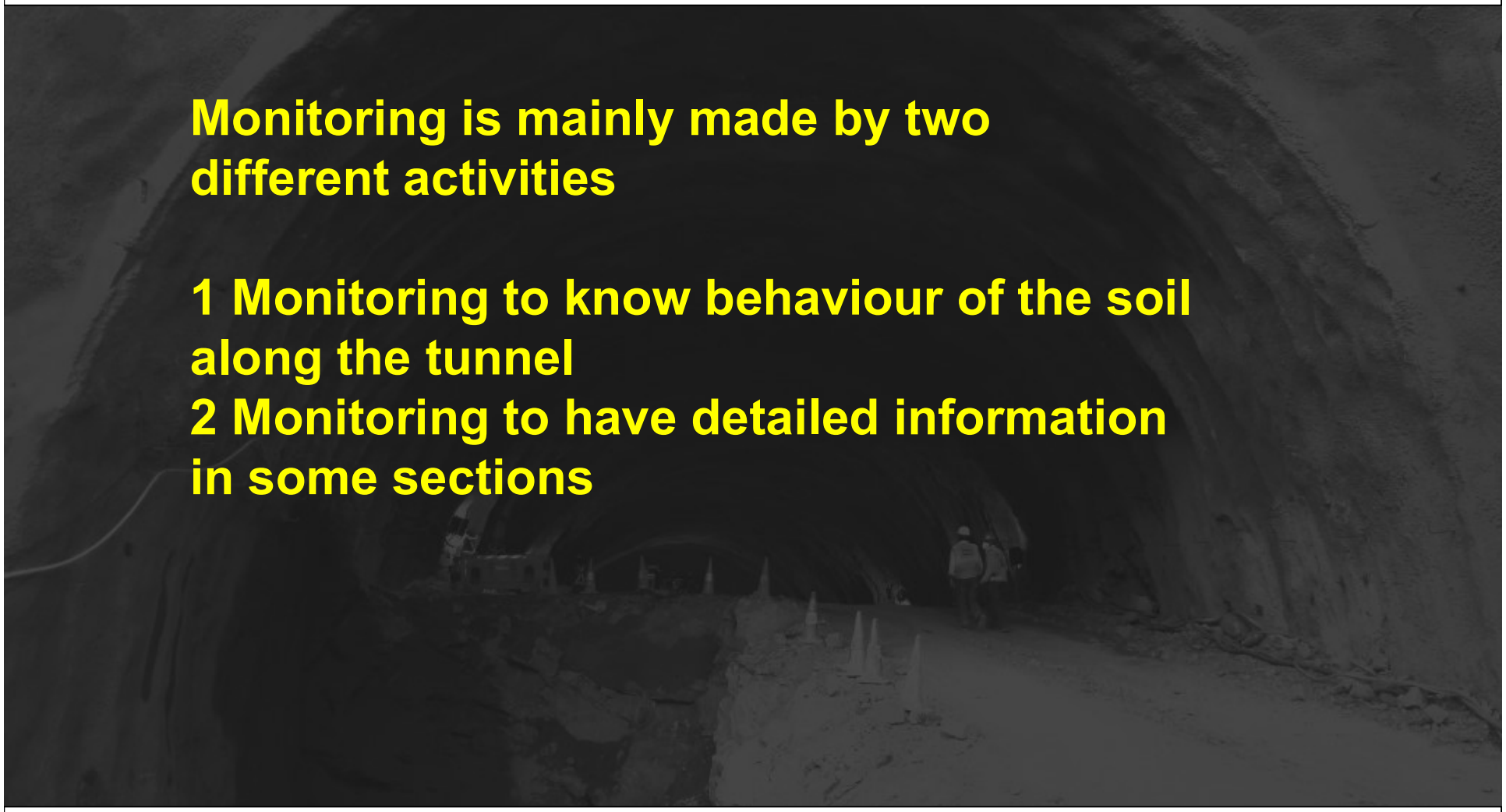
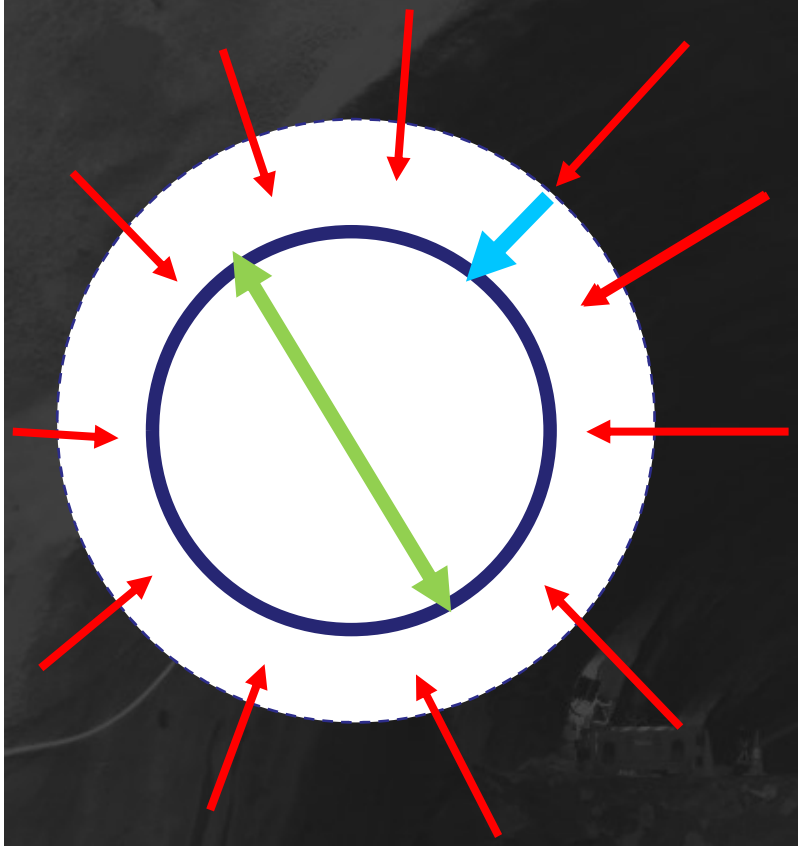
6 Monitoring during construction



Monitoring is mainly made by two different activities

1 Monitoring to know behaviour of the soil along the tunnel
2 Monitoring to have detailed information in some sections

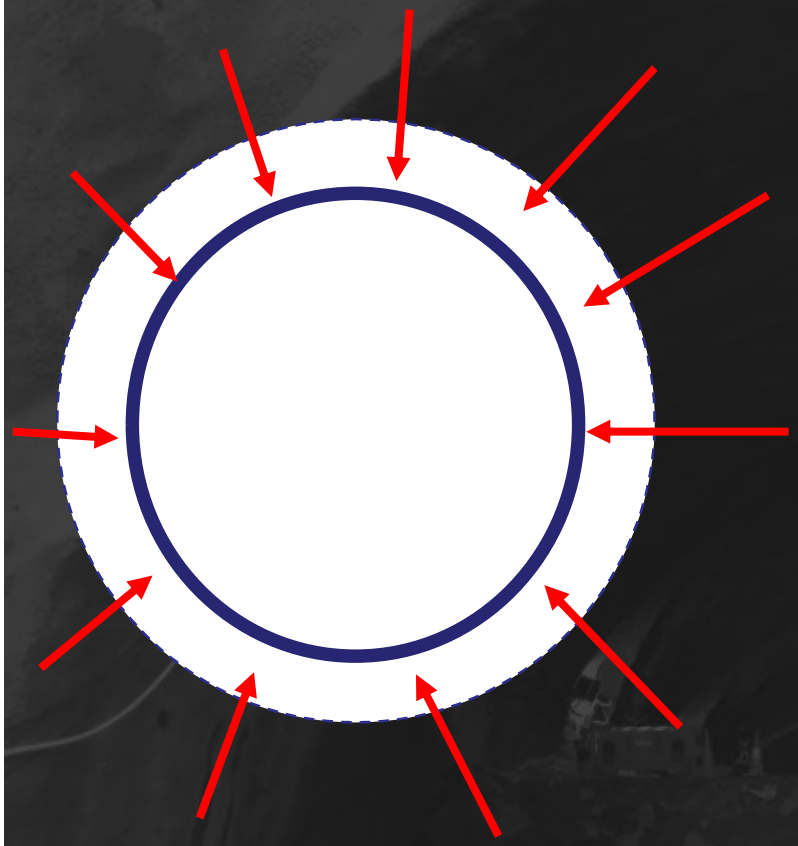


Monitoring along the tunnel

To know if the behaviour of the tunnel follow what the designer provided whe have to know the REAL displacement of the soil and the convergence of the tunnel.

Displacement is referred to movement of one point

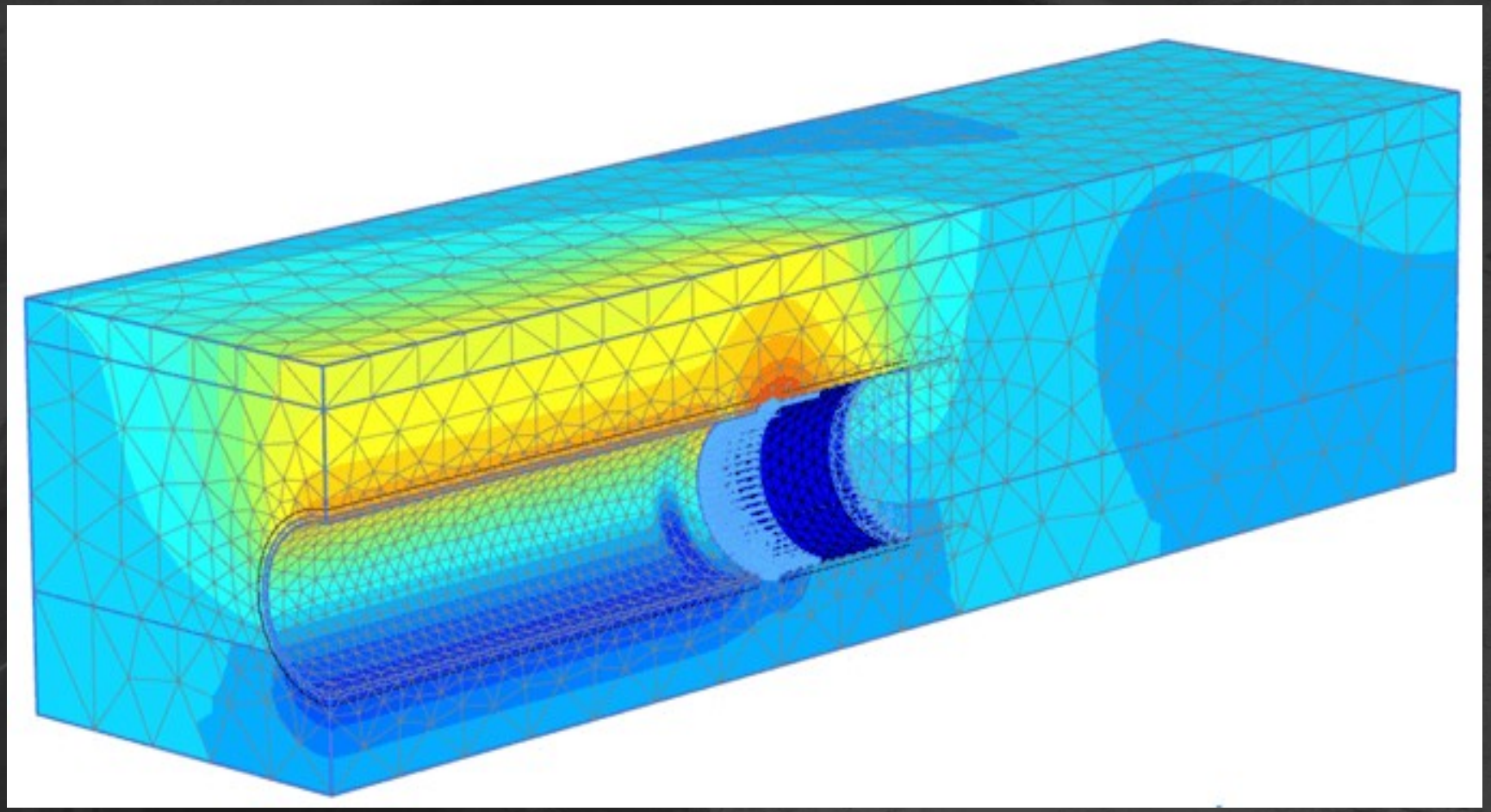
Convergence is the variation of the distance between two point i.e chord variation



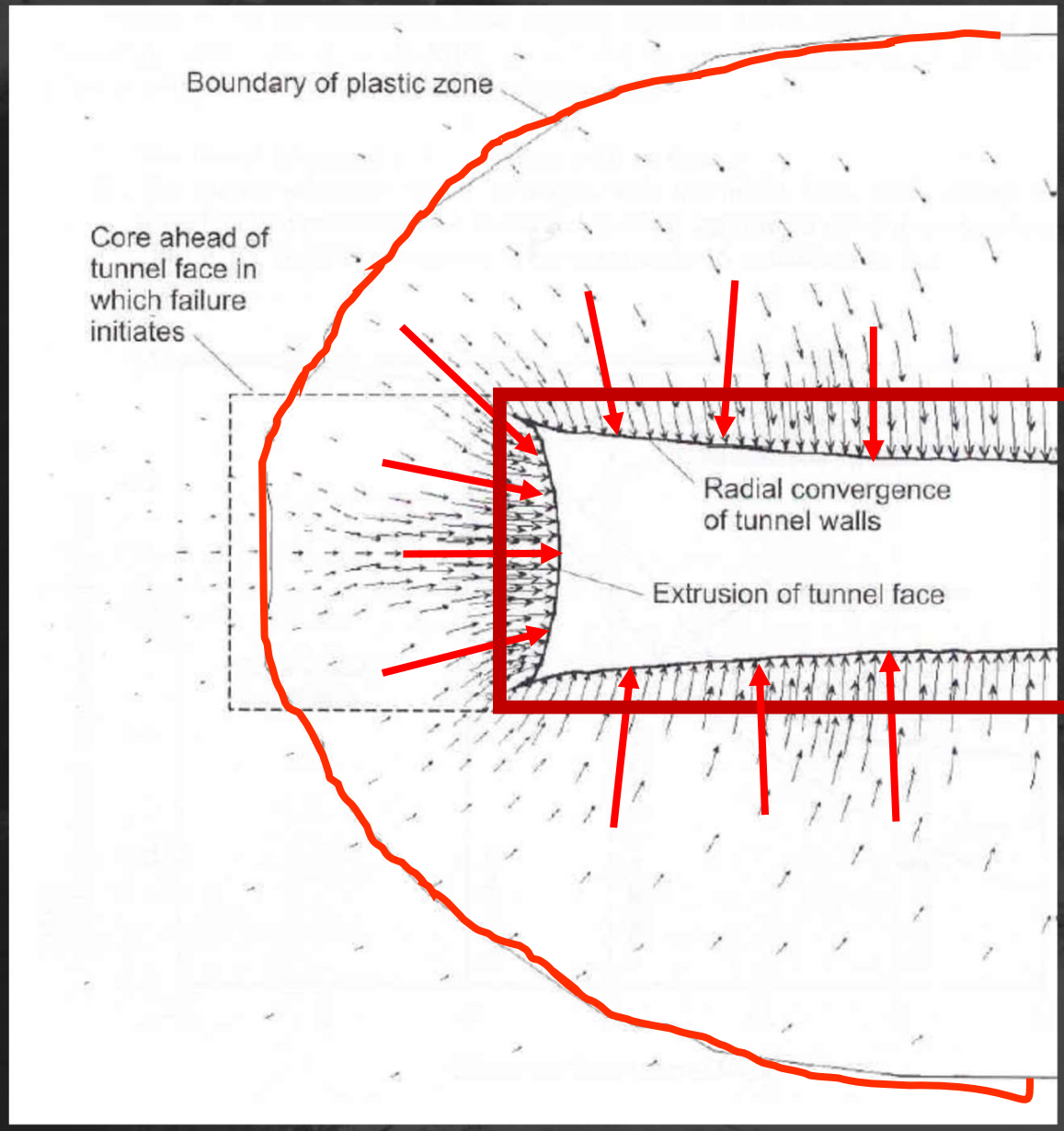
We want to use sufficient support but not too much to avoid waste of time and money

Analisis of Displacement and Convergence inform us if the support provided is enough, is not sufficient or is overestimated .

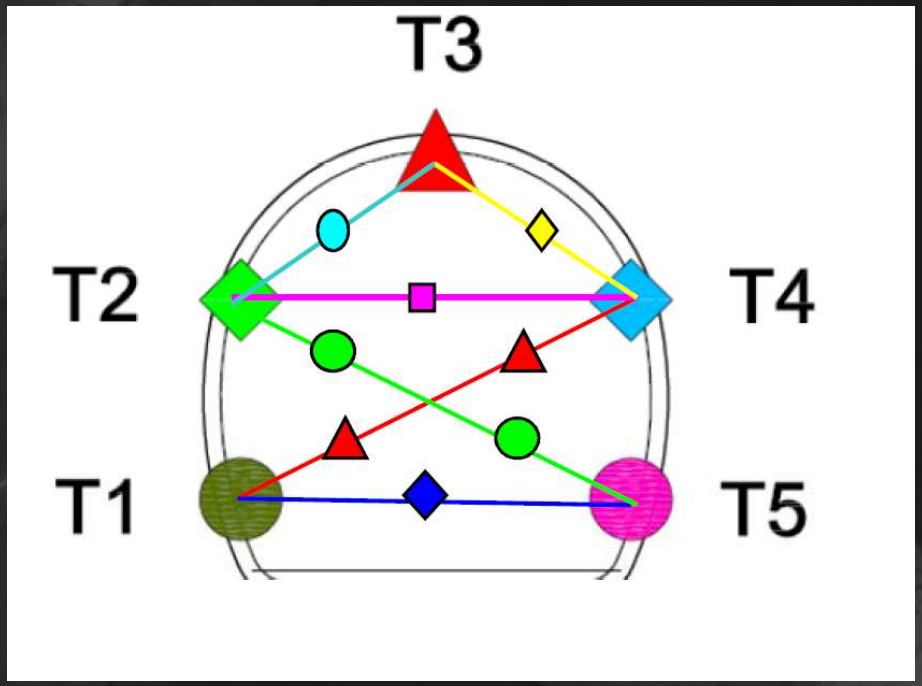
From this information we can take timely action

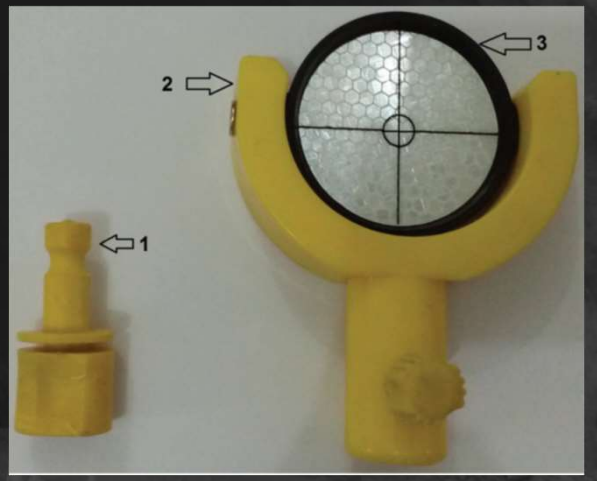


3D model of vertical displacement


Boundary of plastic zone
Core ahead of tunnel face in which failure initiates
Radial convergence of tunnel walls
Extrusion of tunnel face

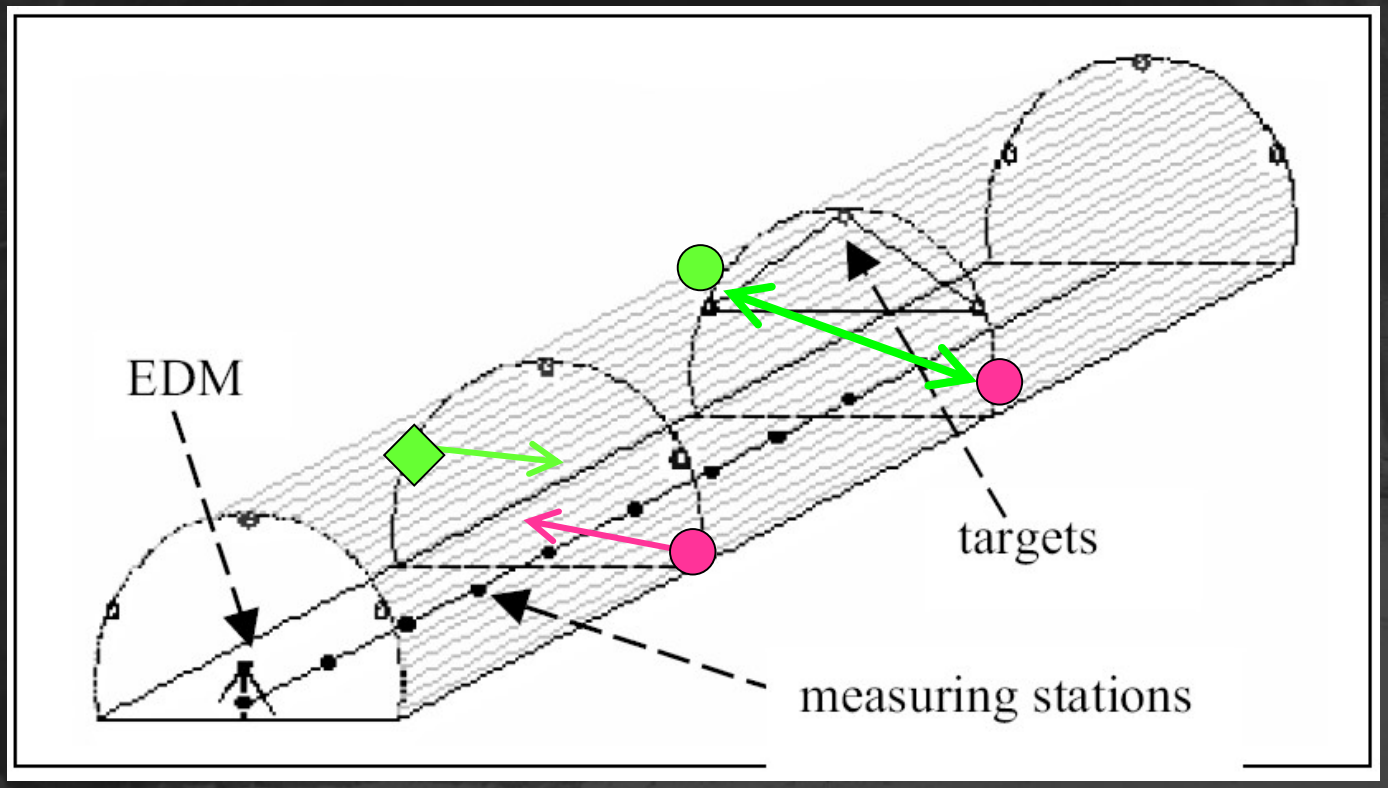
Usually five removable reflexive target are fixed and six chords are measured (full section)





Total station is used

Measuring section are fixed at distance between 25 and 50 m. Section can be increased if required by local bad contition of the rock or in case of singolarity (cross passages , big niches)



Reading frequence

Reading frequence have to be evaluated according with behaviour of soil.

A standard procedure can be :

1.First week after excavation : every 1/ 2 days

2.Second week after excavation : twice a week

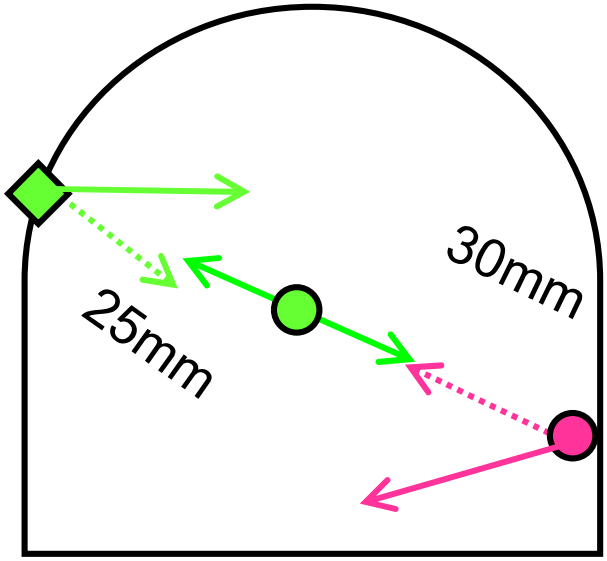
3.Third and fourth week : weekly

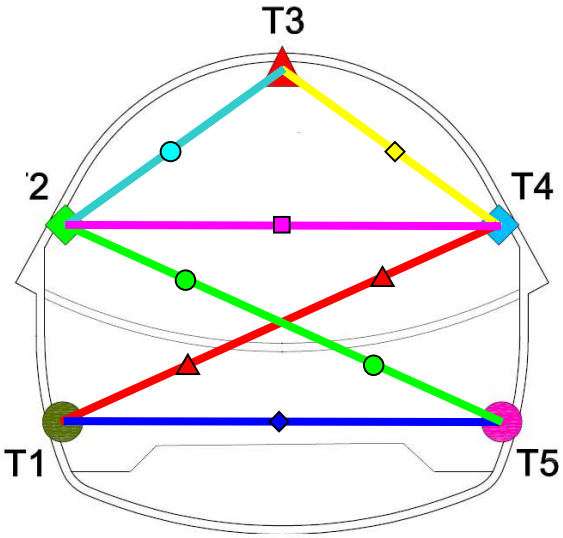
4.Later : monthly and bimontly

Frequency have to be increased or not decreased in case of persisting displacement

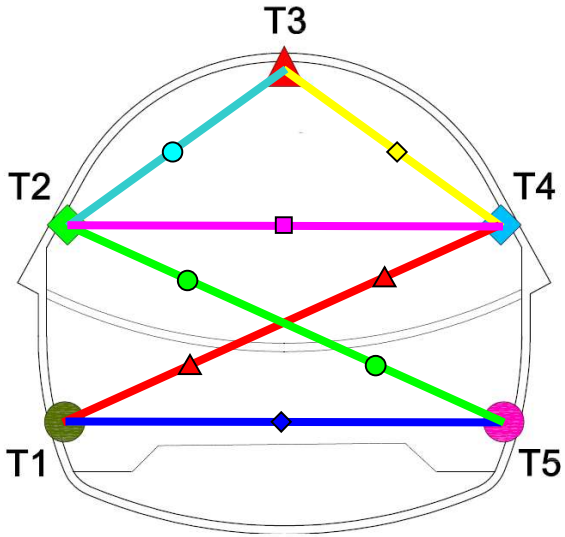
CONVERGENCE

(chord) = 55 mm

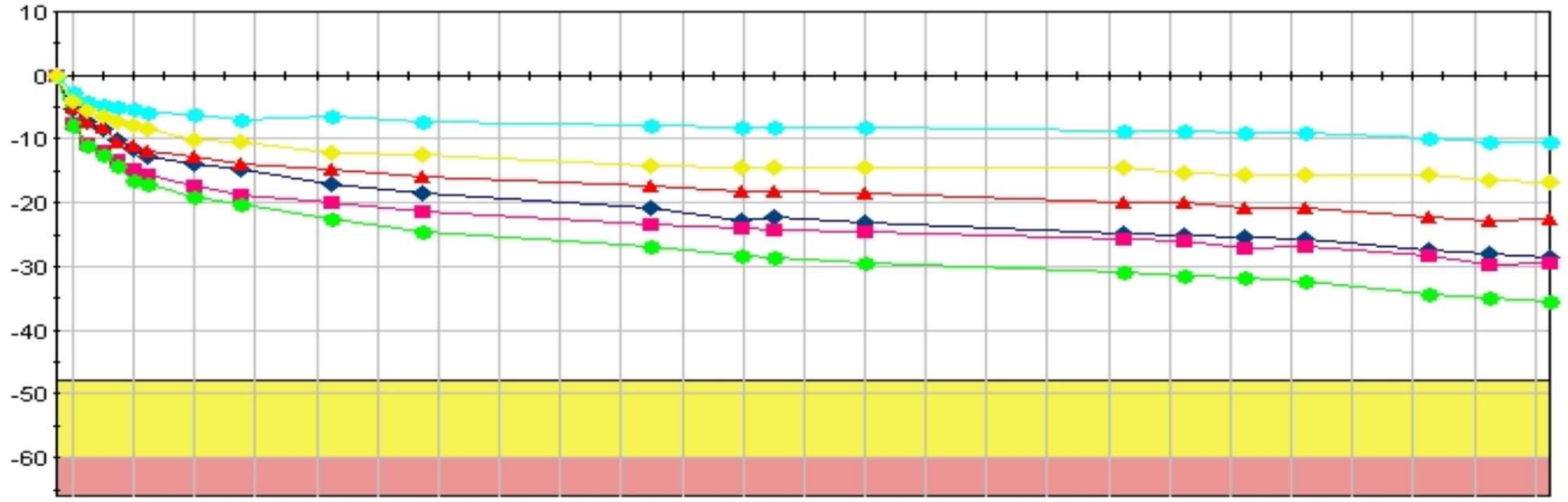




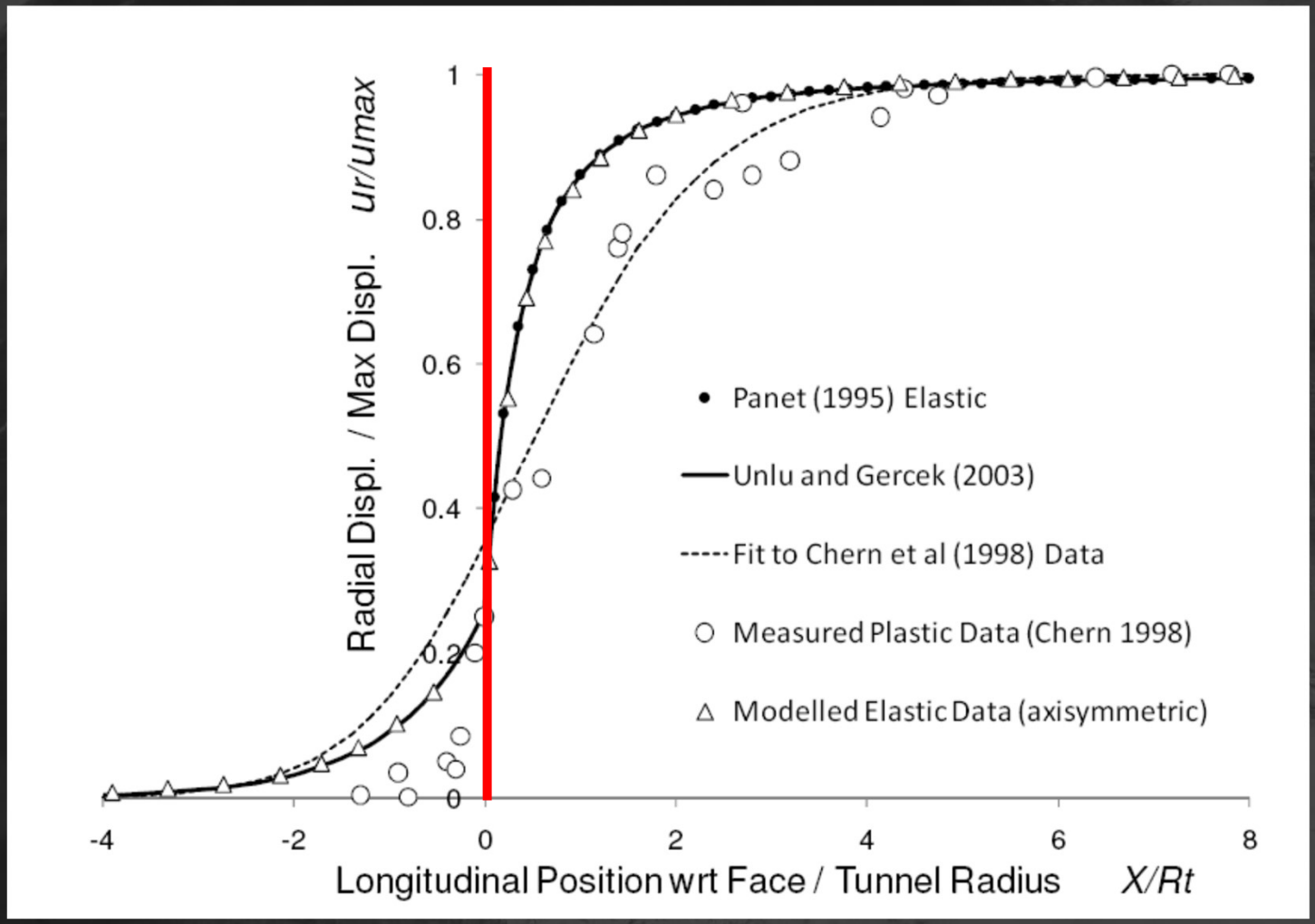
$$chord = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2 + (z_a - z_b)^2}$$



CONVERGENCE Displacement - [mm]



Zero reading



Zero reading

Displacement in one section start mainly immediately after the excavation and decrease along the time .

For this reason is mandatory that zero reading is taken as soon as possible, if possible within 24 hours to avoid lost displacement .

The target have to be removed after reading to avoid to be damaged by successive blasting if any.

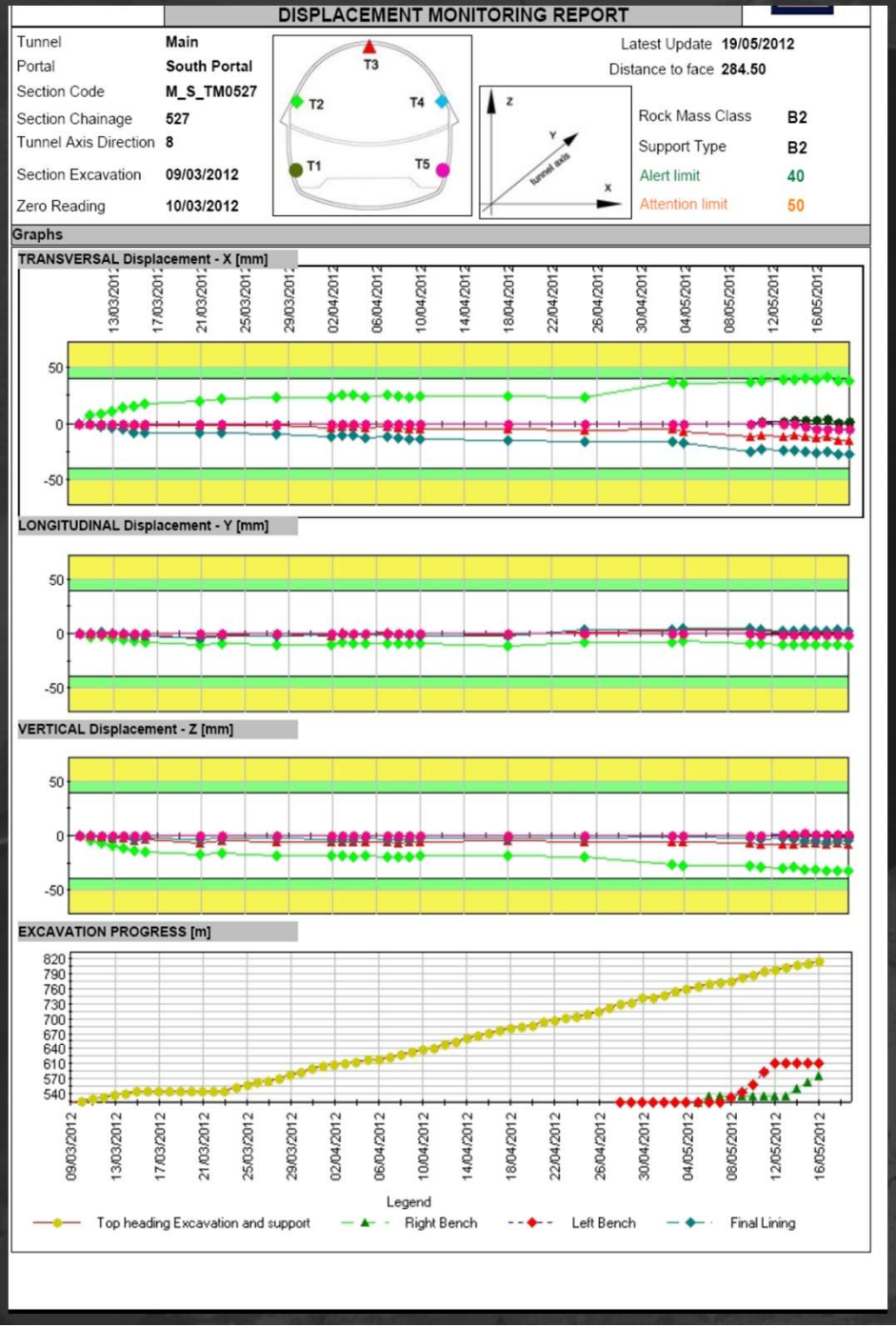
Limits are the value to compare with the data recorded on site

Awareness level: the displacement is within displacement provided in design

Attention limit : The design strenght limit is reached

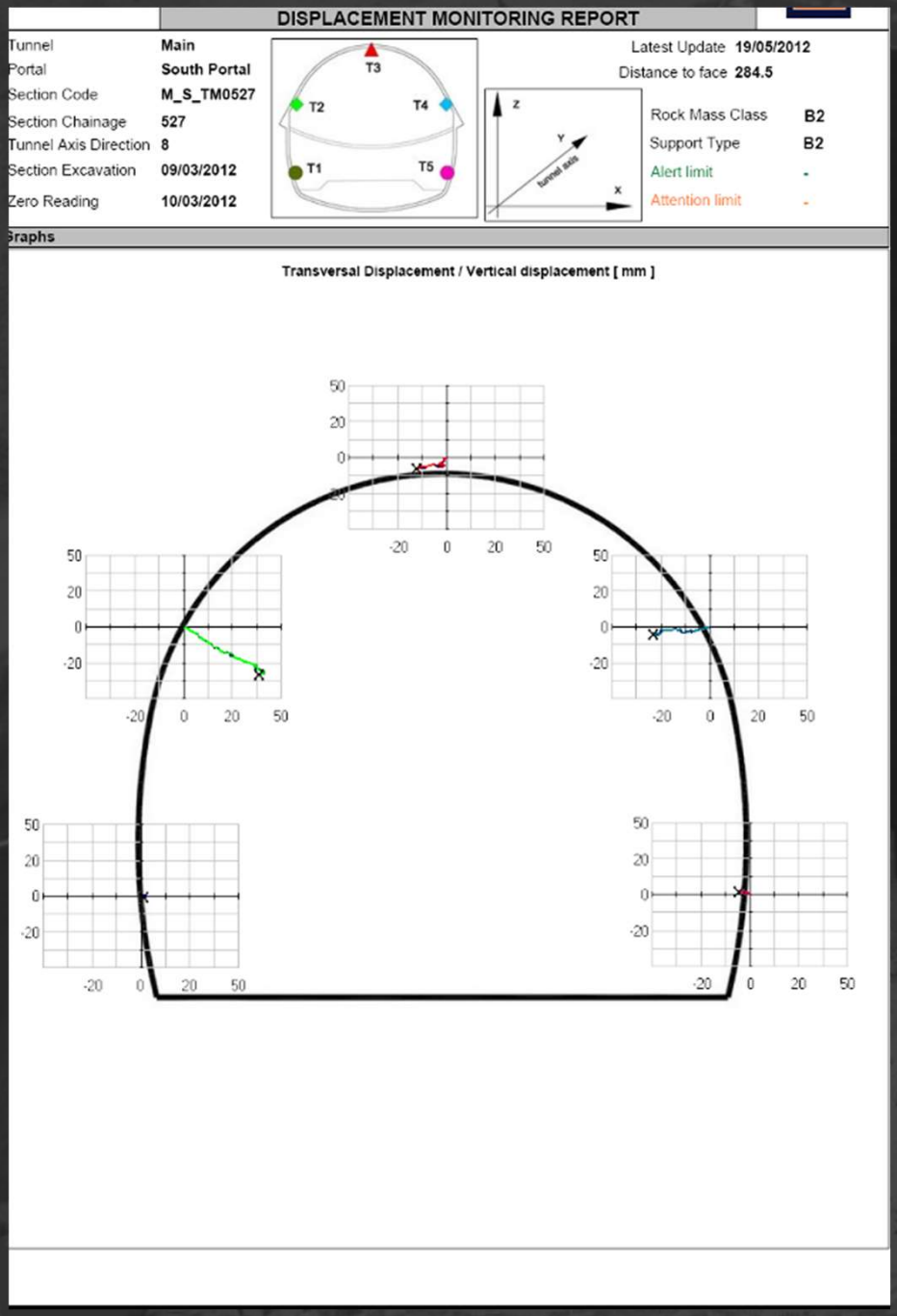
Alarm limit : The design strenght limit is surpassed

Monitoring displacement diagrams



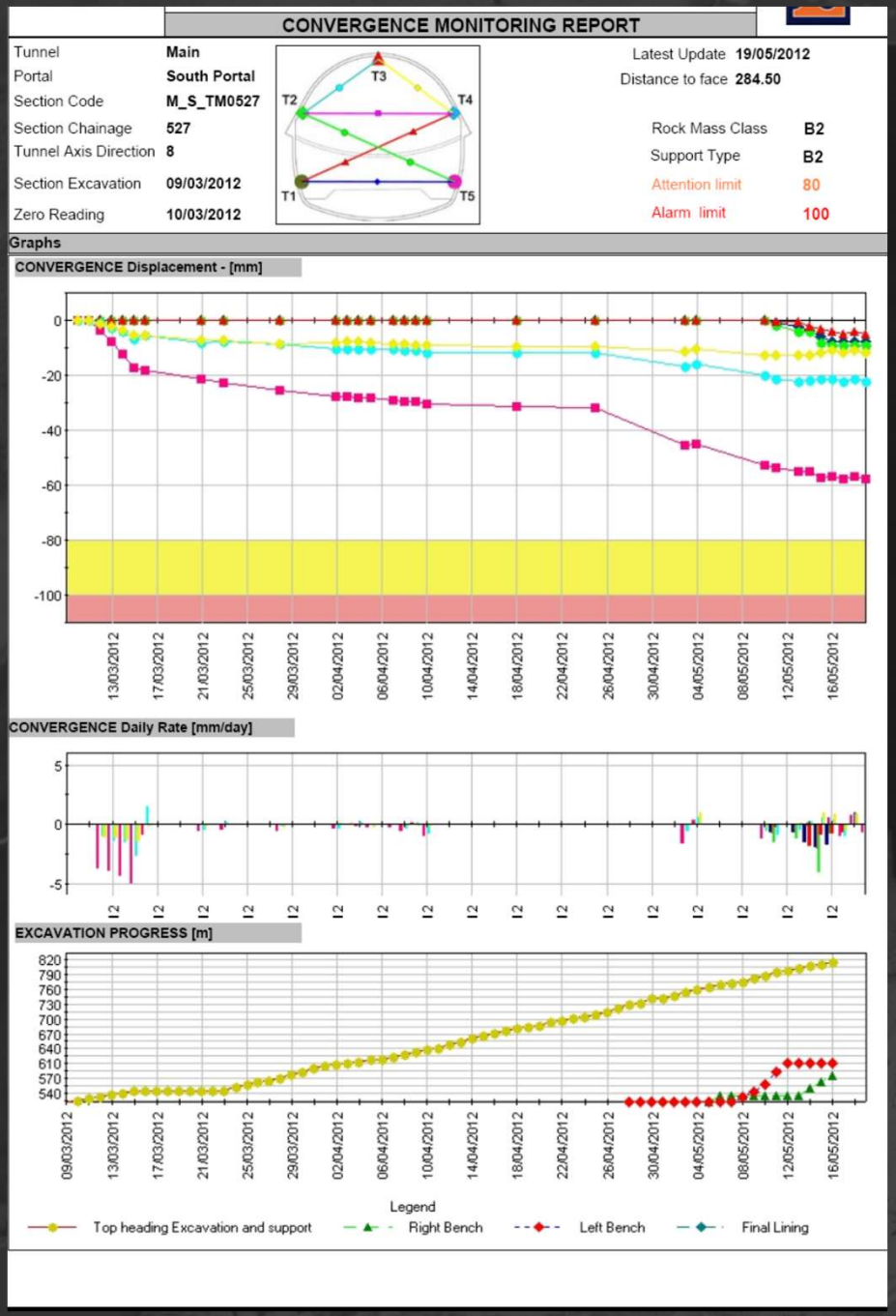
displacement - time

Monitoring displacement diagrams



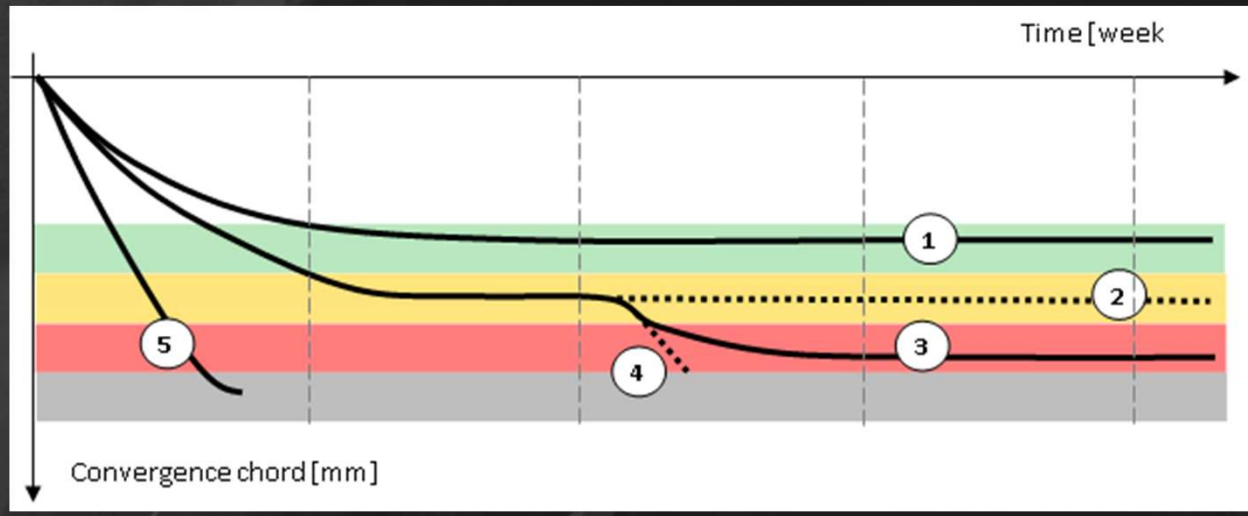
displacement – X Z

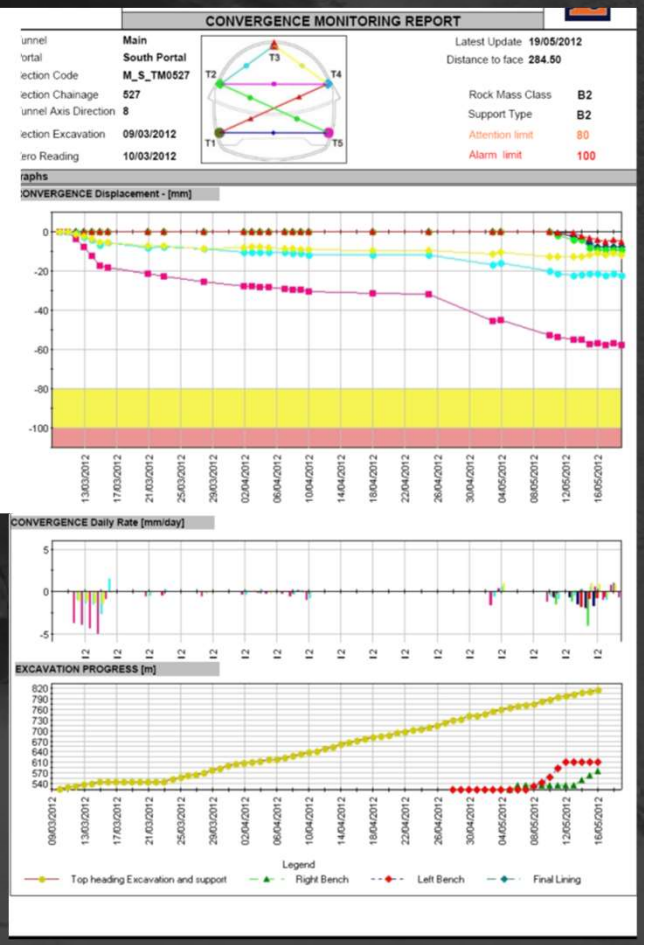
Monitoring displacement diagrams



Convergence (Chord) – time

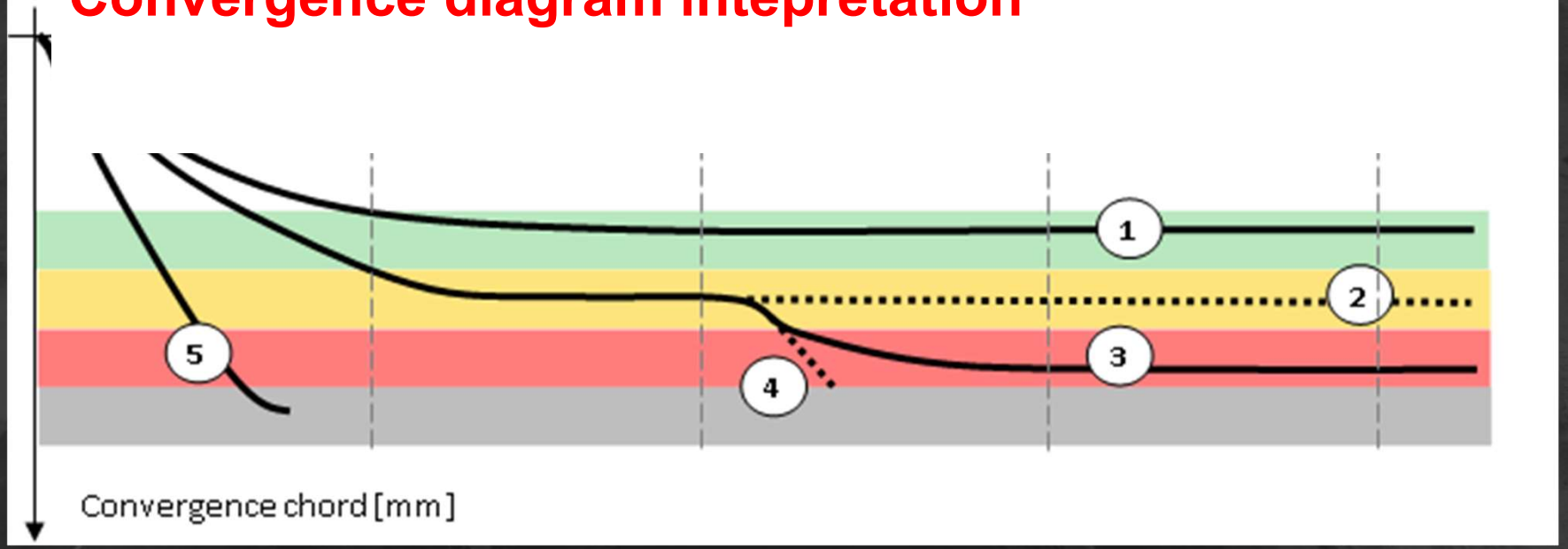
Convergence diagram intepretation





Convergence (NOT DISPLACEMENT) is the best evaluation of the strenght in the support

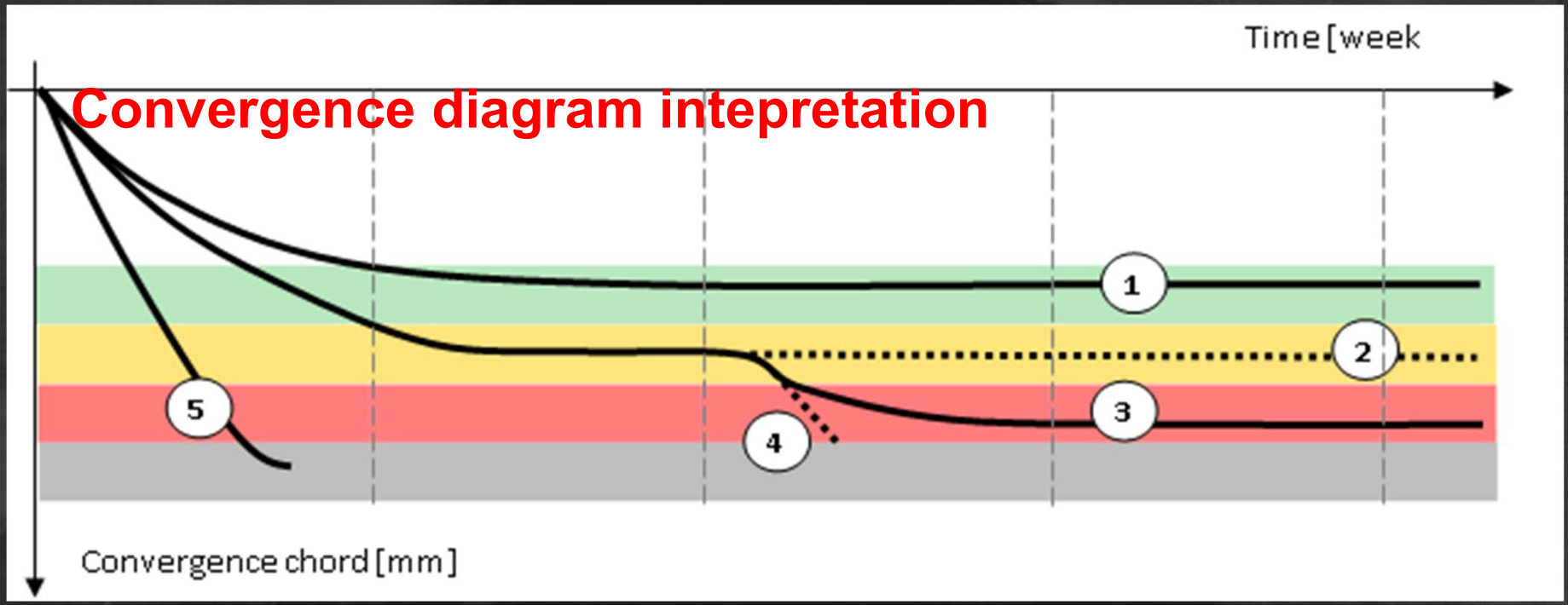
Convergence diagram intepretation



1 – All within awareness limit. The support maybe is conservative

2- Between awareness and attention limit : the support is used in the more efficient way

Convergence diagram intepretation

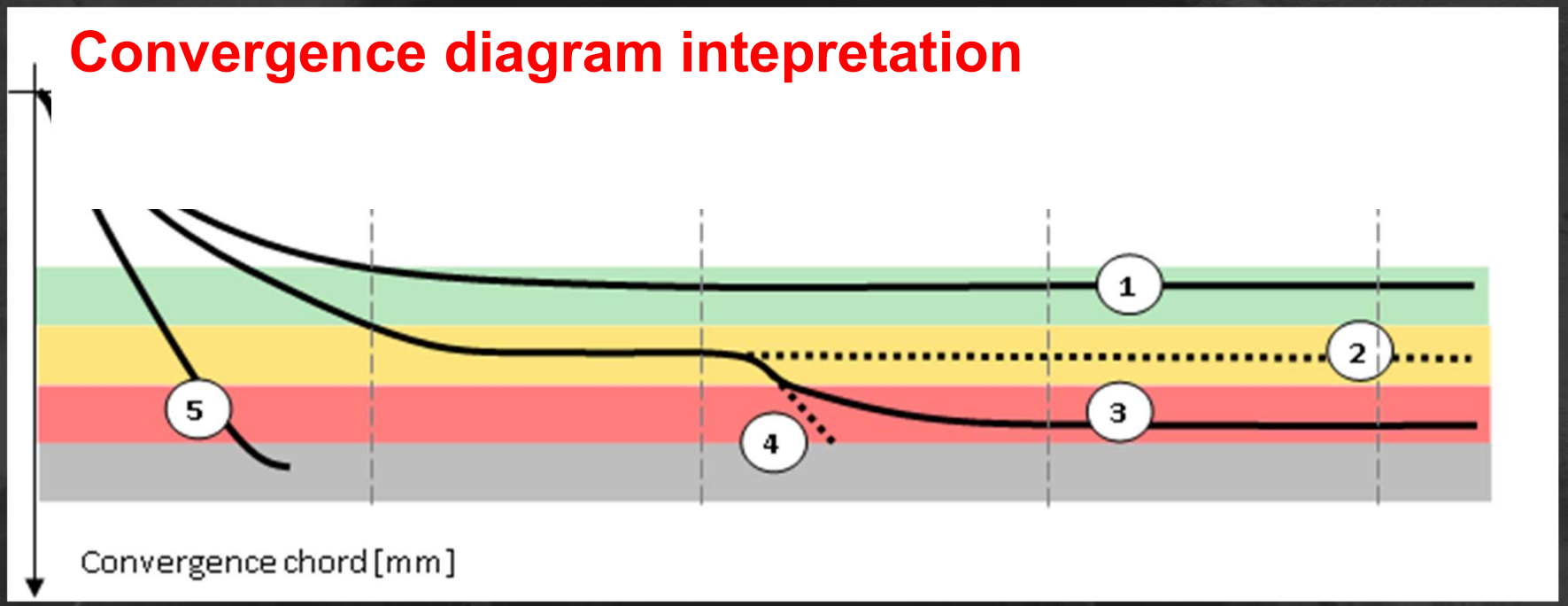


3 – Within alarm limit on way of stabilization . No action only observation .

4- Within alarm limit but on way to cross .

Countemeasures have to been taken (additional rock bolts, scaling if cracks , increased tickness of shoctrete if allowed by final shape of lining

Convergence diagram intepretation



5- Crossing alarm limit. Probably the primary support was underestimate . Immediate countemeasures have to been taken (additional and longer rock bolts, scaling if cracks , increased tickness of shoctrete, rehabilitation of portion)

Countermeasures example

Table 1 *– Summary of ountermeasures*

No	Monitoring section	CM to apply			SUPPORT CLASS	COUNTERMEASURES					
		from (TM)	to (TM)	length (m)		T1	T2	T3	T4	T5	NOTES
1.a	M_N_ TM2260	2240	2260	20	B1		N2	N2			
1.b	M_N_ TM2460	2465	2475	10	B1		N2-1	N2-1			

N2 – scaling + additional bolts (as per ***Figure 3***) + compensation shotcrete

N2-1 – scaling + additional bolts (as per ***Figure 6***) + compensation shotcrete

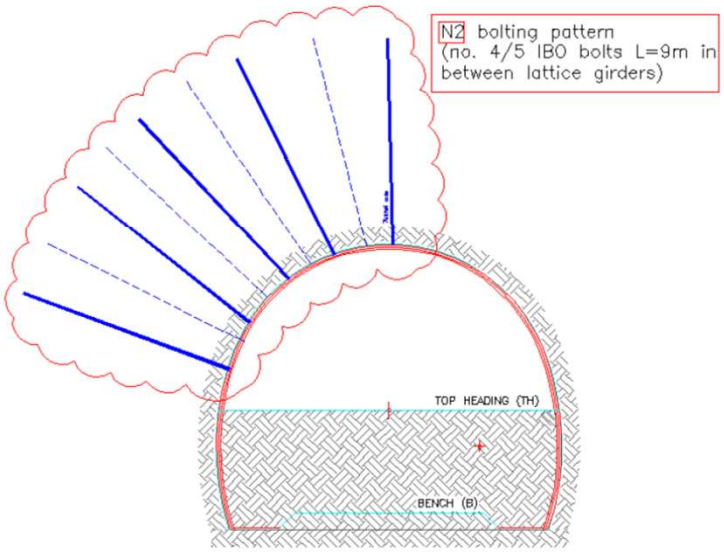
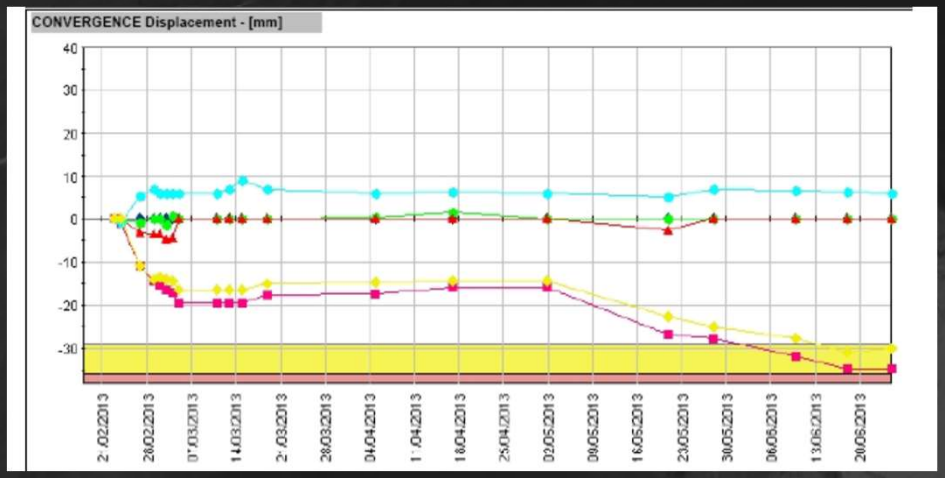


Figure 3 *– Bolting pattern N2*

Countermeasures example

Diagram shows that displacementa are localized in left part of crown : displacement diagrams give information on countermeasures localization.



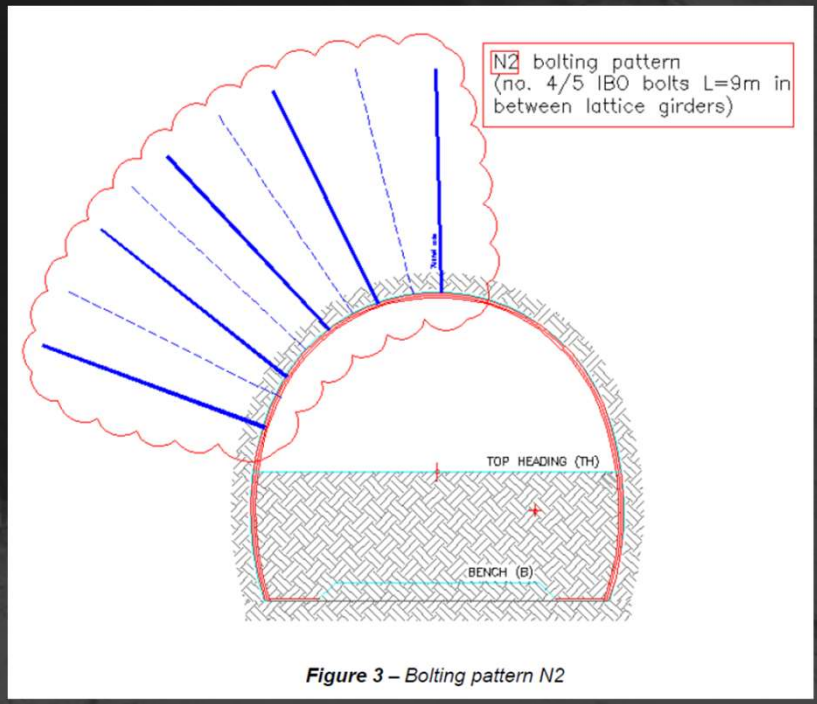


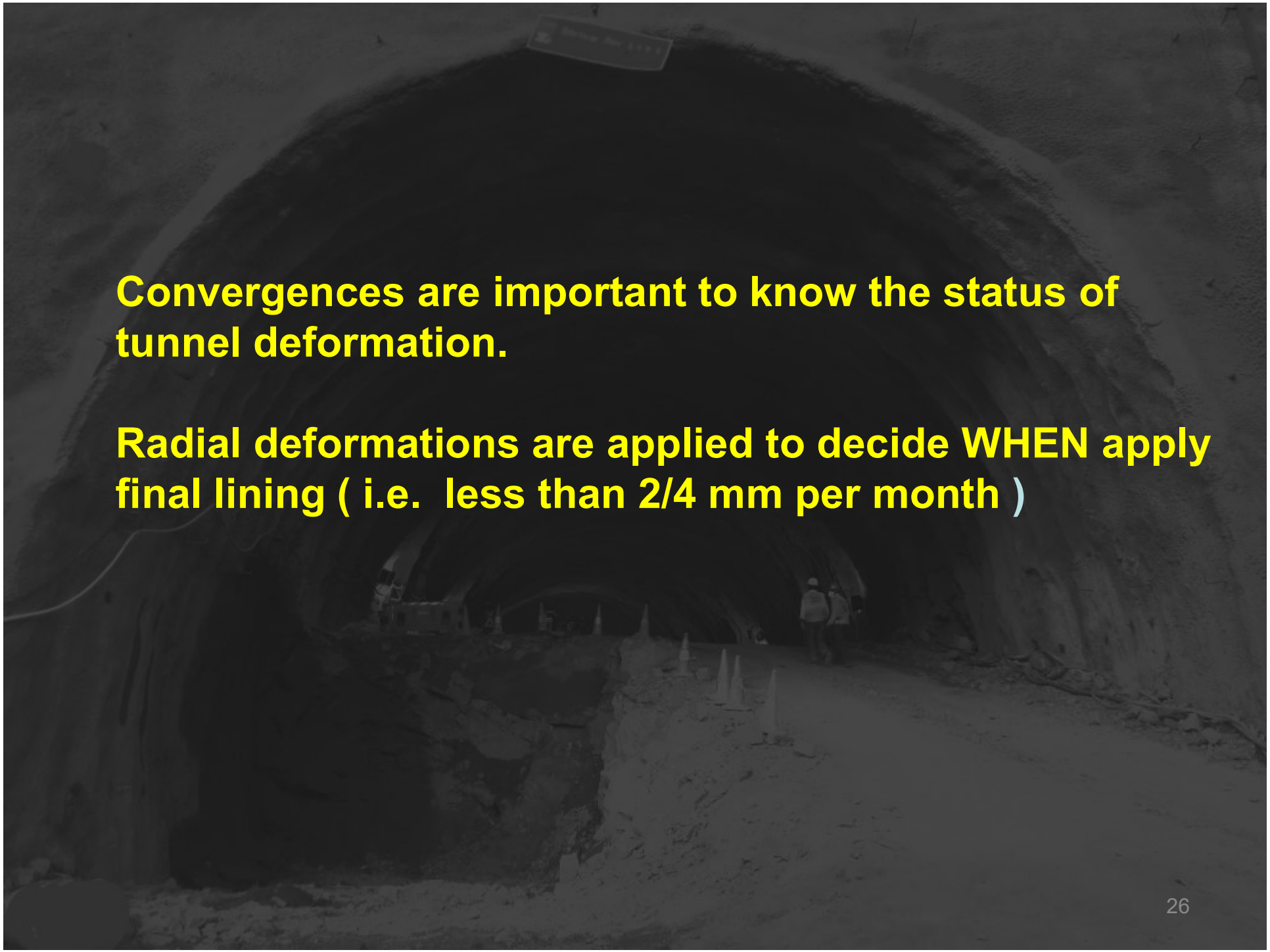
Figure 3 – Bolting pattern N2

GDMS allow to know as soon data are updated the actualized situation of displacements : below example with attention and alarm limits overtaked

Section	Last Update	Support Type	Convergence Last Maximum Value [mm]	Last Month Normal Delta Convergence [mm]	T1 [mm]	T2 [mm]	T3 [mm]	T4 [mm]	T5 [mm]
M_N_TM0628 Time / XZ / Long Disp / Long Conv	14/07/2013	B1*	-14.2	-1.12	0.51	0.06	0.47	0.32	0.46
M_N_TM0660 Time / XZ / Long Disp / Long Conv	11/07/2013	B1*	-63.9	-2.42	0.12	0.68	1.67	2.73	2.84
M_N_TM0680 Time / XZ / Long Disp / Long Conv	11/07/2013	B1*	-19.2	-1.16	25.60	3.16	0.00	5.25	2.89
M_N_TM0735 Time / XZ / Long Disp / Long Conv	11/07/2013	B1*	-51.7	-1.67	0.88	0.45	0.00	2.73	2.26
M_N_TM0790 Time / XZ / Long Disp / Long Conv	22/06/2013	B1*	-30.1	-1.84	0.10	0.00	0.97	0.80	2.17
M_N_TM0845 Time / XZ / Long Disp / Long Conv	11/07/2013	B1*	-13.8	-0.73	0.00	0.33	0.81	1.00	0.08
M_N_TM0900 Time / XZ / Long Disp / Long Conv	16/04/2013	B1*	-11.1	-0.80	0.08	0.00	0.00	0.00	0.67
M_N_TM0955 Time / XZ / Long Disp / Long Conv	08/07/2013	B1*	-13.7	-2.03	1.92	0.36	0.88	0.36	0.03
M_N_TM1005 Time / XZ / Long Disp / Long Conv	03/07/2013	B1*	-9.3	-0.52	0.38	0.49	0.00	0.00	0.00
M_N_TM1055 Time / XZ / Long Disp / Long Conv	04/06/2013	B1*	-15	-0.83	1.46	2.39	0.00	1.34	1.39
M_N_TM1105 Time / XZ / Long Disp / Long Conv	02/07/2013	B1*	-24.5	-1.54	0.00	1.30	0.73	1.30	1.34

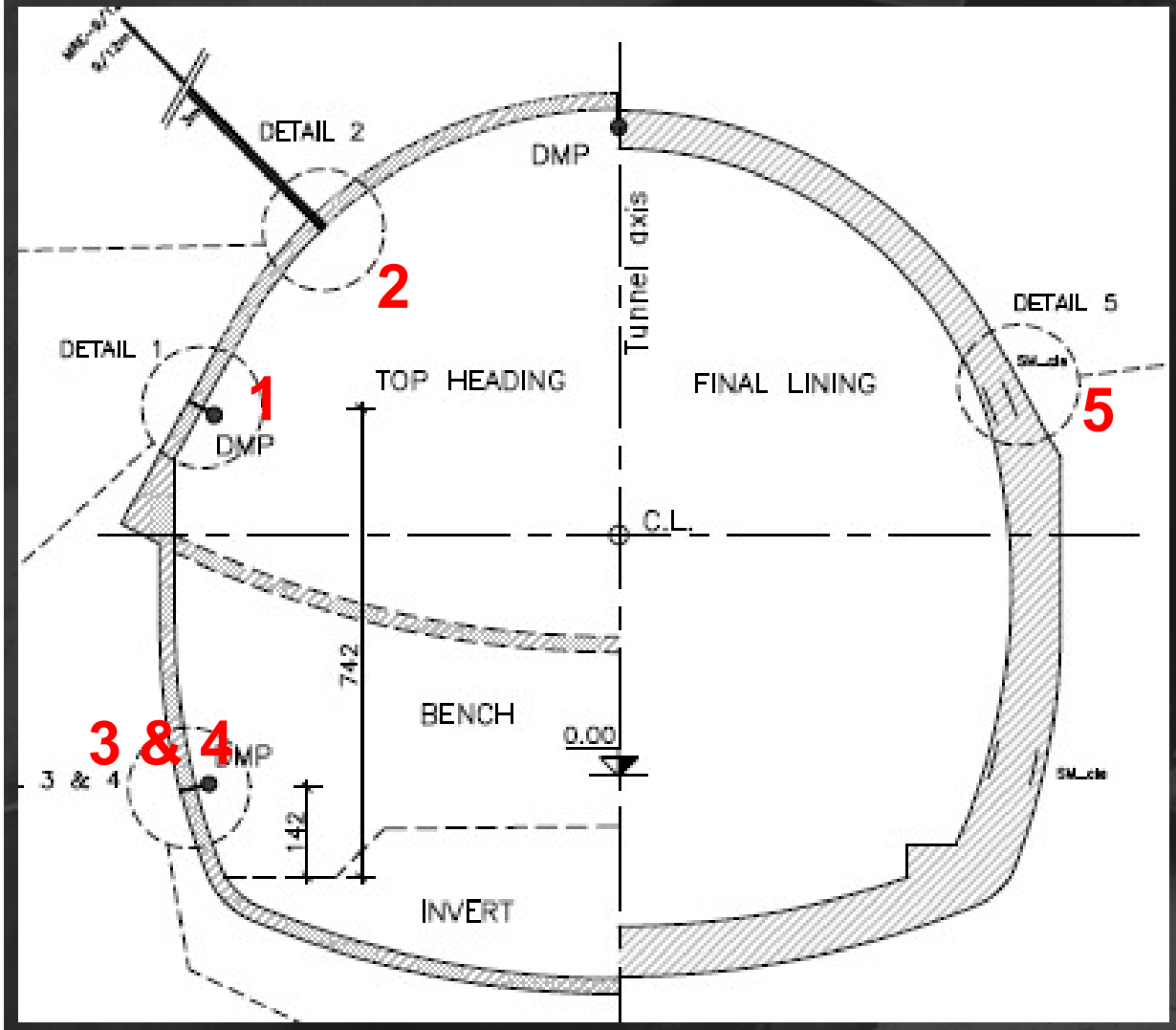
Example of diagram

Section	Last Update	Support Type	Convergence Last Maximum Value [mm]	Last Month Delta					
				Convergence [mm]	T1 [mm]	T2 [mm]	T3 [mm]	T4 [mm]	T5 [mm]
M_N_TM0022 Time / XZ / Long Disp / Long Conv	20/05/2012	B1*	-3.8	-0.77	3.24	2.89	3.96	3.60	2.13
M_N_TM0078 Time / XZ / Long Disp / Long Conv	30/04/2012	B1*	-5.8	-0.94	1.26	1.26	2.00	1.86	0.00
M_N_TM0133 Time / XZ / Long Disp / Long Conv	17/05/2012	B1*	-15.8	-1.73	2.55	2.93	2.10	2.08	5.87
M_N_TM0185 Time / XZ / Long Disp / Long Conv	17/05/2012	B1*	-2.1	-1.50	3.04	1.58	2.47	2.77	2.85
M_N_TM0212 Time / XZ / Long Disp / Long Conv	12/05/2012	B1*	-10.8	-1.30	0.00	1.00	2.83	1.98	0.00
M_N_TM0261 Time / XZ / Long Disp / Long Conv	22/05/2012	B1*	-15.5	-3.94	3.12	1.28	0.87	1.58	0.00
M_N_TM0287 Time / XZ / Long Disp / Long Conv	25/05/2012	B1*	-29	-3.21	0.00	6.56	0.84	0.57	0.00
M_N_TM0310 Time / XZ / Long Disp / Long Conv	25/05/2012	B1*	-11.7	-4.58	0.00	3.11	0.84	2.67	1.08
M_N_TM0370 Time / XZ / Long Disp / Long Conv	15/05/2012	B1*	-14.9	-10.20	1.98	0.99	0.99	4.94	9.04
M_N_TM0422 Time / XZ / Long Disp / Long Conv	22/05/2012	B1*	-7.9	-6.44	0.00	1.09	1.30	5.63	2.65
M_N_TM0470 Time / XZ / Long Disp / Long Conv	23/05/2012	B1*	-8.5	-9.84	0.00	1.79	6.53	8.17	0.00
M_N_TM0520 Time / XZ / Long Disp / Long Conv	16/05/2012	B1*	-9.4	-2.90	0.00	11.73	10.84	9.11	0.00
M_N_TM0556 Time / XZ / Long Disp / Long Conv	23/05/2012	B1*	-5.3	-5.30	0.00	3.84	2.59	9.23	0.00



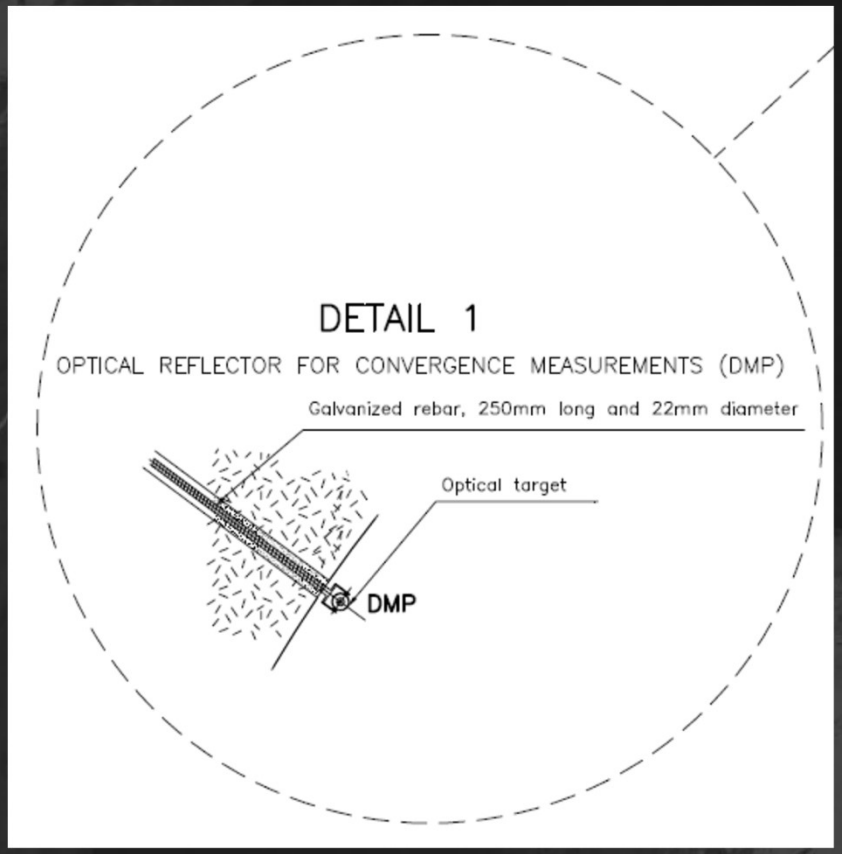
Convergences are important to know the status of tunnel deformation.

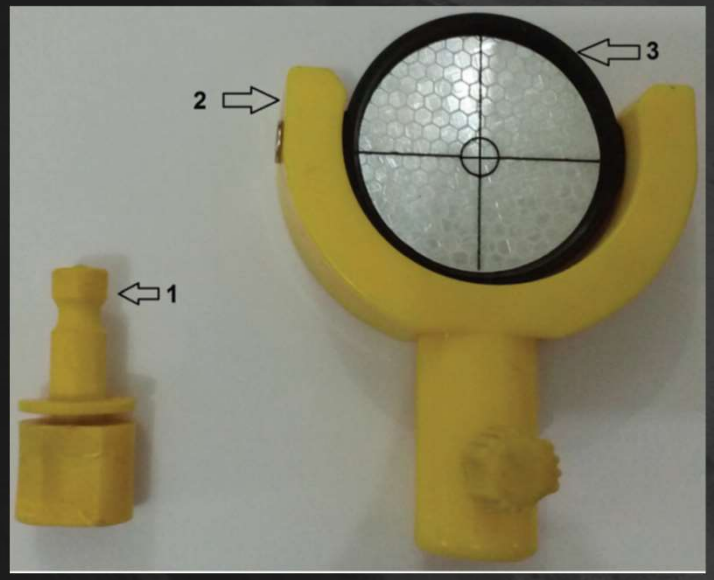
Radial deformations are applied to decide WHEN apply final lining (i.e. less than 2/4 mm per month)



1Optical target
2 Multipoint extensometer
3 Vibrating wire Strain gauges
4Radial Pressure cell
5 Vibrating wire Strain gauges in final lining

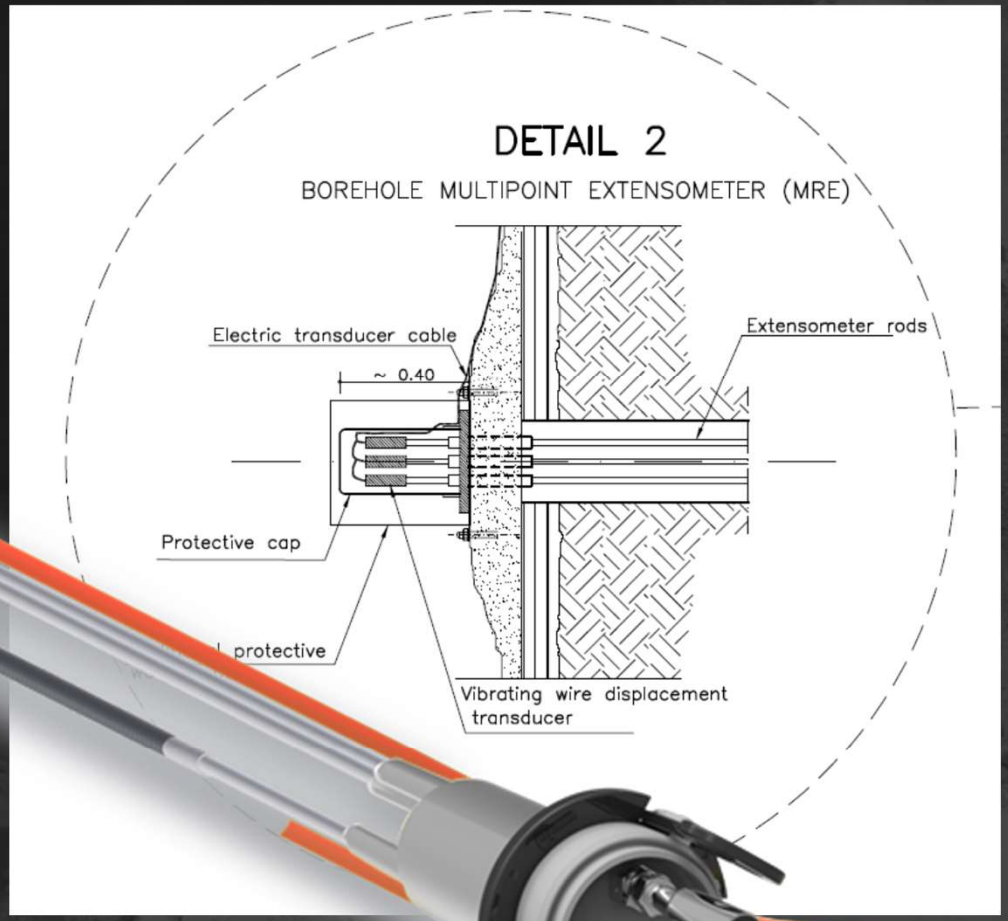
1 Optical target



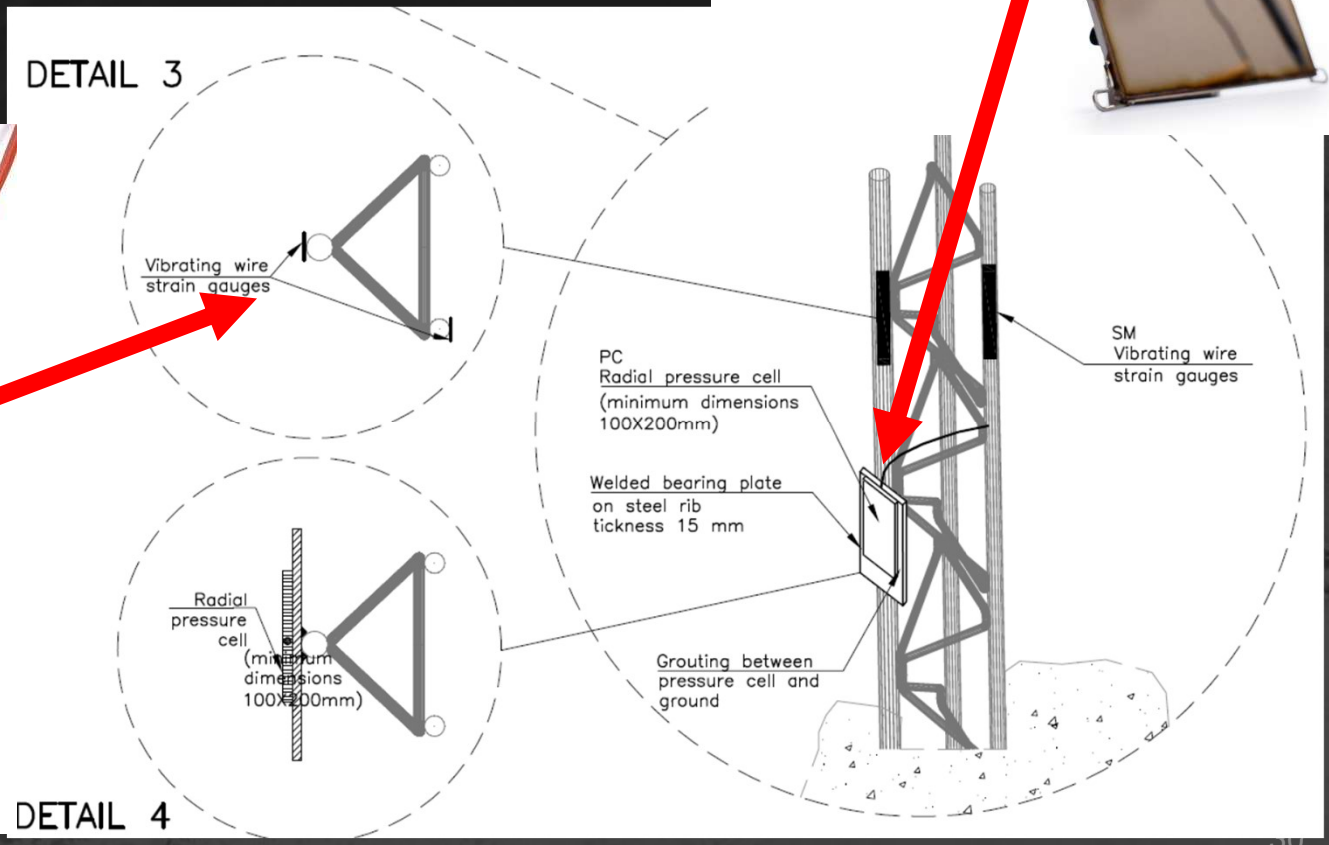


Optical target is removable to avoid damage during blasting

2 Multipoint extensometer (3-9-12 m)



3 Vibrating wire Strain gauges ESTENSIMETER (to know the stress on the LG reinforcement)
4 Radial pressure cell



5 Vibrating wire Strain gauges (to know the stress on the final lining reinforcement)