5th International Workshop on Design in Civil and Environmental Engineering
Sapienza University of Rome



Design of temporary deep foundation and monitoring for the erection of an arched bridge over an active landslide

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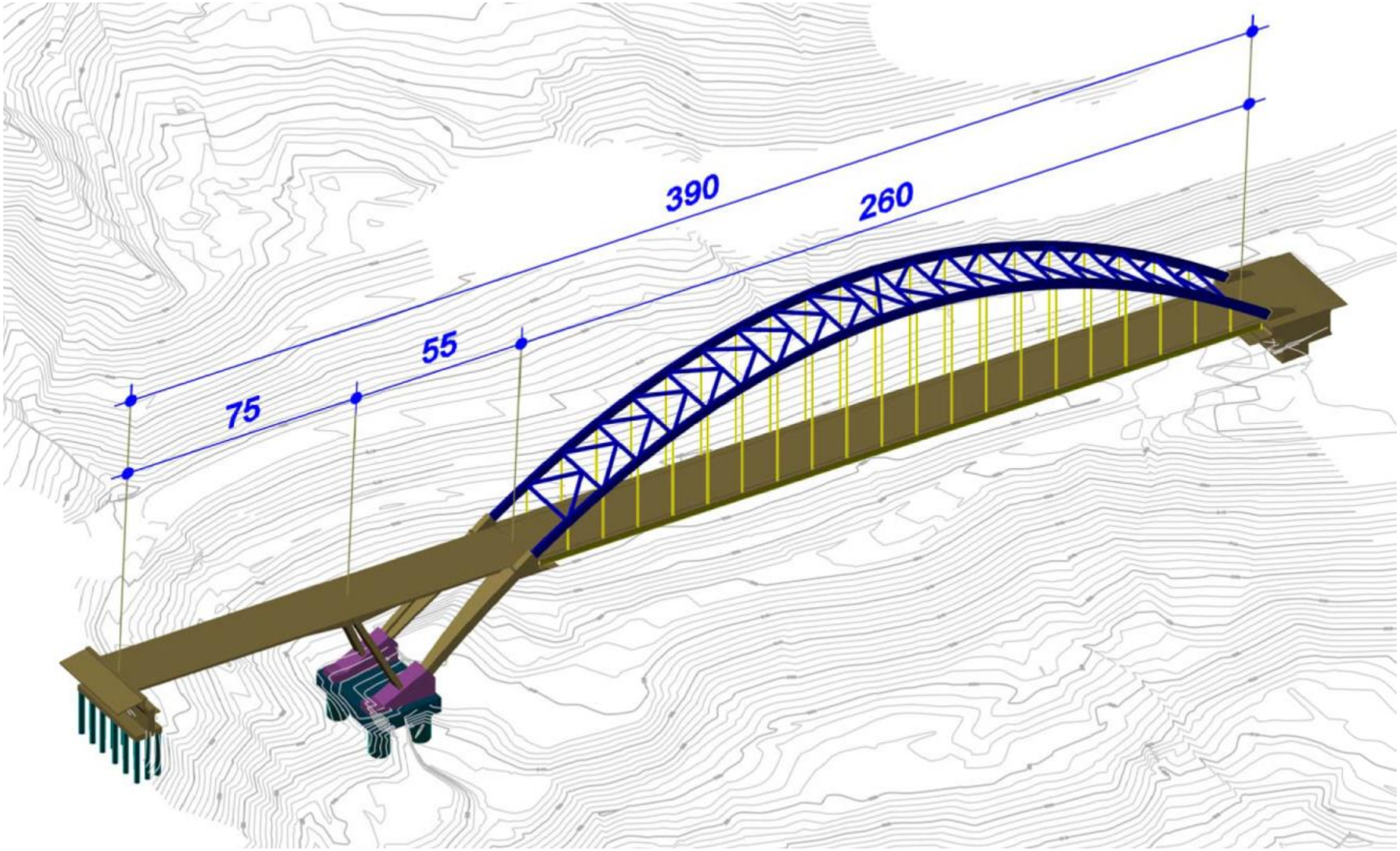
Major landslide event

In 2003 a major landslide destroyed a highway in southern Greece causing a mass displacement of about 6.000.000m^3.

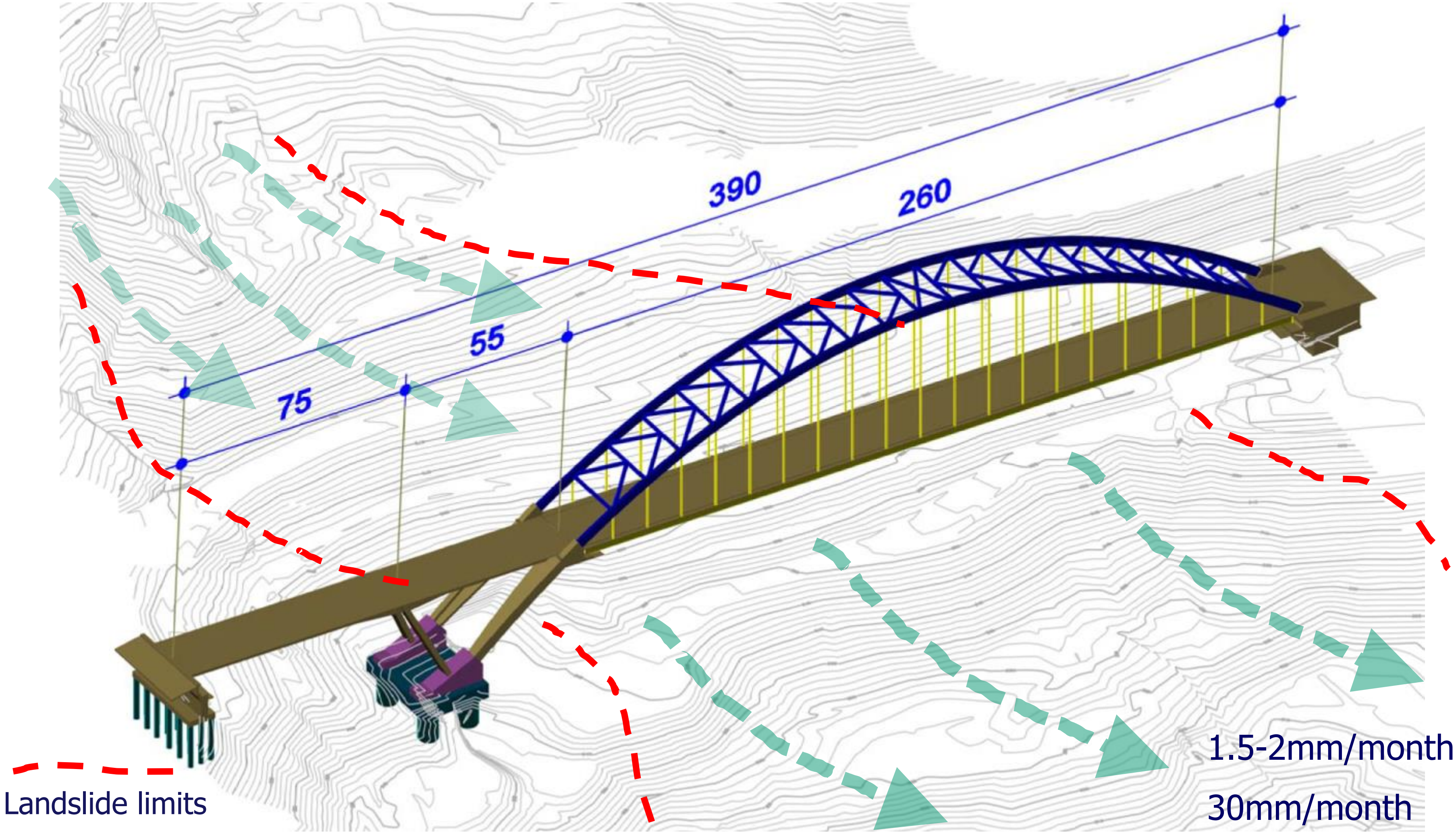
Bridge project

An arched steel bridge was designed over the active landslide creating geotechnical and structural challenges during the construction.

Bridge project

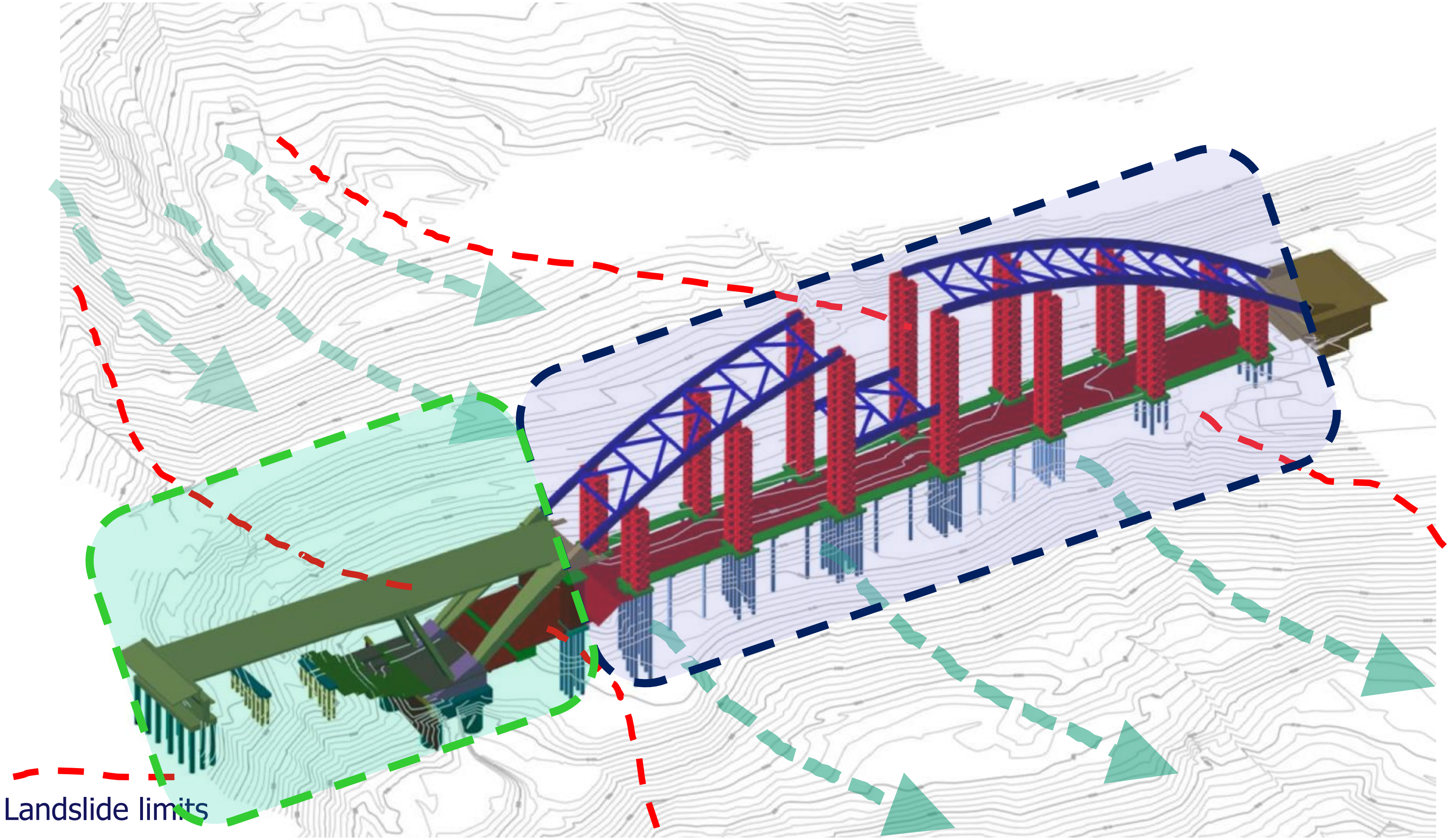


Bridging an active landslide

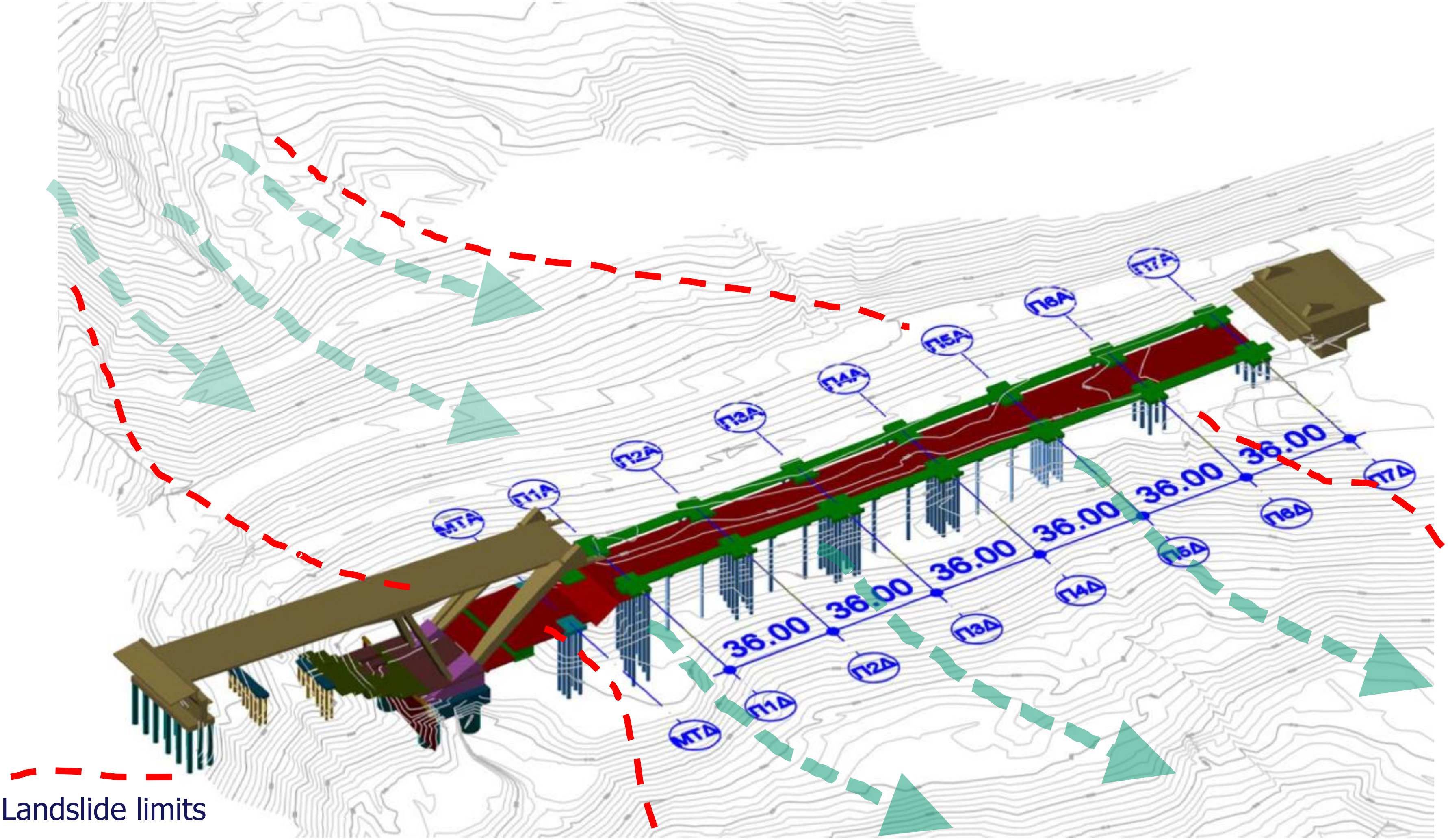


- **INTRODUCTION**
- **TEMPORARY INFRASTRUCTURE PROJECTS**
- **INSTRUMENTATION, MONITORING AND EARLY WARNING SYSTEM**
- **DESIGN OF TEMPORARY INFRASTRUCTURE PROJECTS**
- **THE BRIDGE UNDER CONSTRUCTION**

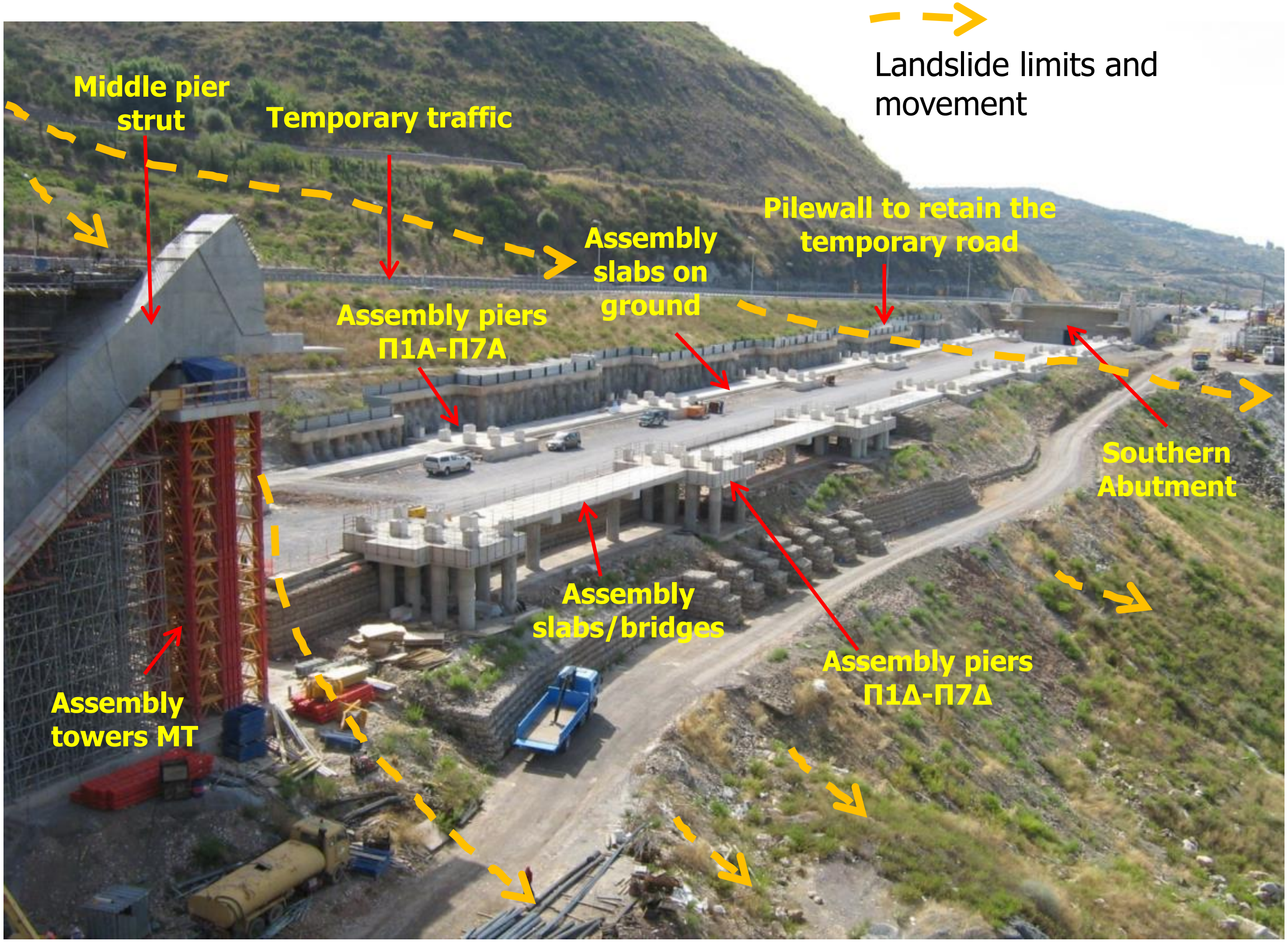
Construction of the superstructure



Foundation of the towers



Infrastructure for the erection of the steel arches



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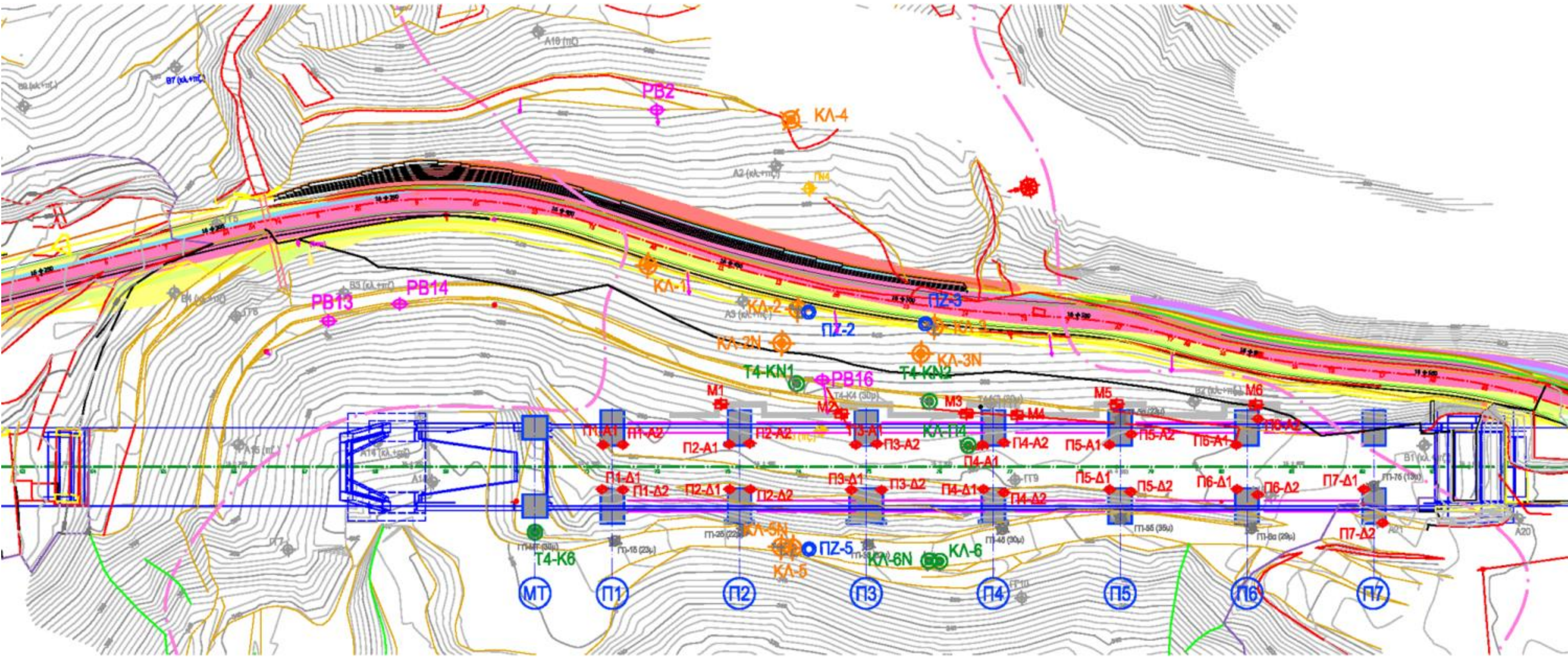
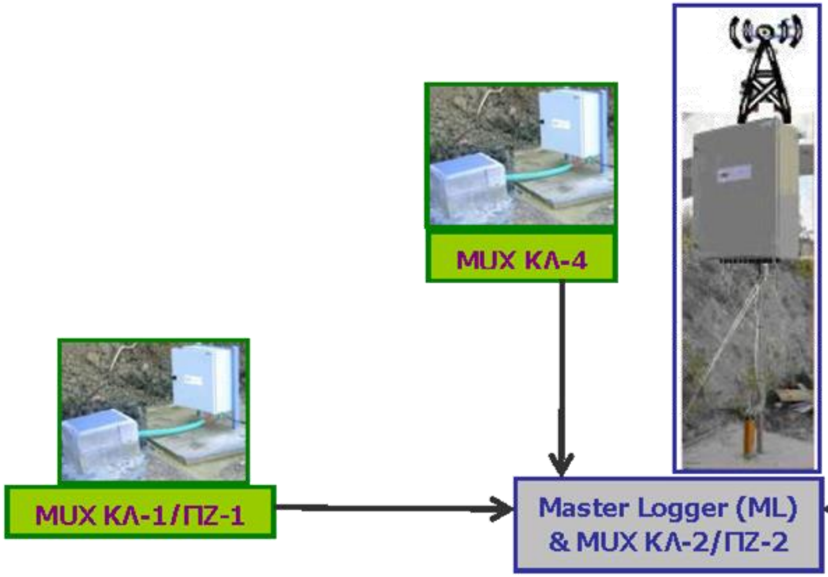
Geotechnical instruments

- 4 optical targets for surface movements
- 26 optical targets for movements of pier foundation
- 6 optical targets for movements of the pile wall
- 4 automated permanent inclinometers
- 3 automated permanent piezometers
- 7 conventional inclinometers
- conventional piezometers



Automated Monitoring - Schematic Function



Data Logger & Modem Scheduled Readings (i.e. every 4 hours)

→ Readings downloaded to server in txt format

→ Programmed spreadsheet collects downloaded data

→ Data elaborated, analyzed and graphs for each instrument is created automatically

→ The updated spreadsheet is uploaded on a shared cloud server and provides the evaluation of the developments at least every 4 hours.

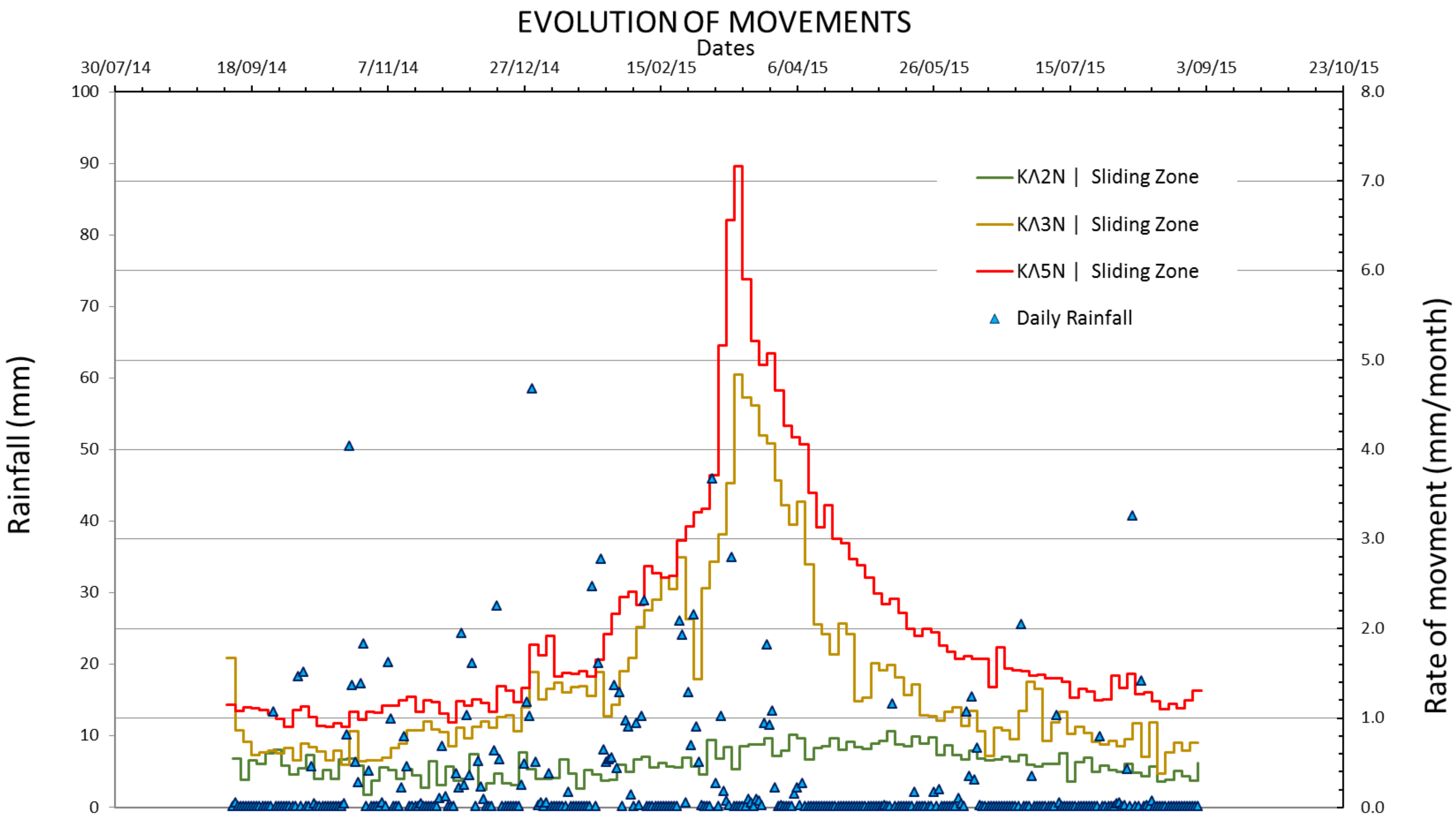
→ Monthly reports submitted

Alarm SMS is released in case the movements exceed the limits **(TSAKONA ALARM)**

→ Extra readings and evaluation performed, instruction for contingency measures provided.

Main conclusions drawn from monitoring results

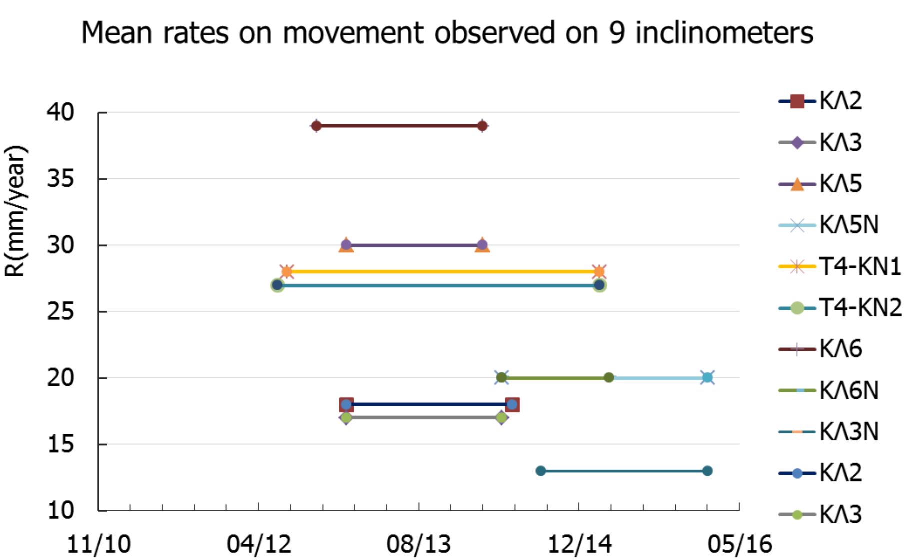
- A seasonal variation of the rate of movement of the slide was noted related to rainfall.

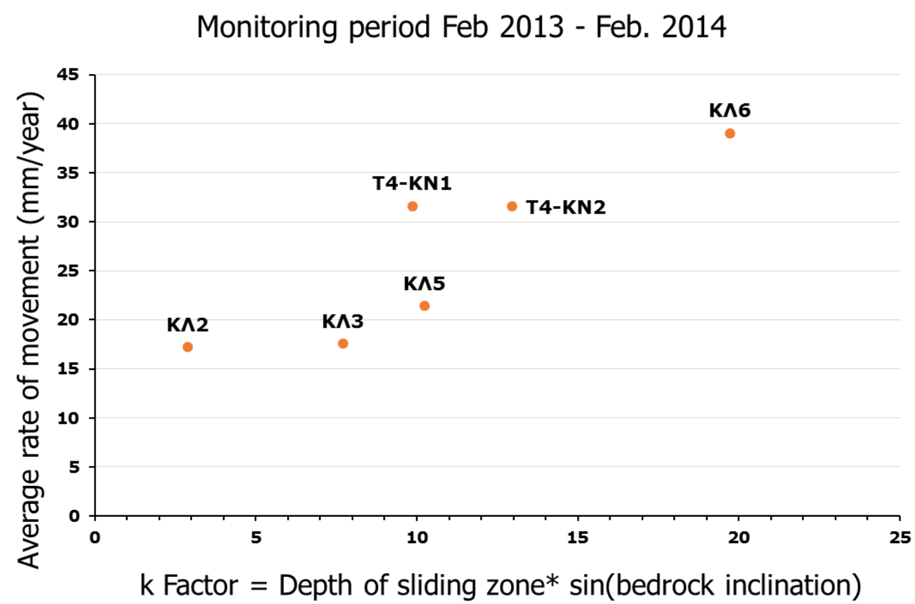


Note: Rate calculated for 3days intervals

Main conclusions drawn from monitoring results

- A seasonal variation of the rate of movement of the slide was noted related to rainfall.
- Differences of the rate of movement were observed among the various monitoring locations (13 - 40mm/year). Factors influencing the rate are the depth of the sliding surface and the inclination of the bedrock surface.





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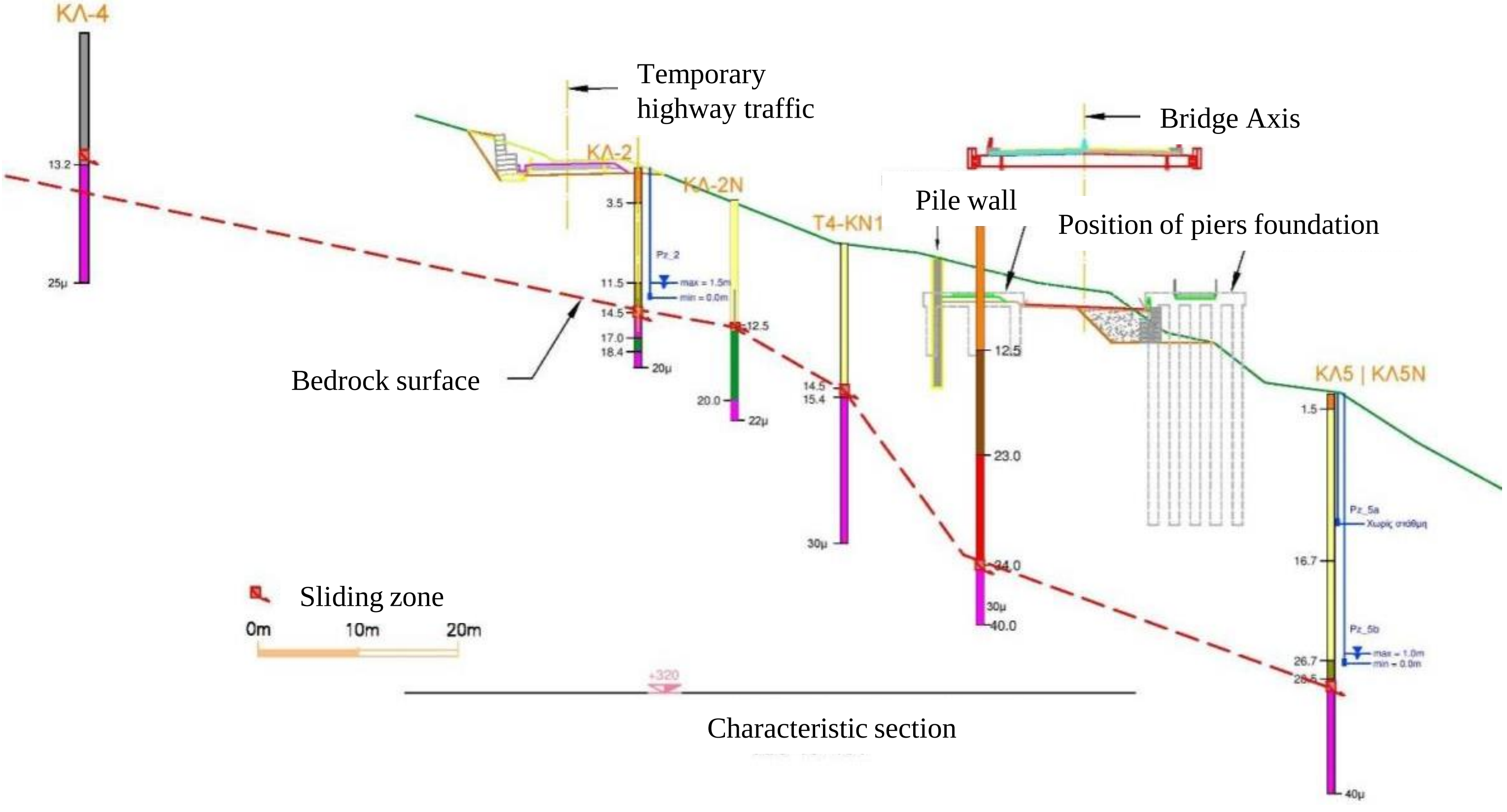

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- A seasonal variation of the rate of movement of the slide was noted related to rainfall.
- Differences of the rate of movement were observed among the various monitoring locations (13 - 40mm/year). Factors influencing the rate are the depth of the sliding surface and the inclination of the bedrock surface.
- Deep movements (inclinometric readings) and surface movements (optical targets movements) were in good agreement.
- For the design of the projects a two years construction period was assumed and the proposed design movement (**transverse** to the bridge axis) was **30mm/year** and for the **longitudinal** direction a total differential movement between temporary piers of about **15mm/year** was considered.

Comparison of Deep Vs Surface movements (28/03/13÷7/03/14)

Location of readings	Depth of sliding zone	Mean total annual movement
Sliding zone T4-KN1 and T4-KN2	15-20m	27mm
Optical targets on pile wall M2, M3, M4	18-22m	25mm
Optical targets on pile caps Π2Α, Π3Α, Π4Α	18-20m	29mm
Optical targets on pile caps Π2Δ, Π3Δ, Π4Δ	30-34m	34mm
Sliding zone ΚΛ5 and ΚΛ6	35-40m	32mm

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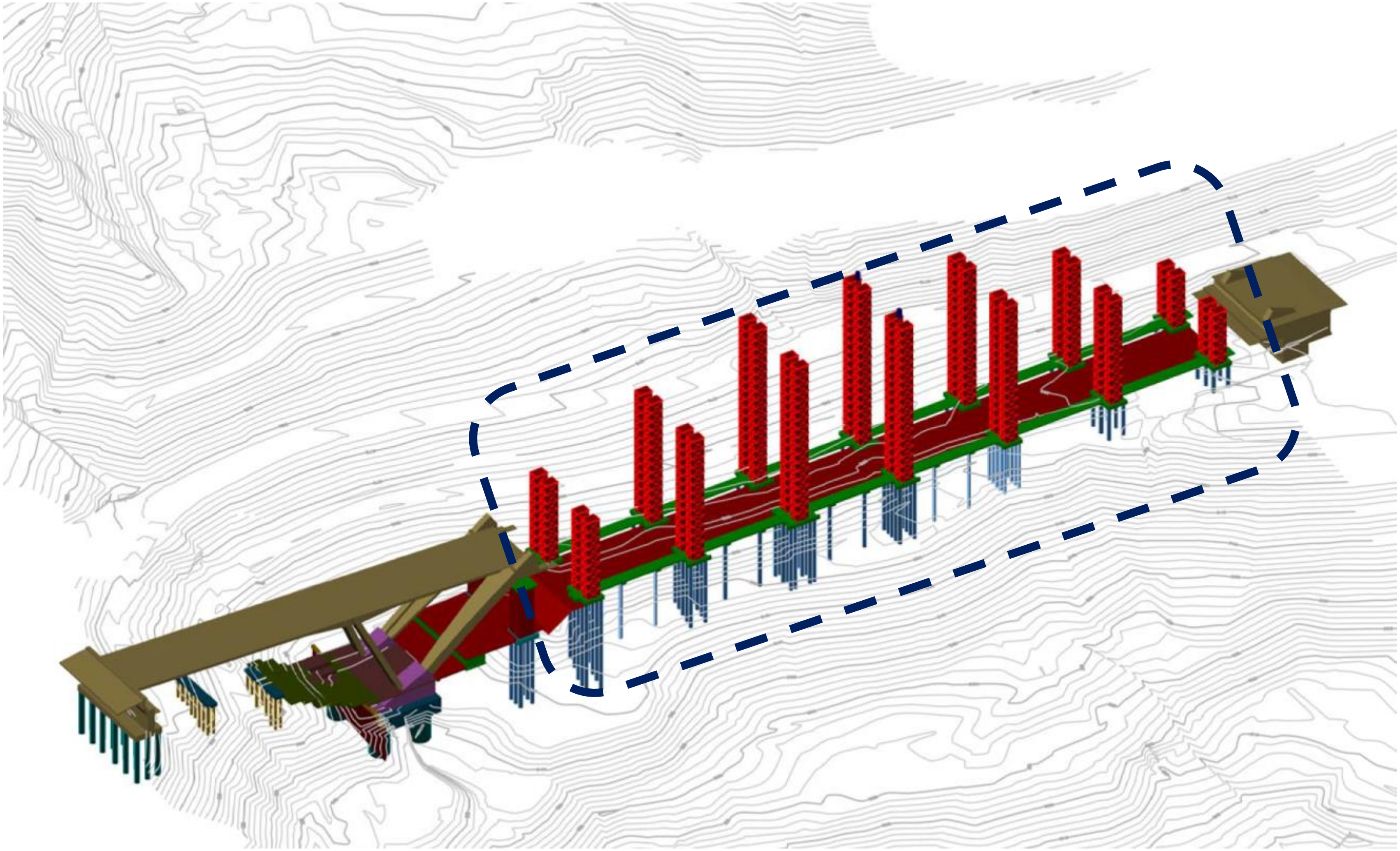
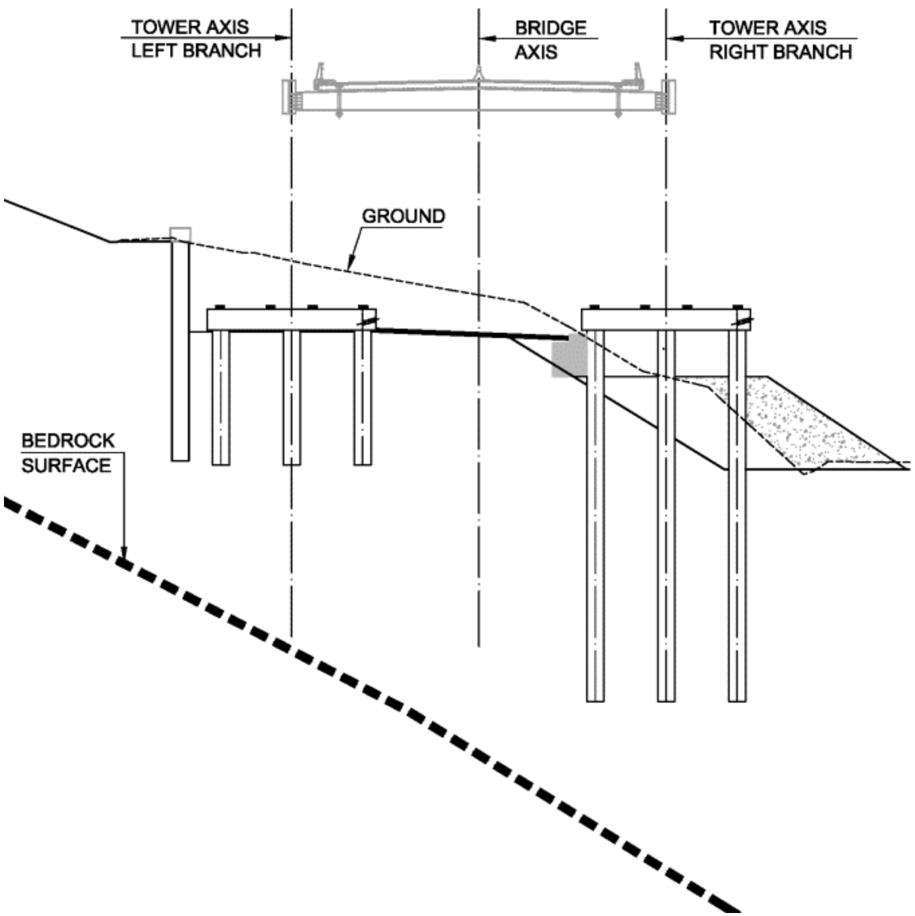
Design of the towers foundation



Assumptions

- Two years of arch construction
- 30mm/year max horizontal movement
- Temporary structures – low cost



Aim

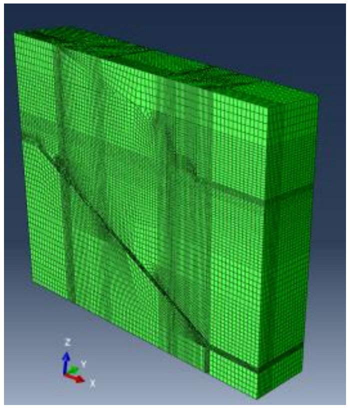
- Not possible to stabilize the landslide
- Safety of the temporary traffic of the highway
- Safe erection of the arch
- Stability and tight accuracy for the welding activities

Design Criteria

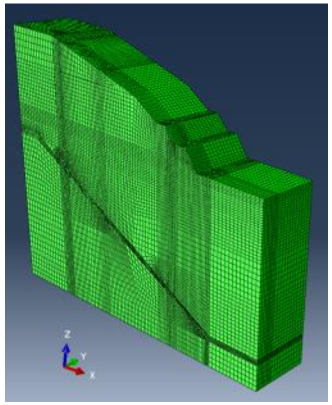
- Deep foundation with pile groups
- Piles in the rock for depth of sliding mass smaller than 5m
- Floating piles in the sliding mass (depth 8m-22m)

Phase 1: 3D geotechnical analysis (guide-model, ABAQUS)

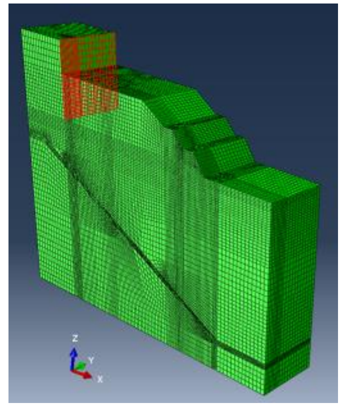
Step 1



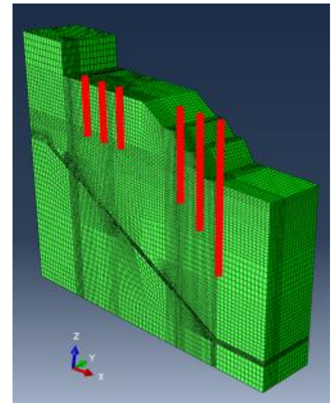
Step 2



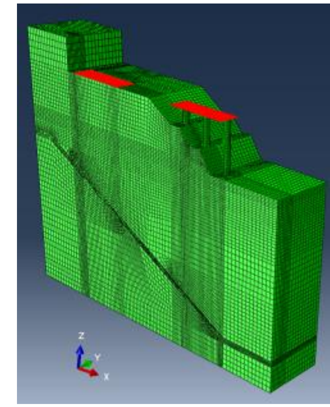
Step 3



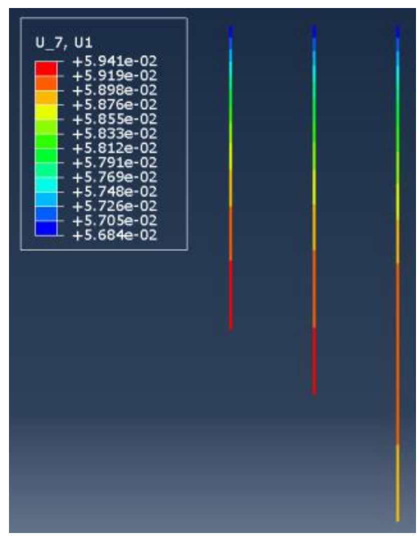
Step 4

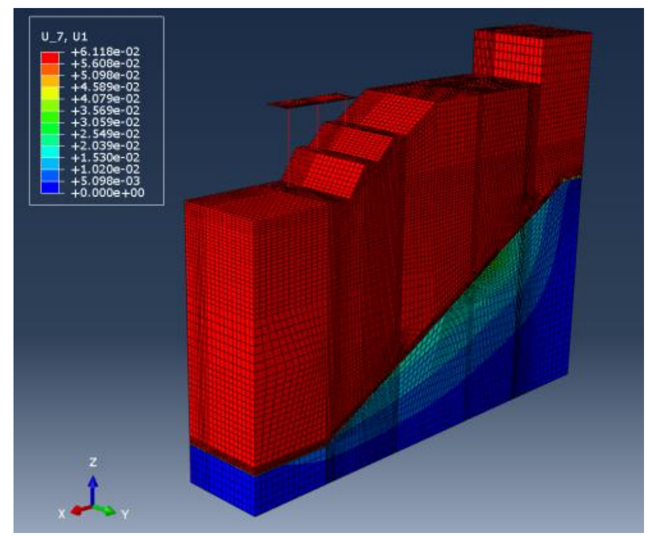


Step 5



The slope movement practically led to a uniform movement of the soil above the failure plane, causing small increase of bending, shear and axial internal forces of the piles. (ΔN=+3.4%, ΔQ=4.2%, ΔM=37.5%)

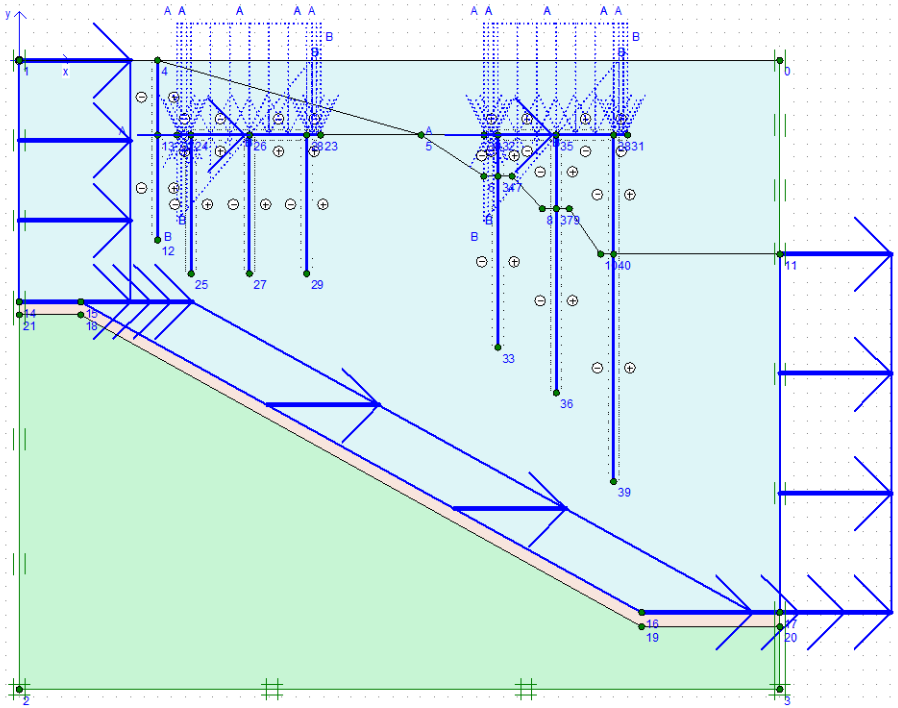




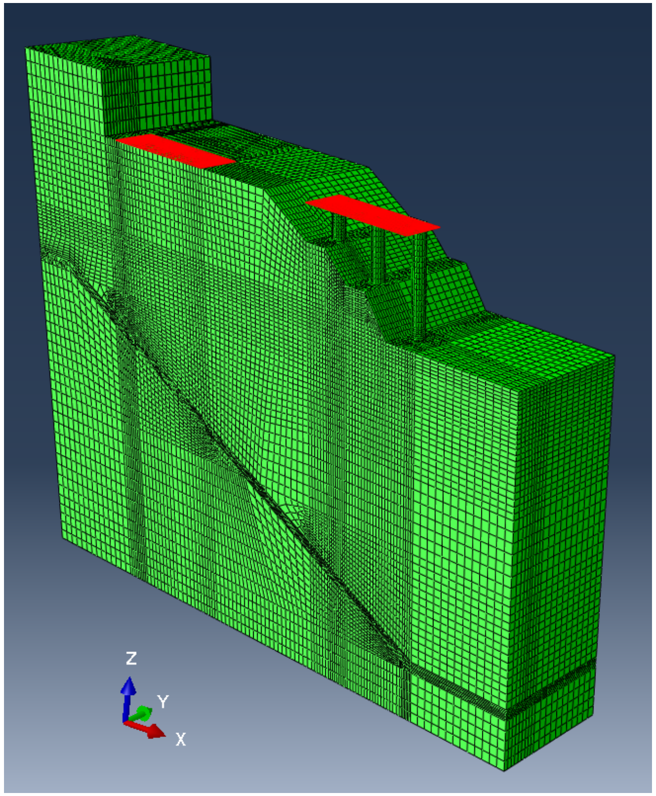
Transverse slope movement

Phase 2: 2D geotechnical analyses (PLAXIS)

Model calibration



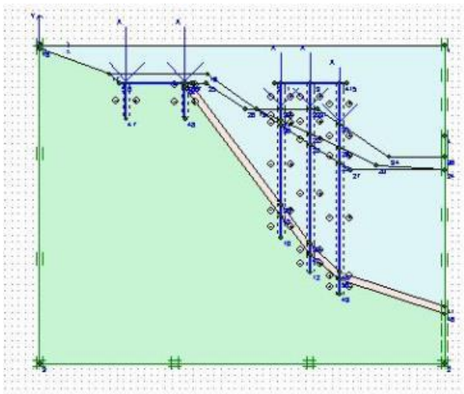
PLAXIS



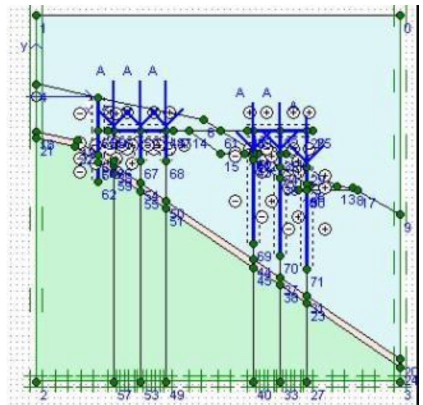
ABAQUS

Phase 3: 2D geotechnical analyses for each pair of piers (PLAXIS)

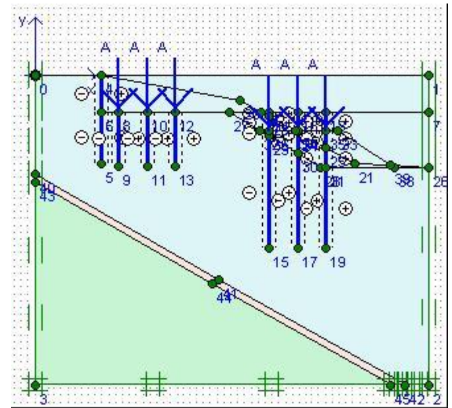
П1



П2

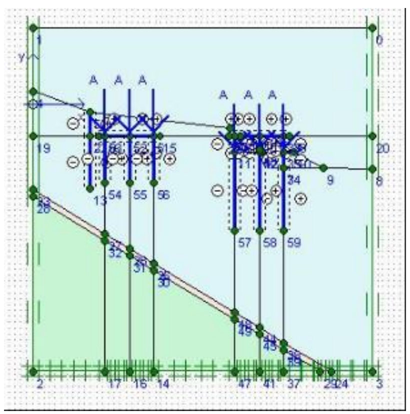


П3

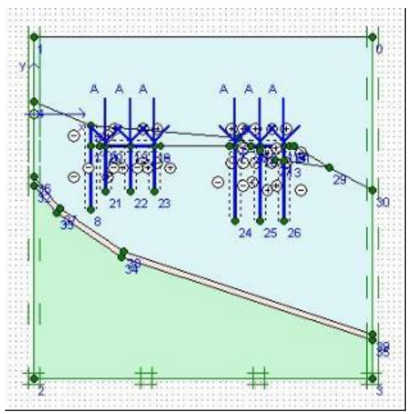


Earth pressure and soil spring values calculated to be fed into structural models in Phase 4.

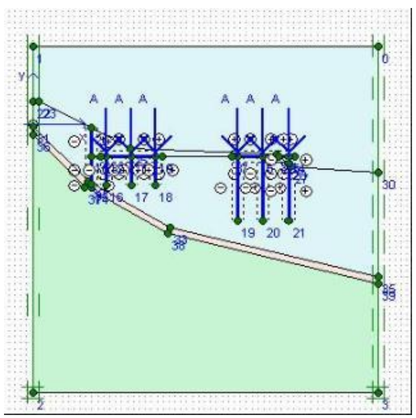
П4



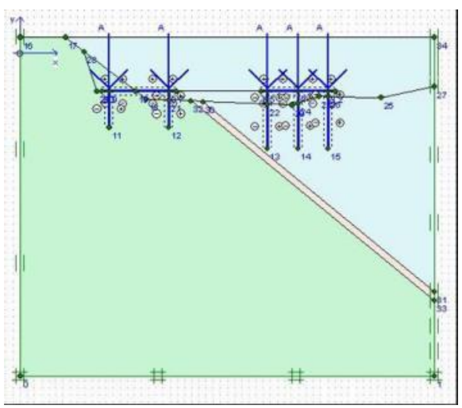
П5



П6

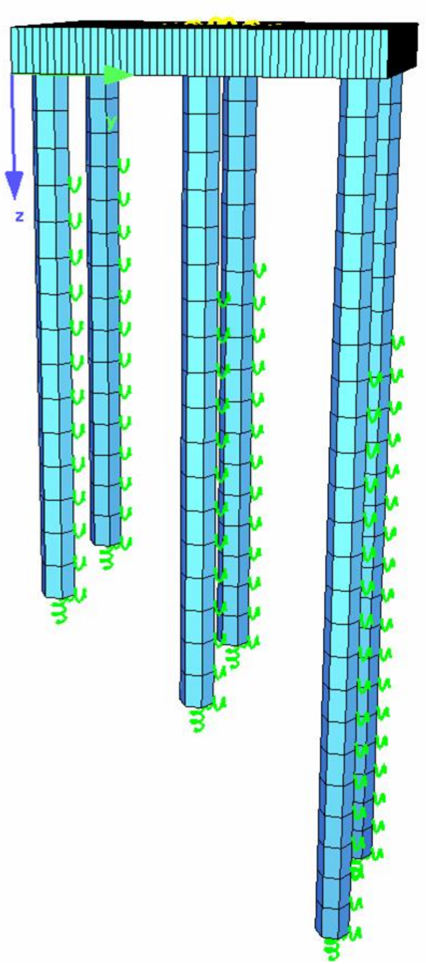


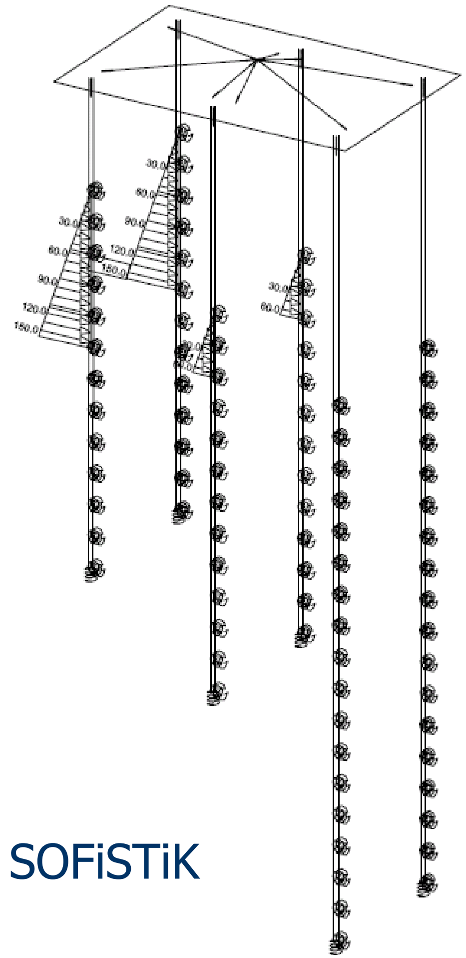
П7



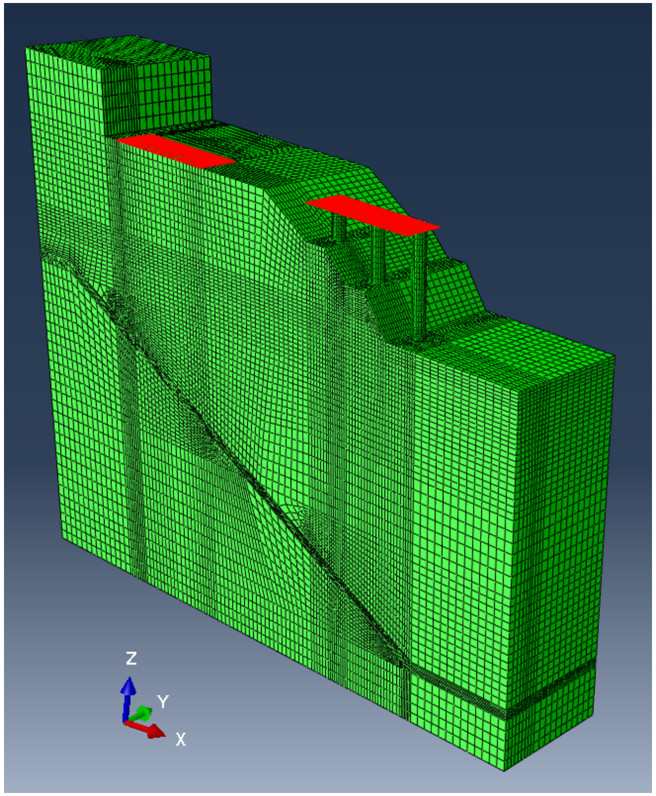
Phase 4: 3D structural analyses (SOFiSTiK)

Model calibration and design





SOFiSTiK

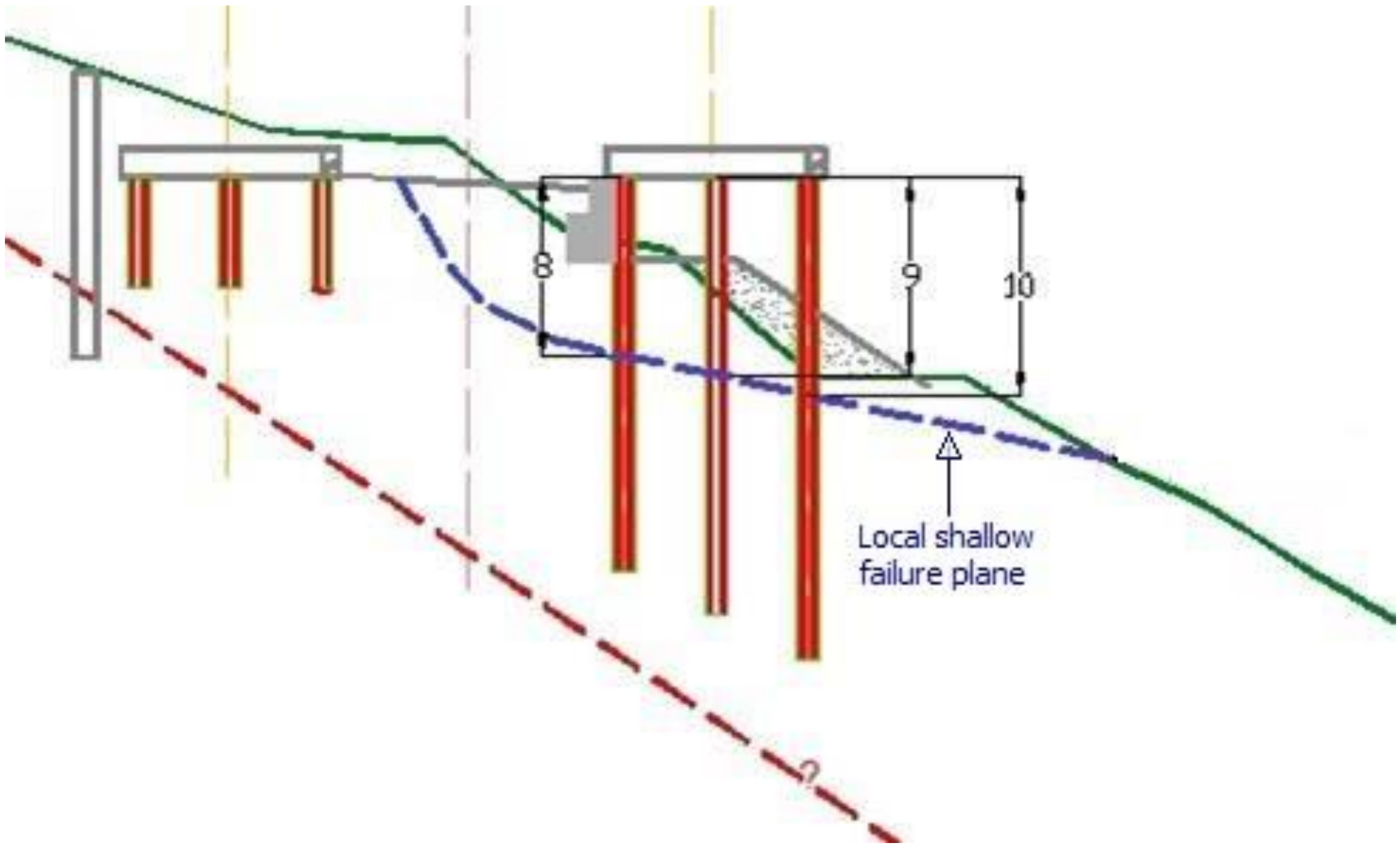


ABAQUS

Phase 5: 3D structural analyses (SOFiSTiK)

Contingency working hypotheses

- Local shallow failure plane developed introducing a 15mm transverse movement. Anchoring is also activated in this case.



Phase 5: 3D structural analyses (SOFiSTiK)

Contingency working hypotheses

- Contingency anchoring of the pile caps in case the movements exceeded the predicted values or the tolerance of the superstructure during the erection of the steel arches

Phase 5: 3D structural analyses (SOFiSTiK)

Design of the temporary towers foundation

- Self weight
- Loads from the temporary towers
- Loads from the slabs/bridges
- Earth pressures (static and seismic)
- Seismic action α=0.08g (temporary project)
- Soil movements 15mm (Local shallow failure planes at the piers Π2Δ – Π5Δ)
- Forces from anchoring

Comparison of piles internal forces due to static and seismic load combinations (SOFiSTiK) with the corresponding ones due to the soil movement (PLAXIS)

Small differences were observed up to 3% for the axial forces and 6% for the bending moments. Hence, for the piles of piers Π2Δ – Π5Δ an increase of the required reinforcement was considered up to 10%.

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Contractor:	**Initially J/V TERNA S.A. – ALPINE BAU then TERNA S.A.**
Structural design of the Tsakona bridge:	**DOMI S.A.**
Geotechnical and foundation design of the Tsakona bridge:	**EDAFOS S.A.**
Design of infrastructure projects and construction consulting:	**ODOTECHNIKI Ltd**
Design of heavy lifting scaffolding:	**PERI Formwork Scaffolding Engineering**
Steel fabrication and erection:	**EMEK S.A.**

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