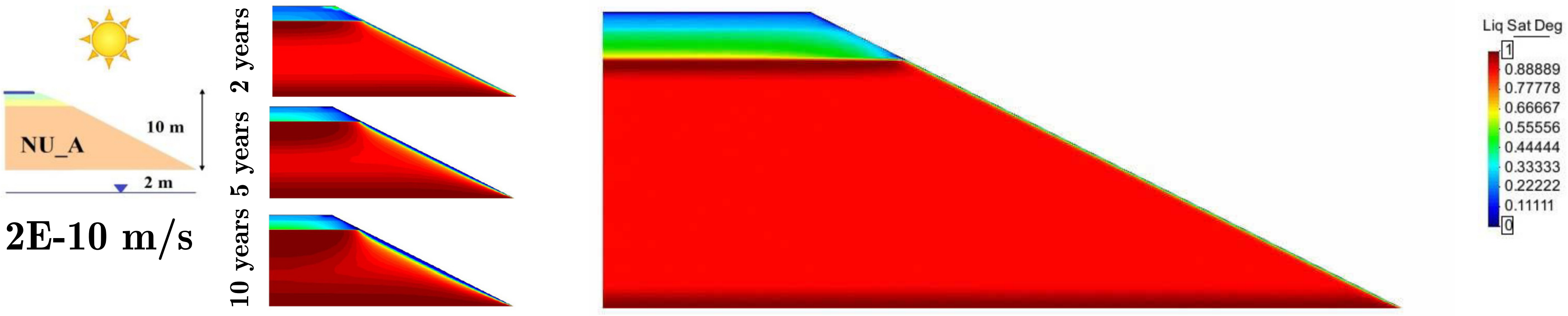


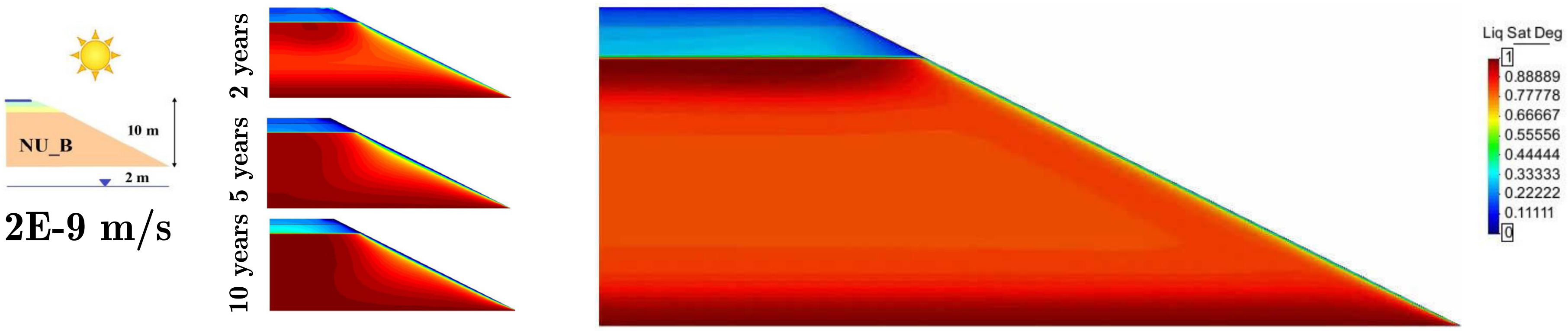


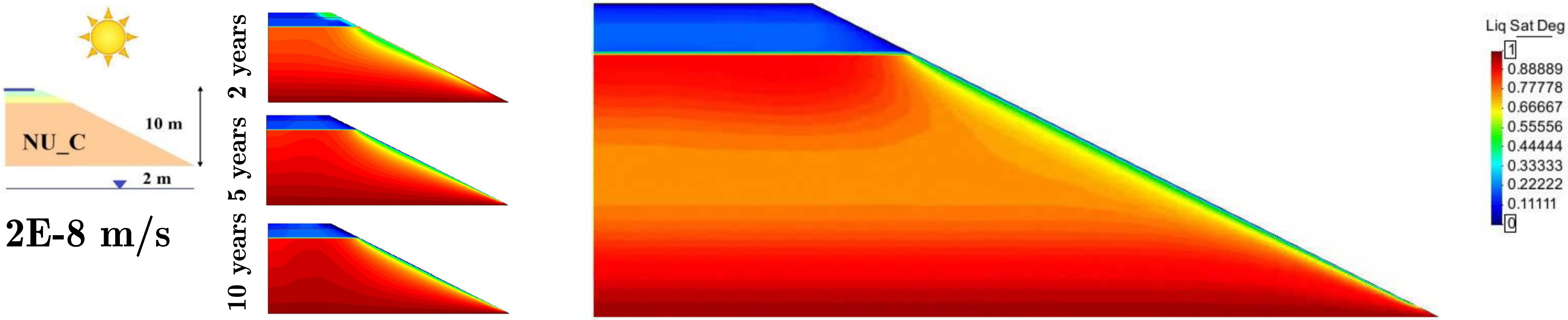
T-H MODEL: Boundary Conditions #2
IMPERMEABLE GEOMEMBRANES



Type of NUCLEOUS #1



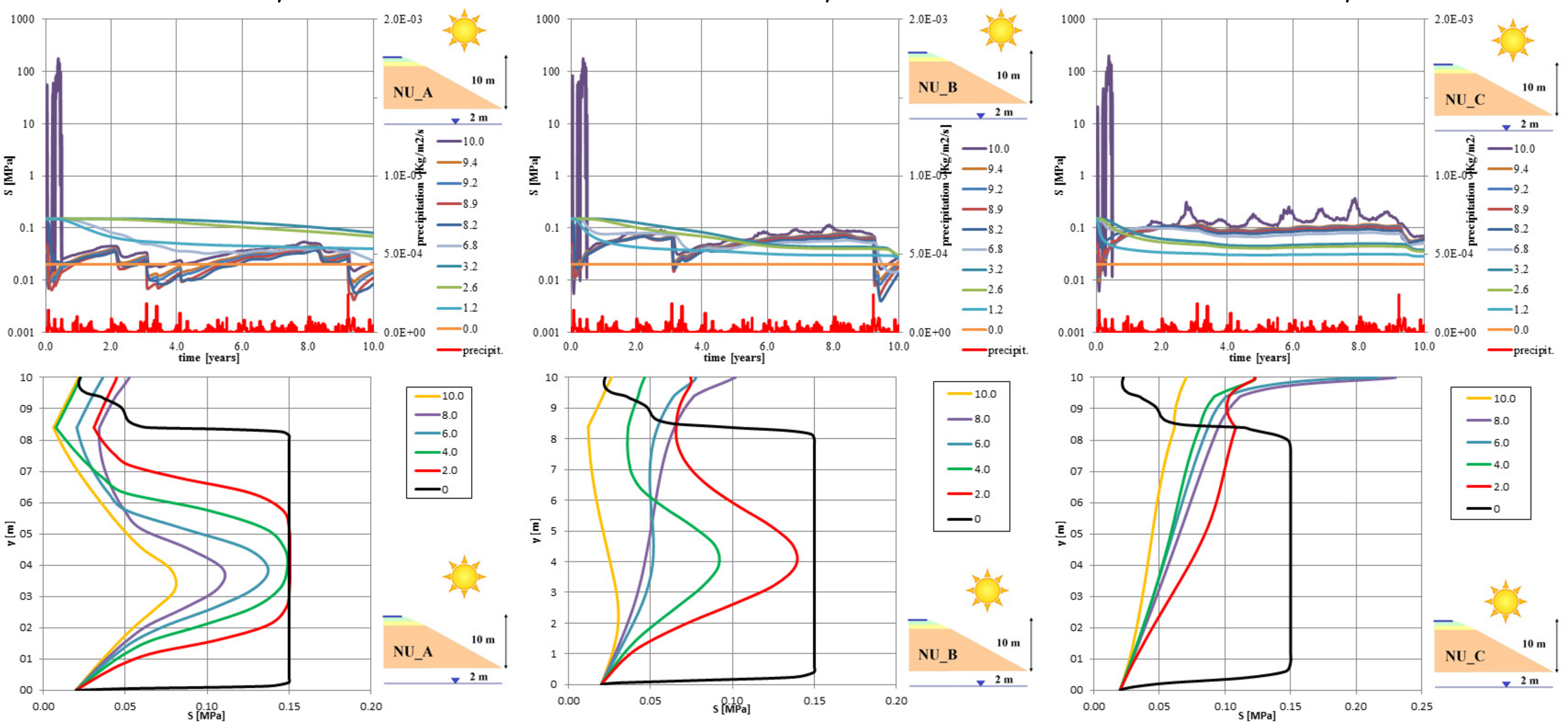




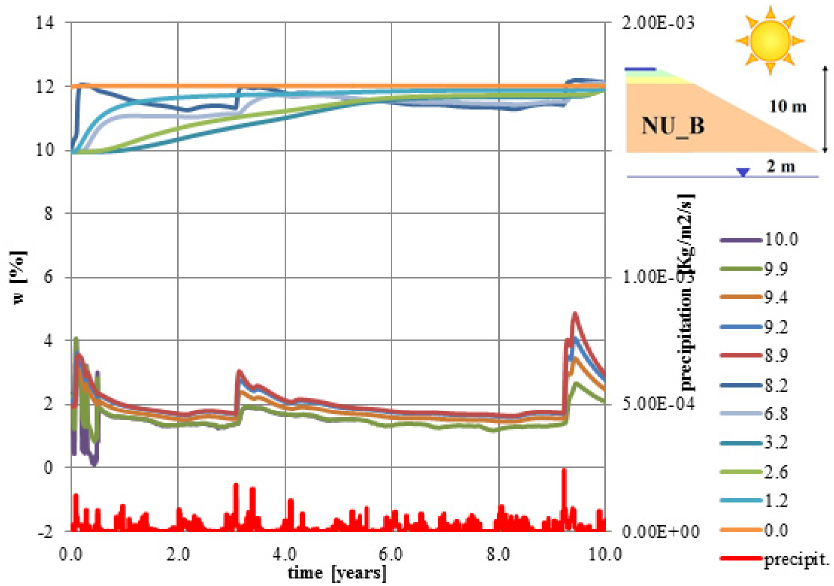
Type of NUCLEOUS #2

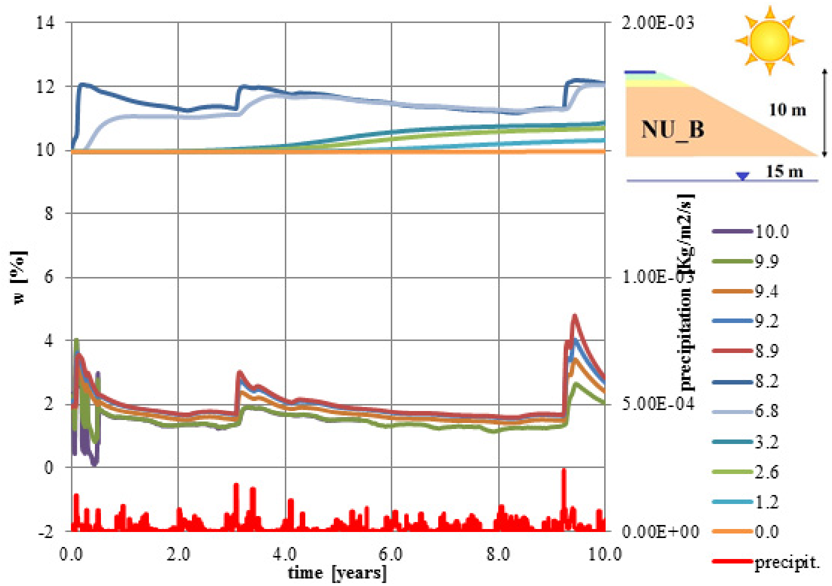
PERMEABILITY

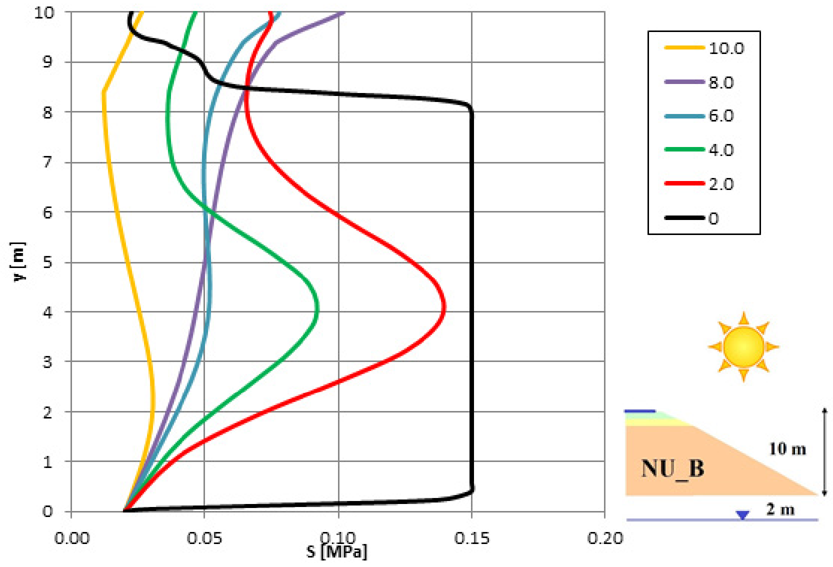
2E-10 m/s | 2E-9 m/s | 2E-8 m/s

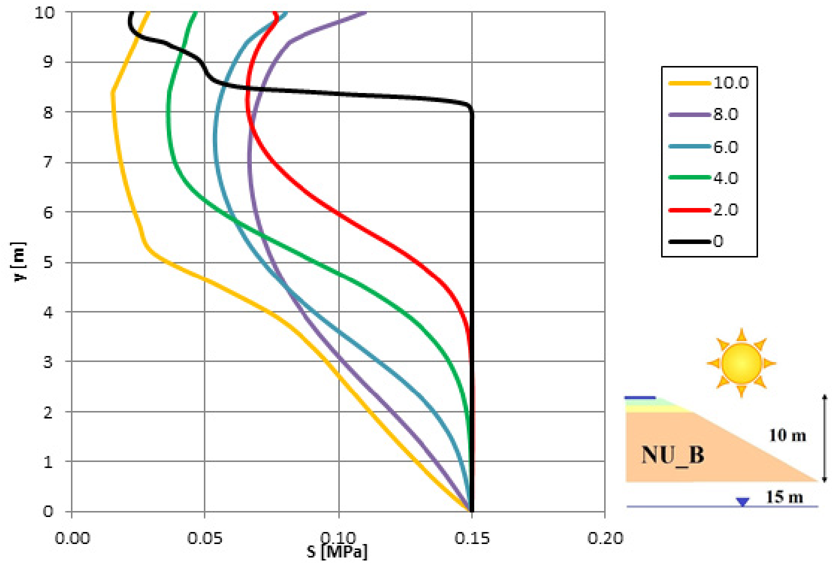


PHREATIC LEVEL

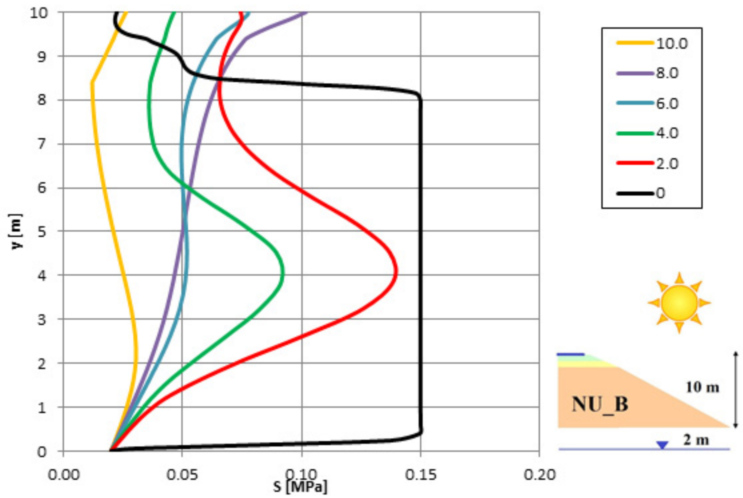


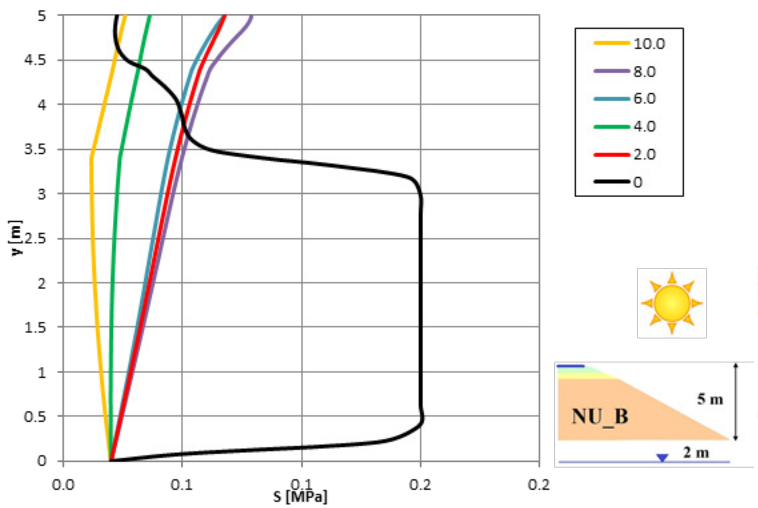


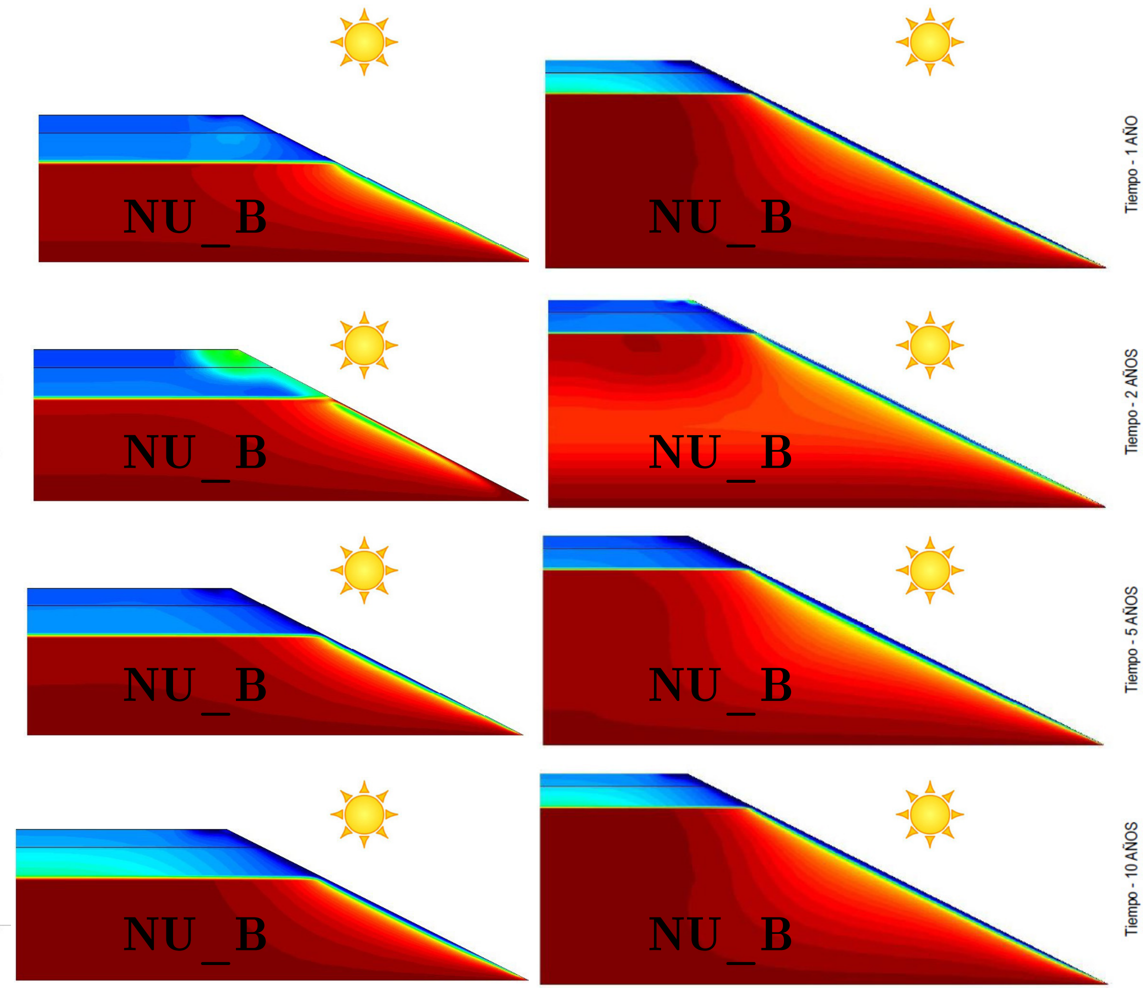




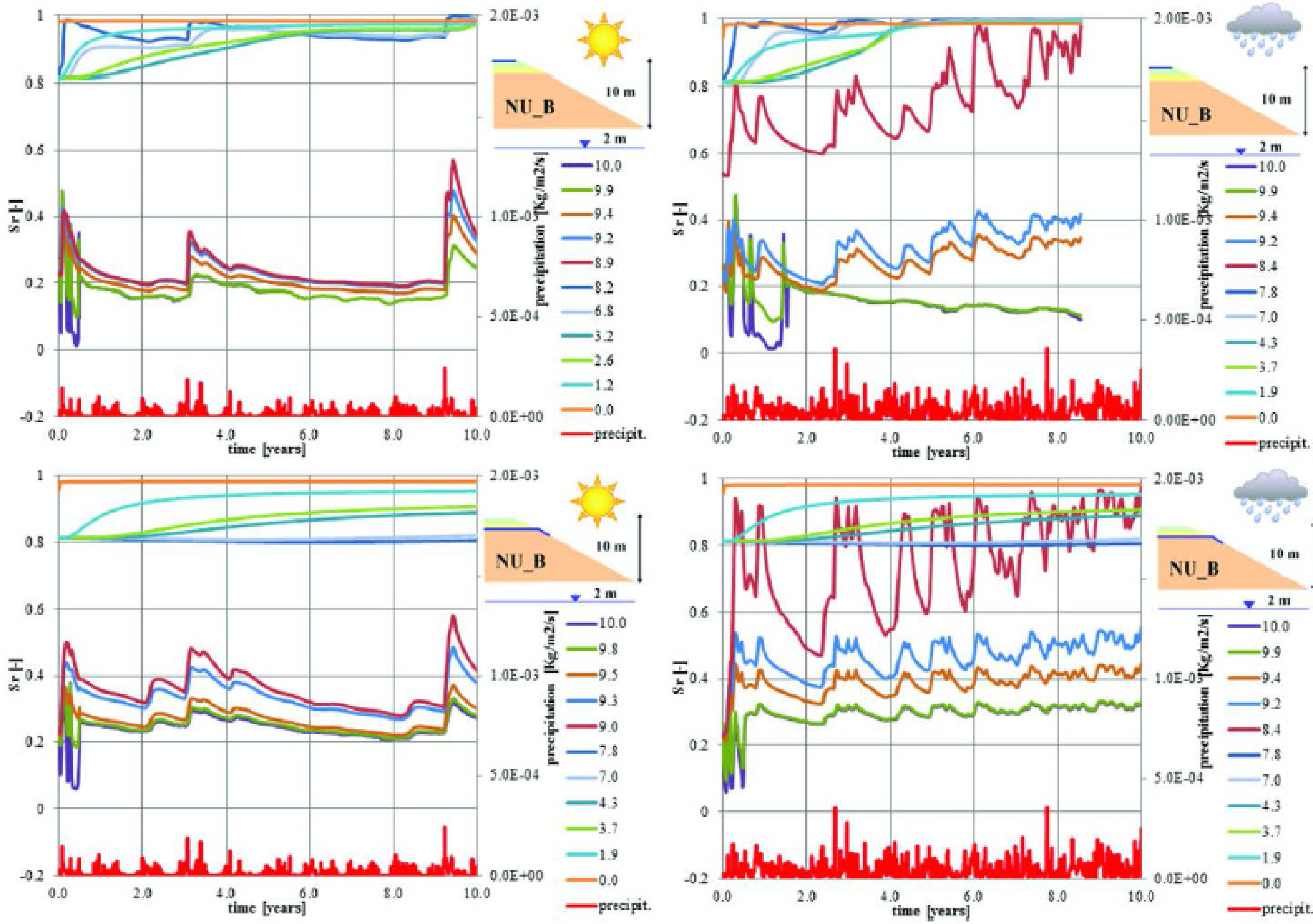
EMBANKMENT DIMENSIONS







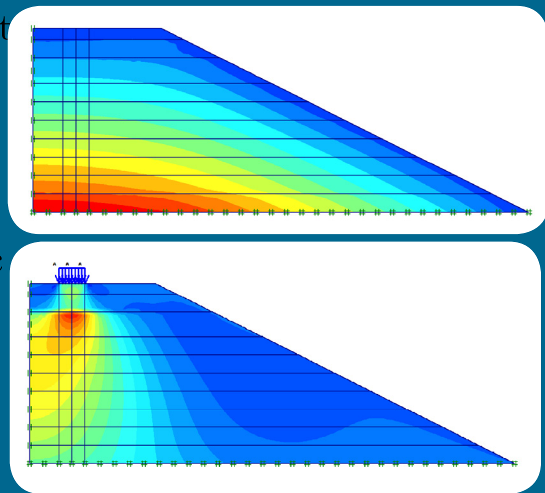
T-H MODEL: Typical Results



T-H + M MODEL: Long term embankment irreversible deformations

$\varepsilon_v^{\text{self-weight}}$

$\varepsilon_v^{\text{traffic}}$



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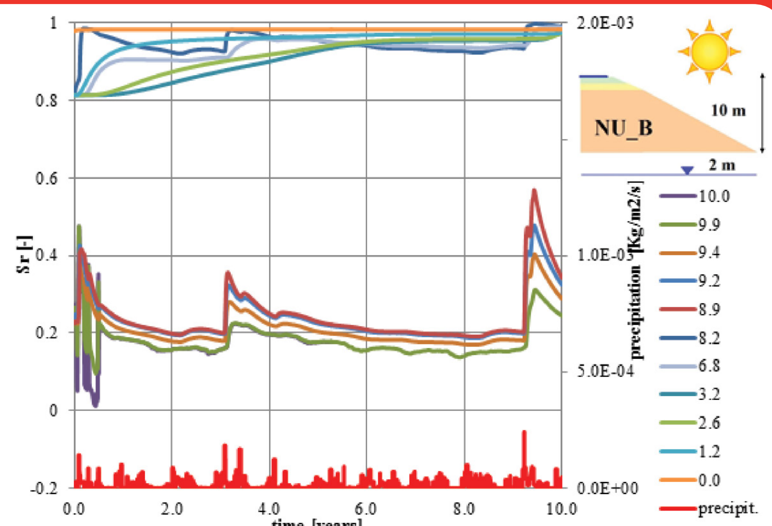
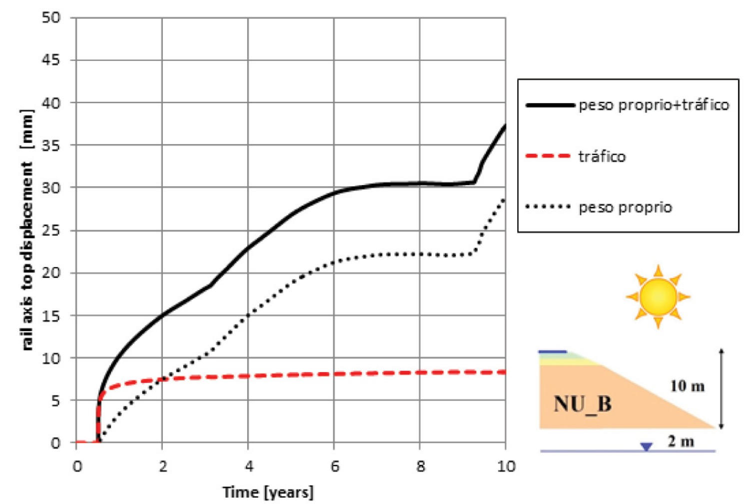
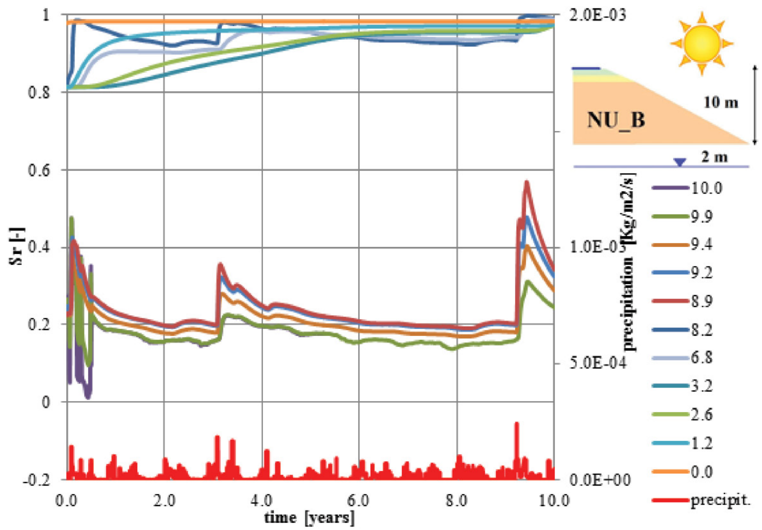


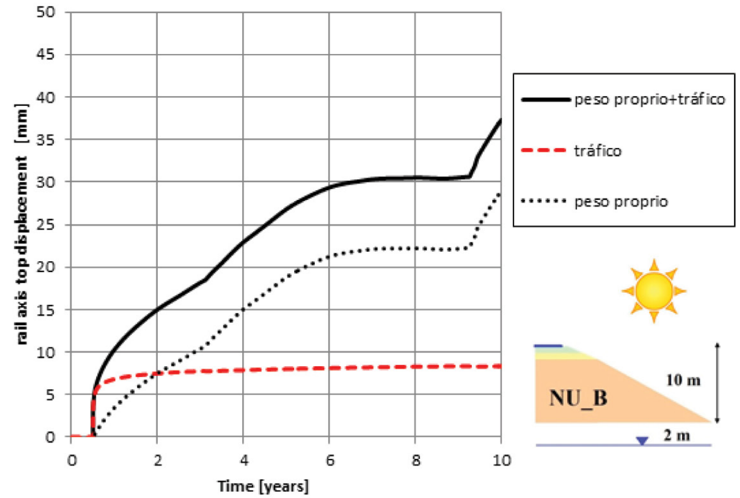
$$\delta_a(N) = \beta_1 \left(\frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \varepsilon_v h$$

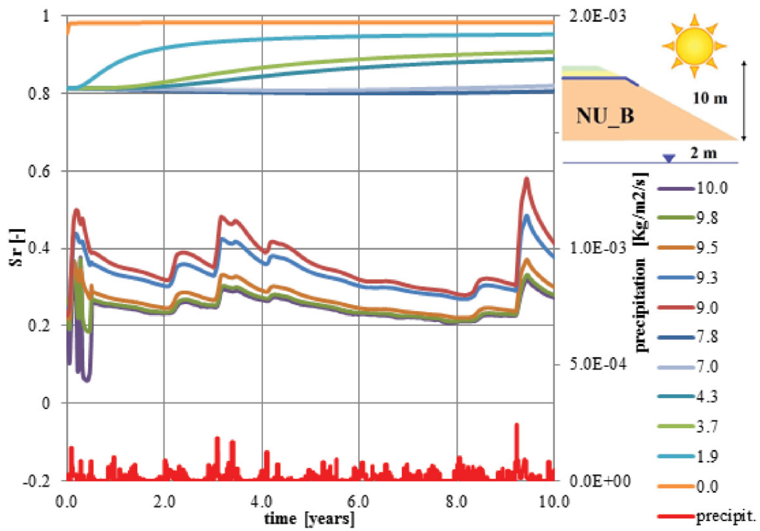
$$\log \beta = -0.61119 - 0.017638 W_c$$

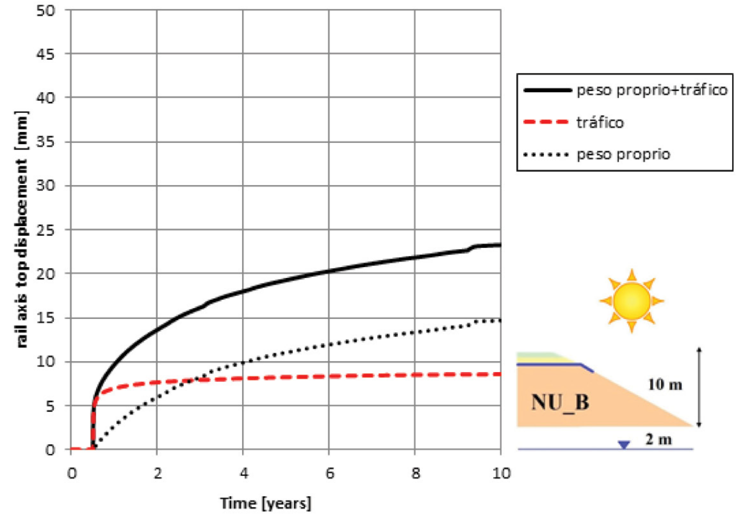


T-H + M MODEL: Long term geomembrane positioning #1

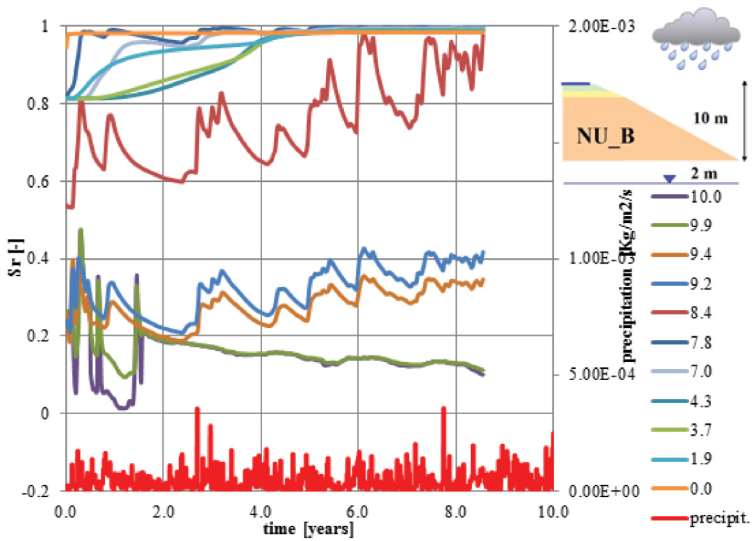


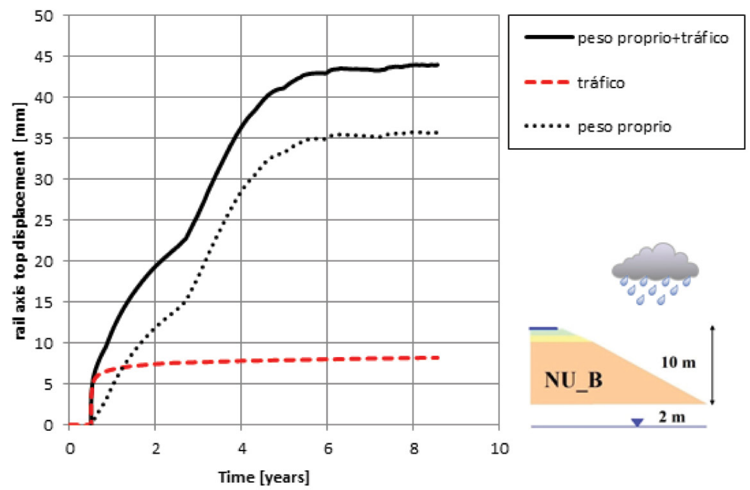


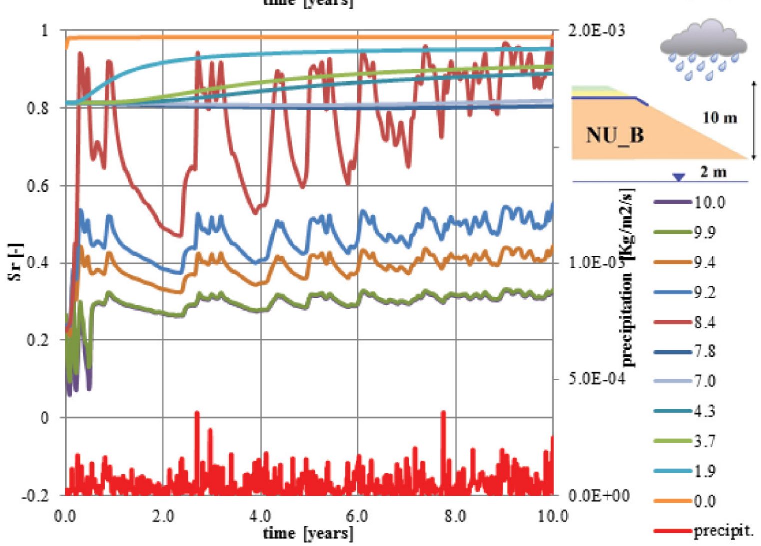


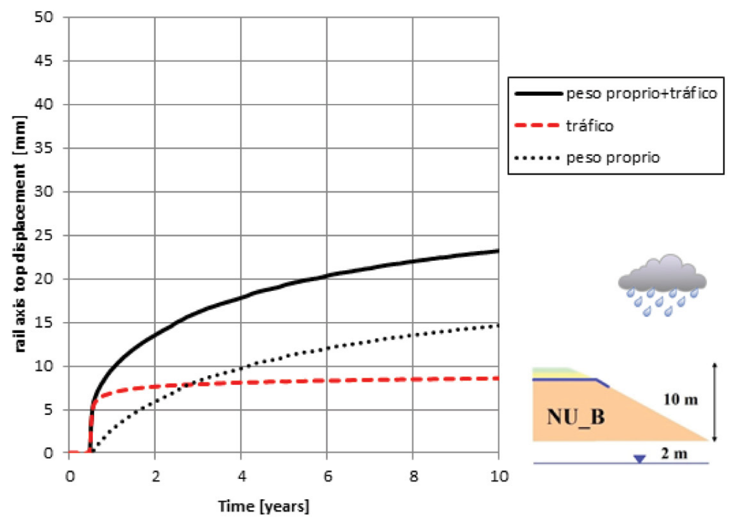


T-H + M MODEL: Long term geomembrane positioning #2

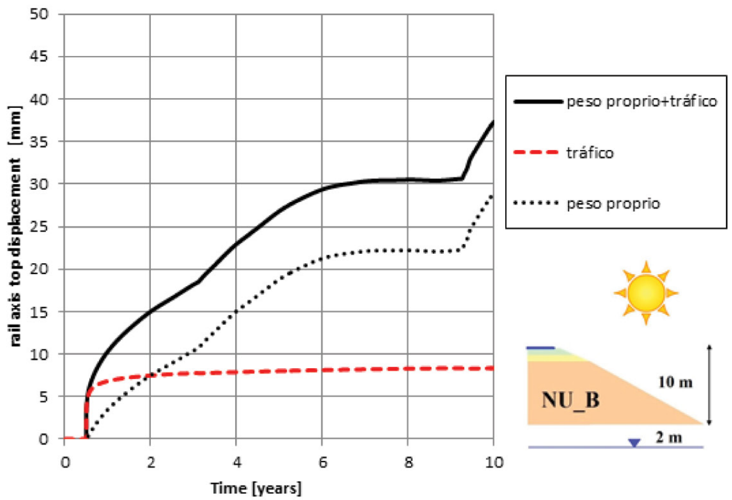


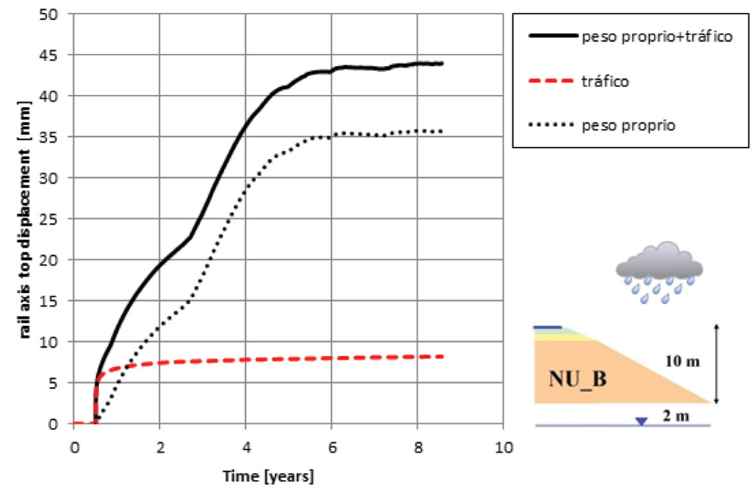


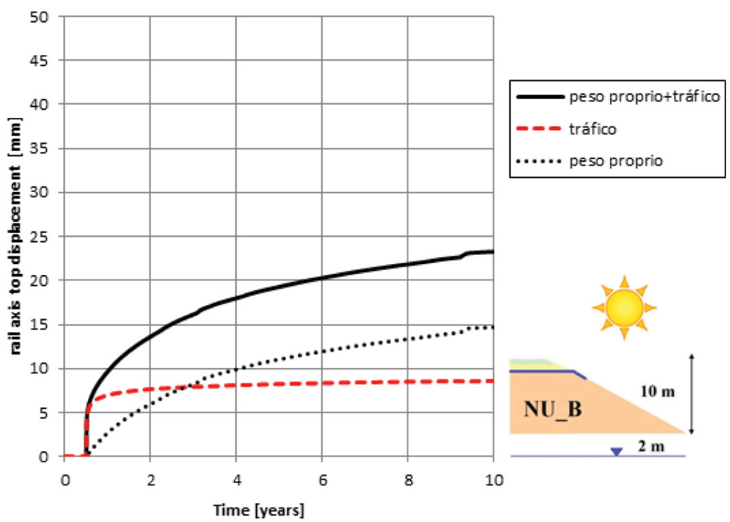


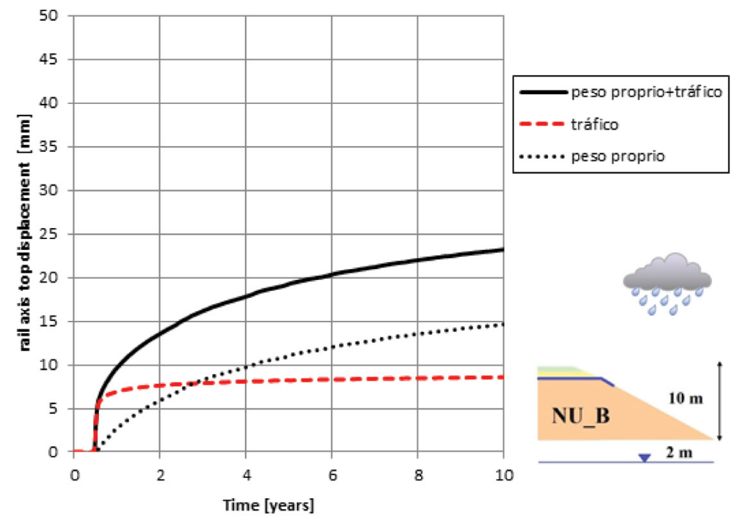


T-H + M MODEL: Long term geomembrane positioning #3

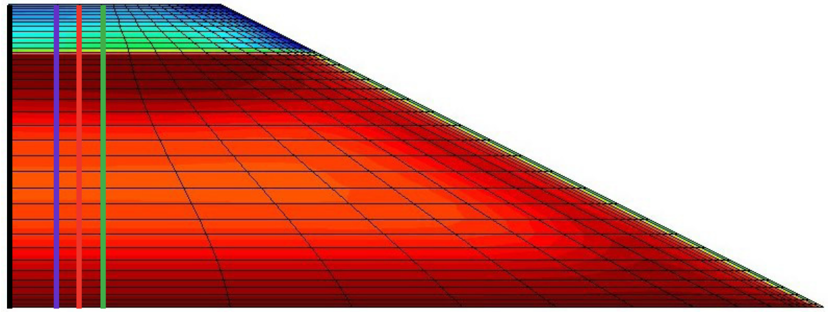


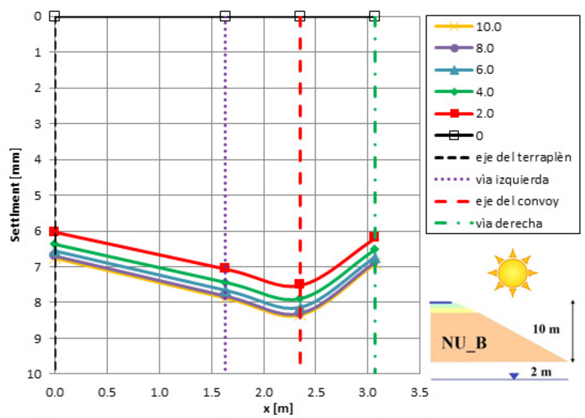


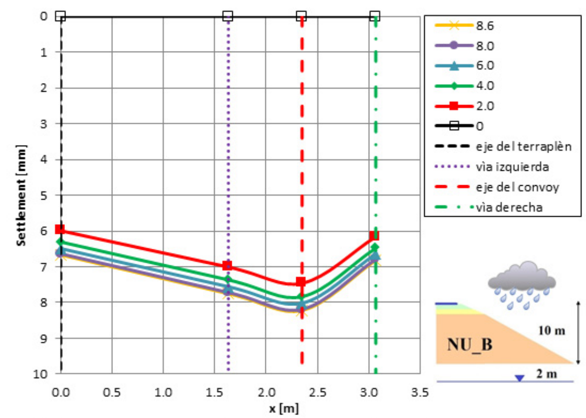


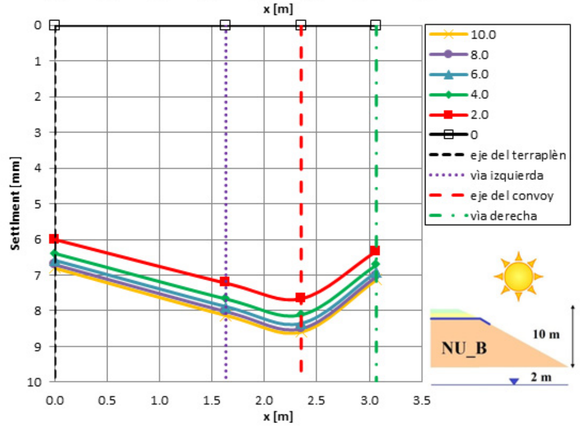


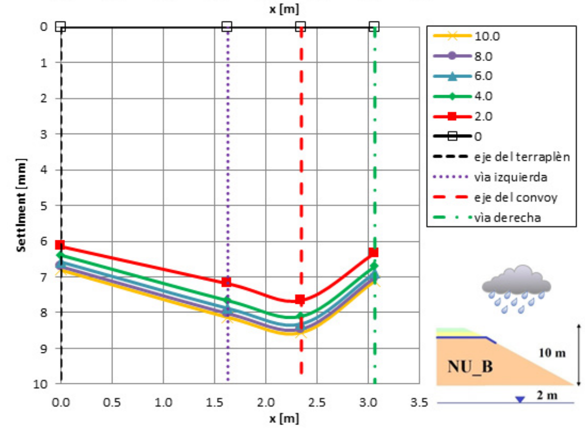
T-H + M MODEL: Long term geomembrane positioning #4





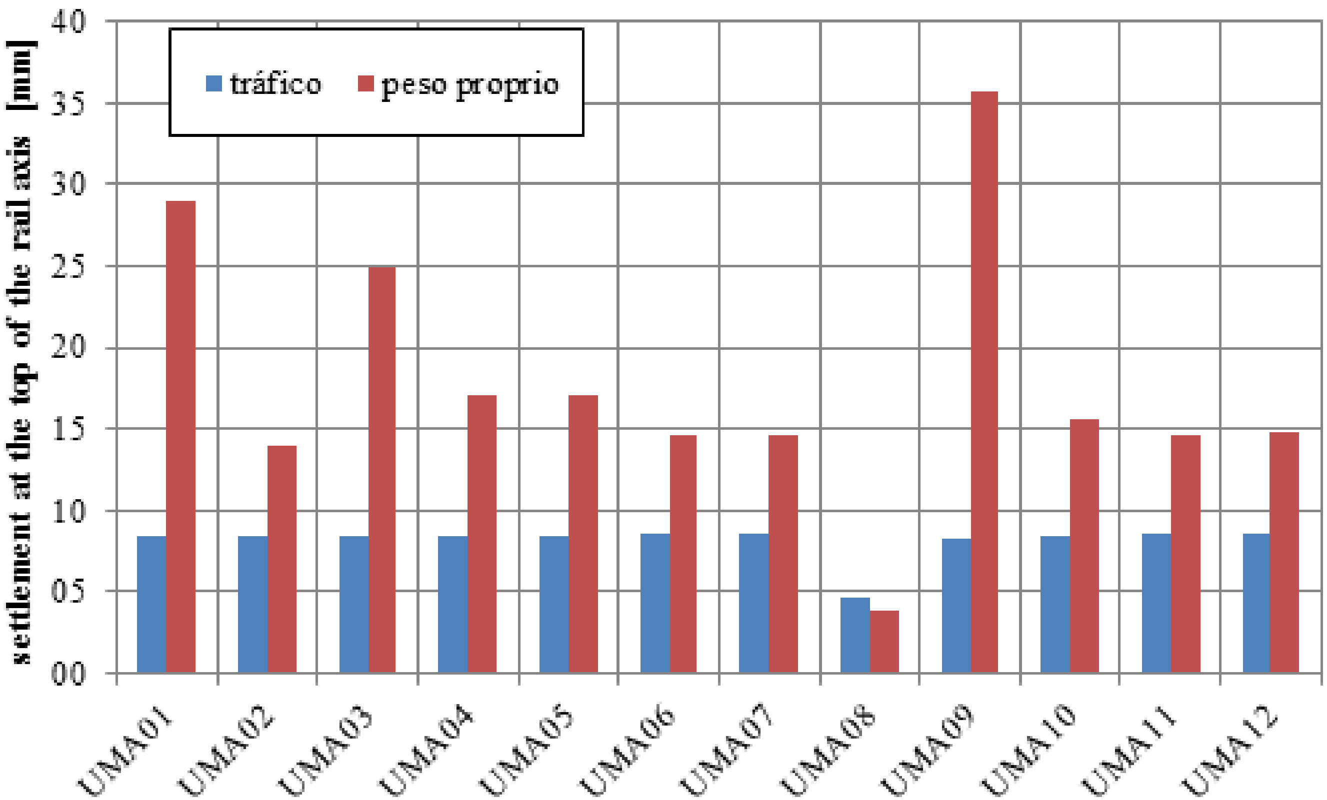






T-H + M MODEL: Long term

10 year self weight and traffic load env-induced settlemen



Name	Icon	WEATHER
UMA01	NU_B 10 m 2 m	
UMA02	NU_A 10 m 2 m	
UMA03	NU_C 10 m 2 m	
UMA04	NU_B 10 m 2 m	
UMA05	NU_B 10 m 2 m	
UMA06	NU_B 10 m 2 m	
UMA07	NU_B 10 m 2 m	
UMA08	NU_B 5 m 2 m	
UMA09	NU_B 10 m 2 m	
UMA10	NU_B 10 m 15 m	
UMA11	NU_B 10 m 2 m	
UMA12	NU_B 10 m 2 m	

CONCLUSIONS

NEW WAY OF PREDICTING THE ATMOSPHERIC INDUCED LONG TERM DEFORMATION OF EMBANKMENTS:

AASHTO INDICATIONS (FATIGUE CALCULATION) + TH FEM ANALYSES

PARAMETRIC STUDY:

1. GEOMETRICAL DISPOSITION OF IMPERMEABLE MEMBRANES
2. PHREATIC LEVEL
3. SIZE OF THE EMBANKMENT
4. CLIMATE

FURTHER RESEARCH

1. MEMBRANES AT THE BASE
2. FULLY COUPLED THM FEM ANALSES

Universitat Politècnica de Catalunya · BarcelonaTech

Department of Geotechnical Engineering and Geosciences
(ETCG)

Thanks for the attention
QUESTIONS?