TC211-218 Workshop
MSE Walls and Reinforced Fills

HYBRID REINFORCED SOIL STRUCTURES WITH PRIMARY AND SECONDARY REINFORCEMENT FOR HIGH WALLS AND SLOPES

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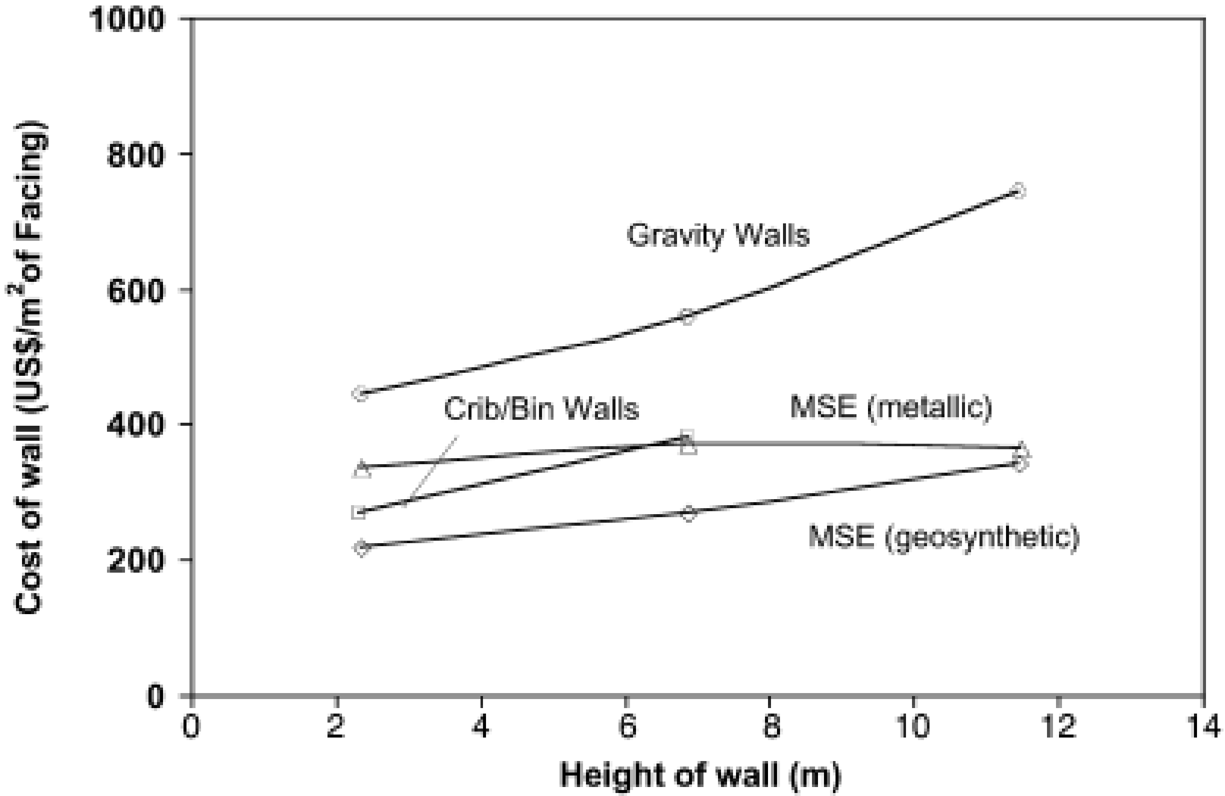
RS walls offer economic advantages over conventional mass gravity wall systems as the height of the wall increases.



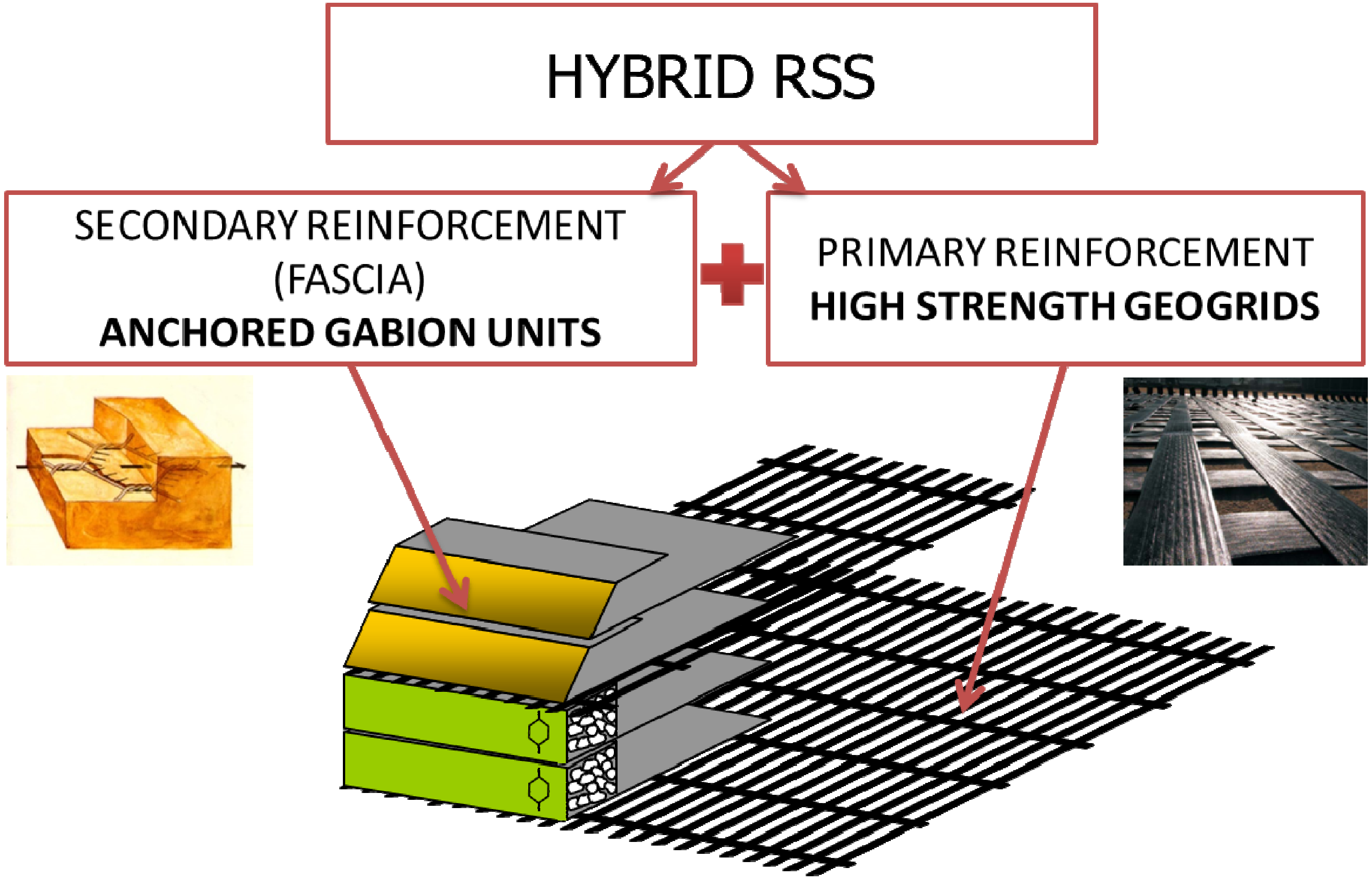
Koerner et al., Earth Retaining wall Costs in USA

The reinforcement cost can be almost 25% of the cost of the wall

In a tall walls the reinforcement load can vary with depth over a wide range of values→ Hatami et al. adresses the possibility of further reducing the total cost of a reinforced soil wall

POSSIBLE SOLUTIONS:

1) Optimization using more than one reinforcement type
2) Optimization modifying the spacing patterns along the wall height



Primary reinforcement → tensile forces to ensure global stability

Facing systems → local stability at the face, no local mechanism of direct sliding, pullout or rotational failure

Ho et. al. (1996 and 1997) found that

1. reinforcement stiffness,
2. vertical spacing
3. and length to wall height ratio, L/H

are important parameters that **influence the wall displacement**.

The magnitude of wall lateral displacement is a function of the soil friction angle and a **reinforcement stiffness factor**, Λ, defined as

$$\Lambda = J / (K_a \gamma H S_v)$$

J = reinforcement stiffness,

Ka = Rankine active earth pressure coefficient,

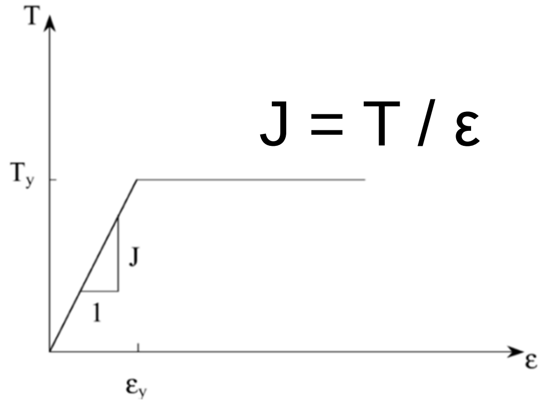
γ = soil unit weight,

H = wall height,

Sv = vertical spacing between reinforcement layers.

The static and deformation behavior of Hybrid MSE walls depend on:

1. Reinforcement stiffness and arrangment

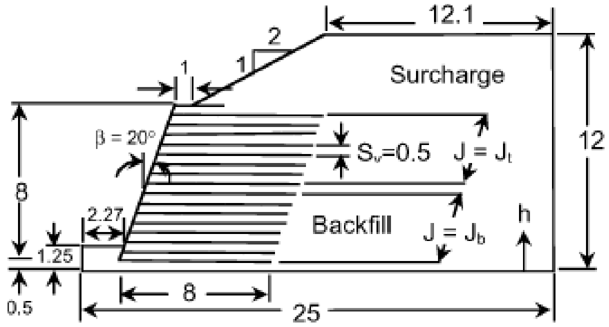


$J = T / \varepsilon$

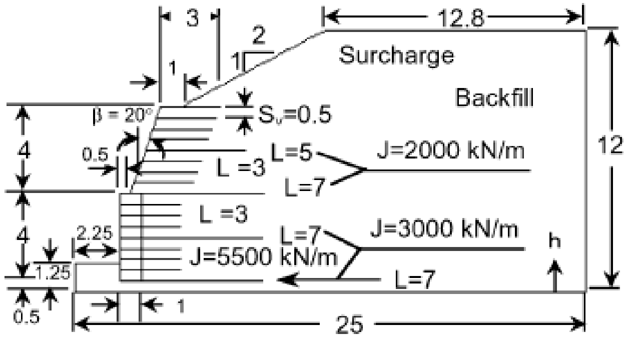
2. Reinforcement quantity

3. Reinforcement ratio $$R_\lambda = \frac{\sum_{i=1}^{n} \frac{J_i l_{fi}(\lambda) L_i}{S_{vi}}}{K_{ah} \gamma H^2}$$

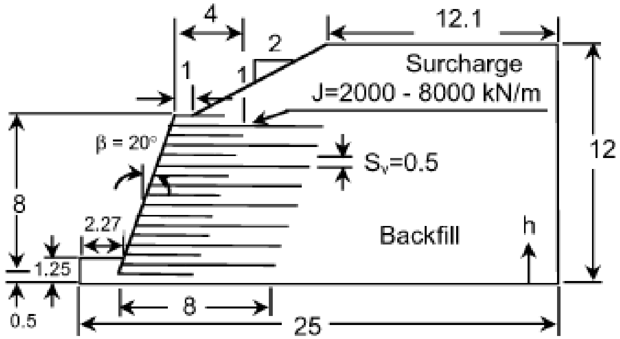
4. Length factor $$l_{fi}(\lambda) = 1 + \frac{L_i/H - \lambda}{L_i/H + \lambda}$$



uniform and grouped reinforcement



tiered wrapped/gabion- faced wall

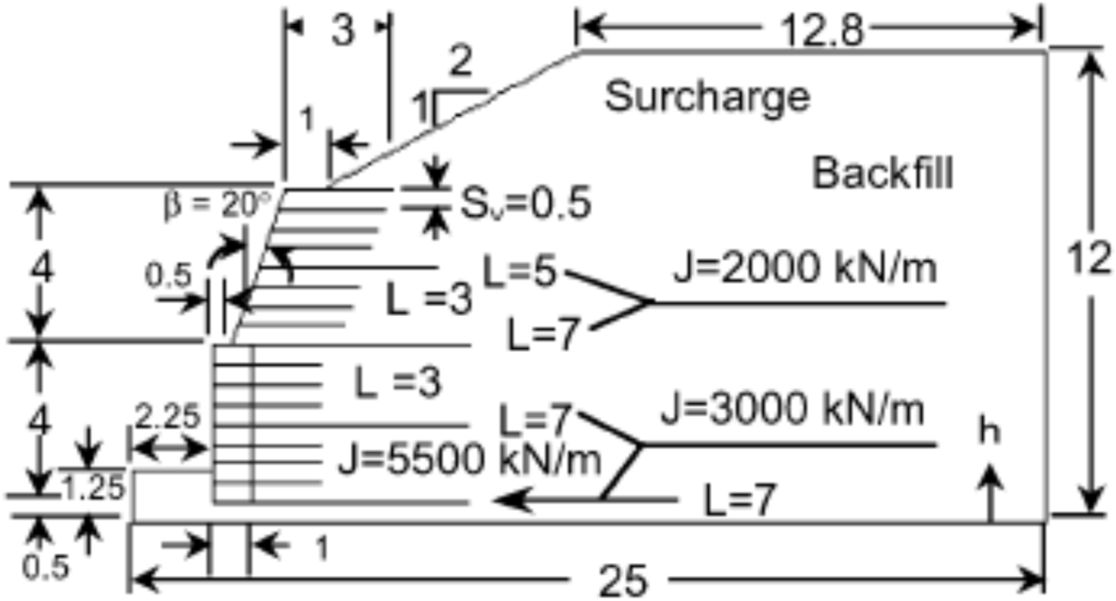


alternating length

- 21 walls evaluated
- Response as a function of → facing lateral displacement / max. reinf. load distribution

RESULTS:

1. Lateral wall displacement in mixed reinforcement configurations is comparable with uniform reinforcement walls
2. Possible 50% reduction of every other reinforcement layer maintain wall serviceability and performance
3. Primary reinforcement every 2 – 3 times facing units & secondary reinforcement spaced at each facing unit
   → *optimal distribution of reinforcement*



Hybrid Reinforced Soil Structures for High Walls And Slopes

Instrumented Full-Scale Wall – IZMIR (Turkey)

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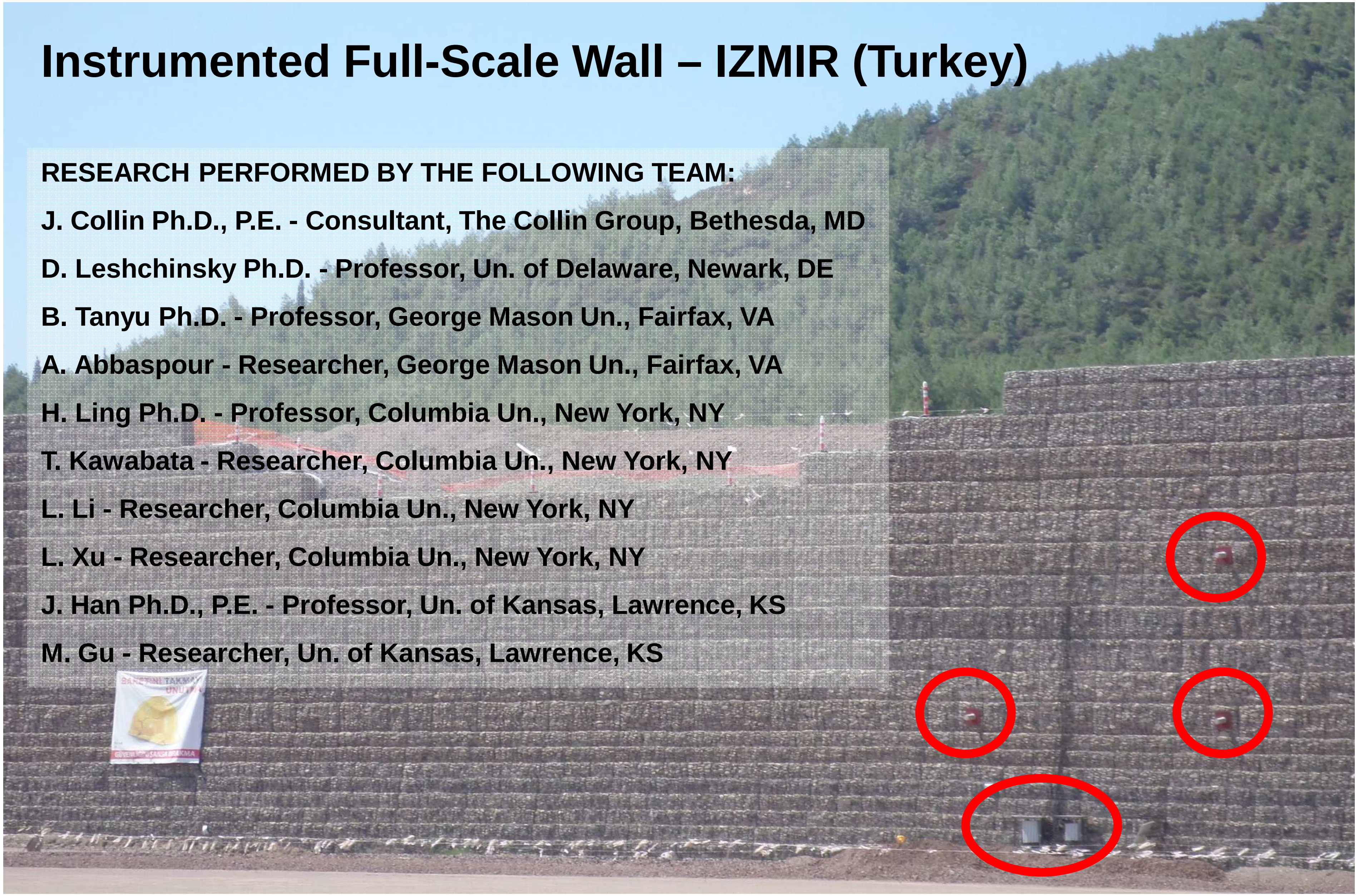

RESEARCH PERFORMED BY THE FOLLOWING TEAM:

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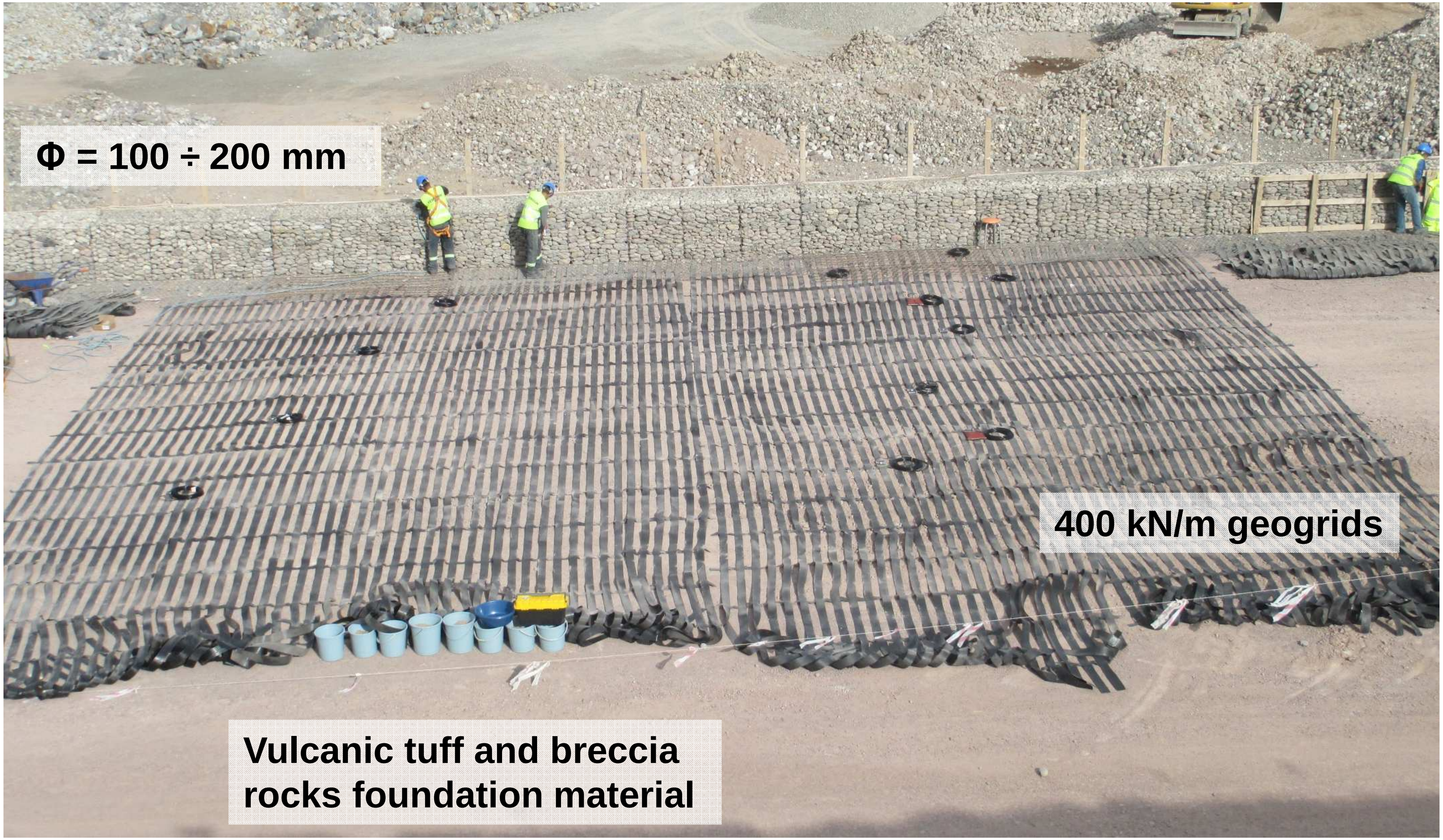
Instrumented Full-Scale Wall – IZMIR (Turkey)



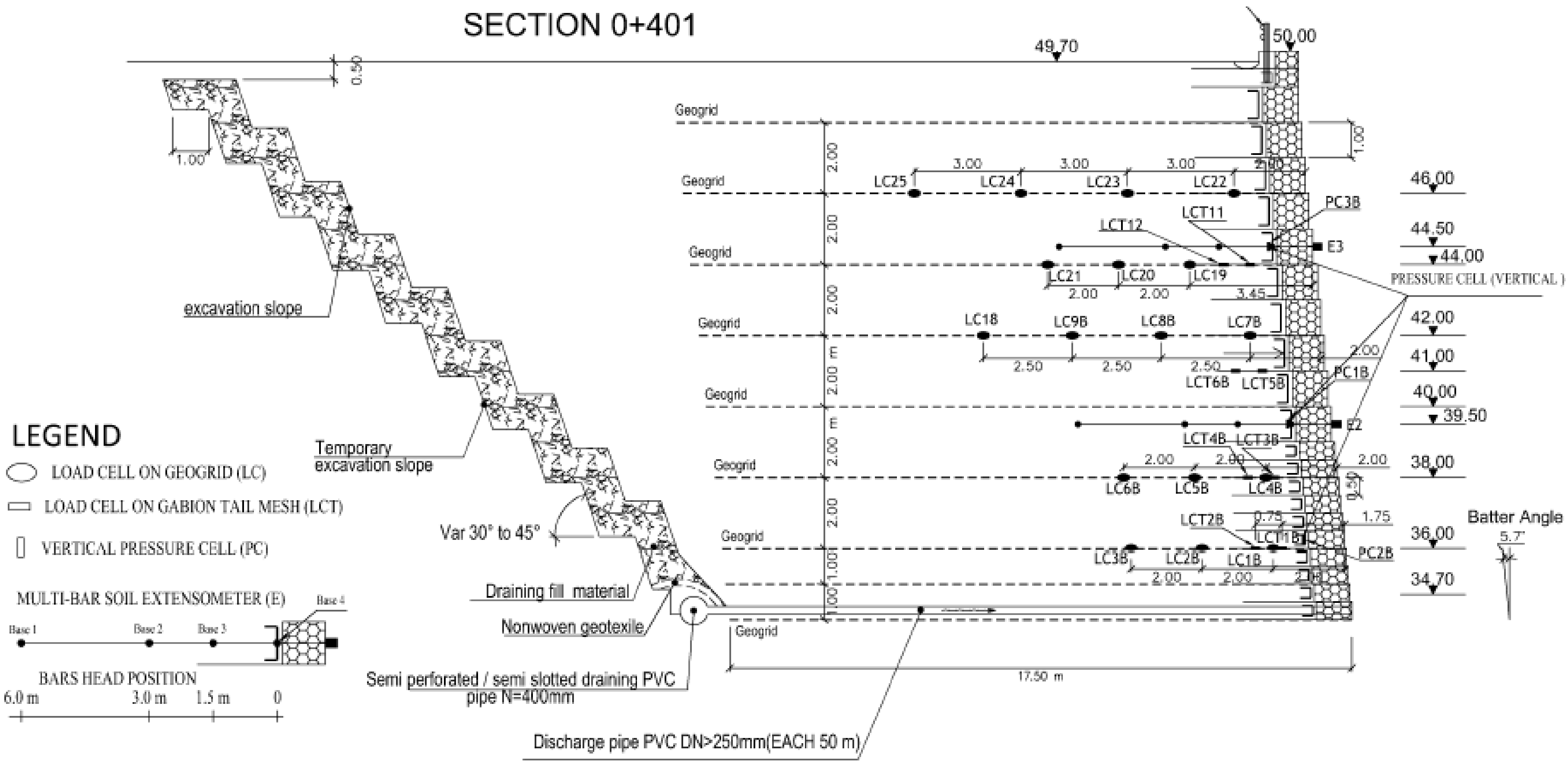
Instrumented Full-Scale Wall – IZMIR (Turkey)

- The walls instrumentation consisted of:
  - Soil extensometer
  - Load cells on geogrid and wire mesh
  - Vertical and horizontal pressure cells on geogrid
  - Temperature sensors
  - Survey targets along the facing

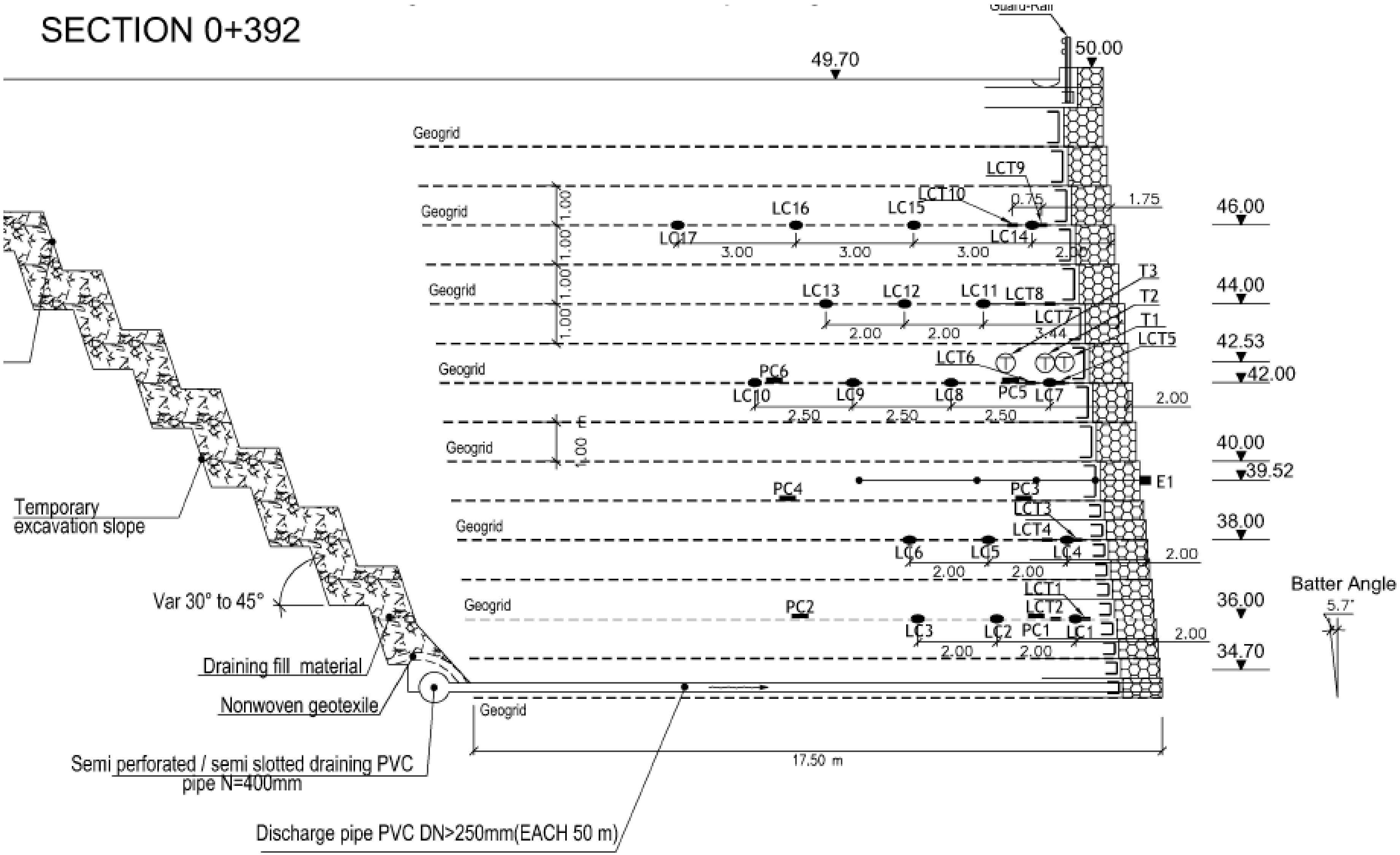
- Section 0+392 has 1m vertical spacing between reinf. layers

  Section 0+401 has 2m vertical spacing between reinf. layers

Instrumented Full-Scale Wall – IZMIR (Turkey)



Instrumented Full-Scale Wall – IZMIR (Turkey)



Instrumented Full-Scale Wall – Horizontal Displacement

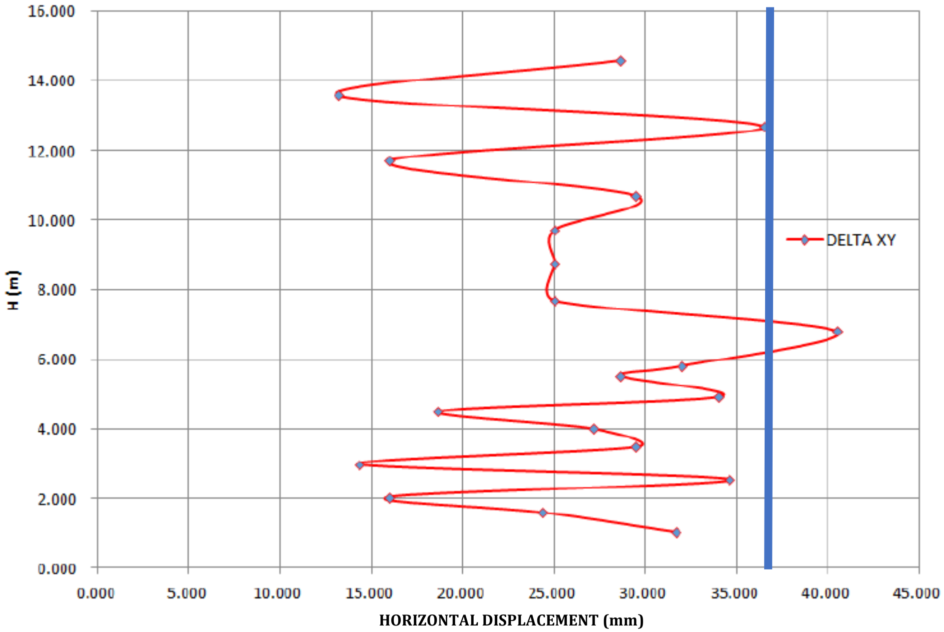


Figure 7 Horizontal Movement Section 1 Station 0+392, 1 m Vertical Spacing

Non-uniform displacement plot due to gabion boulders filling nature

35 mm maximum horizontal displacement

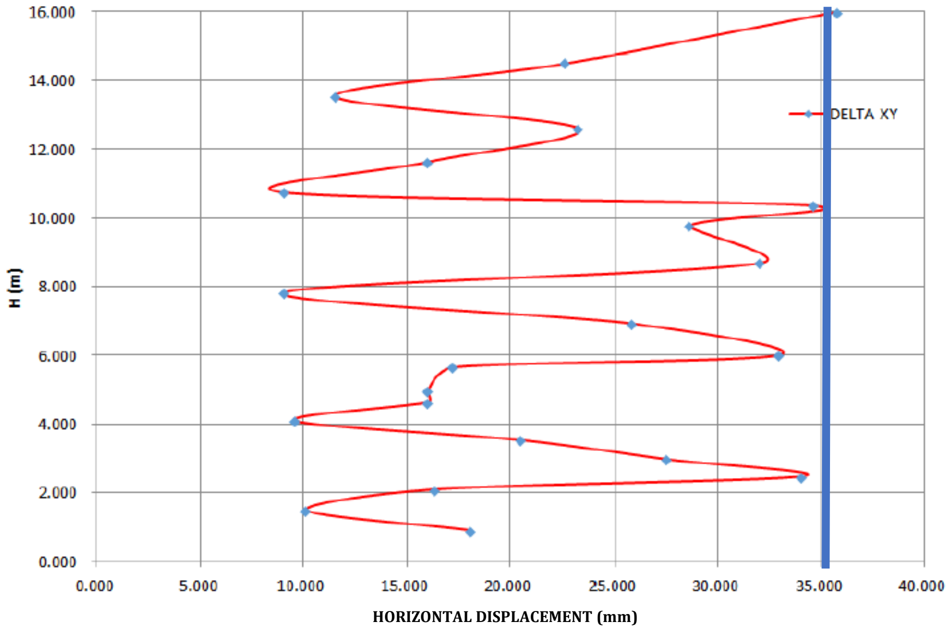
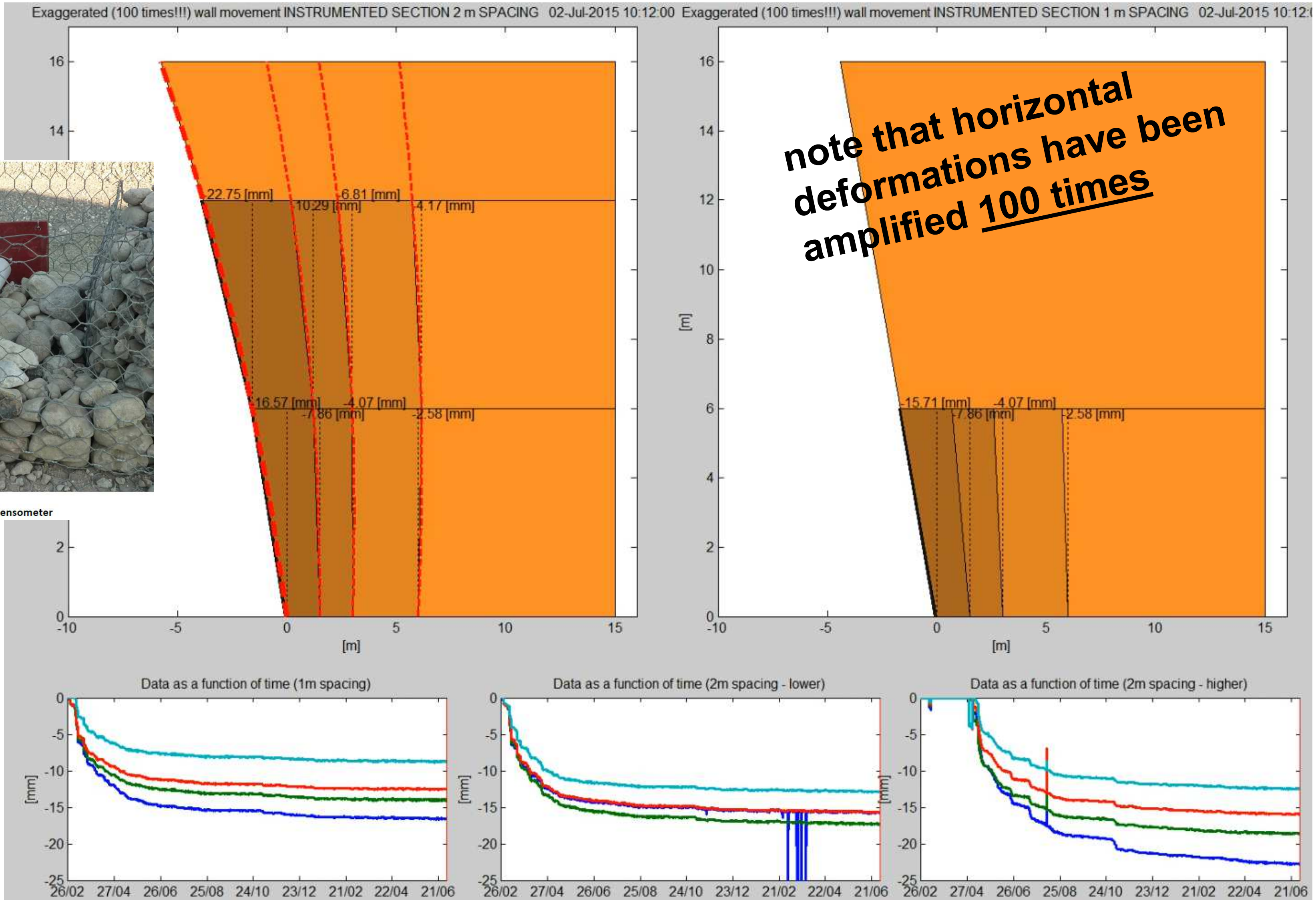


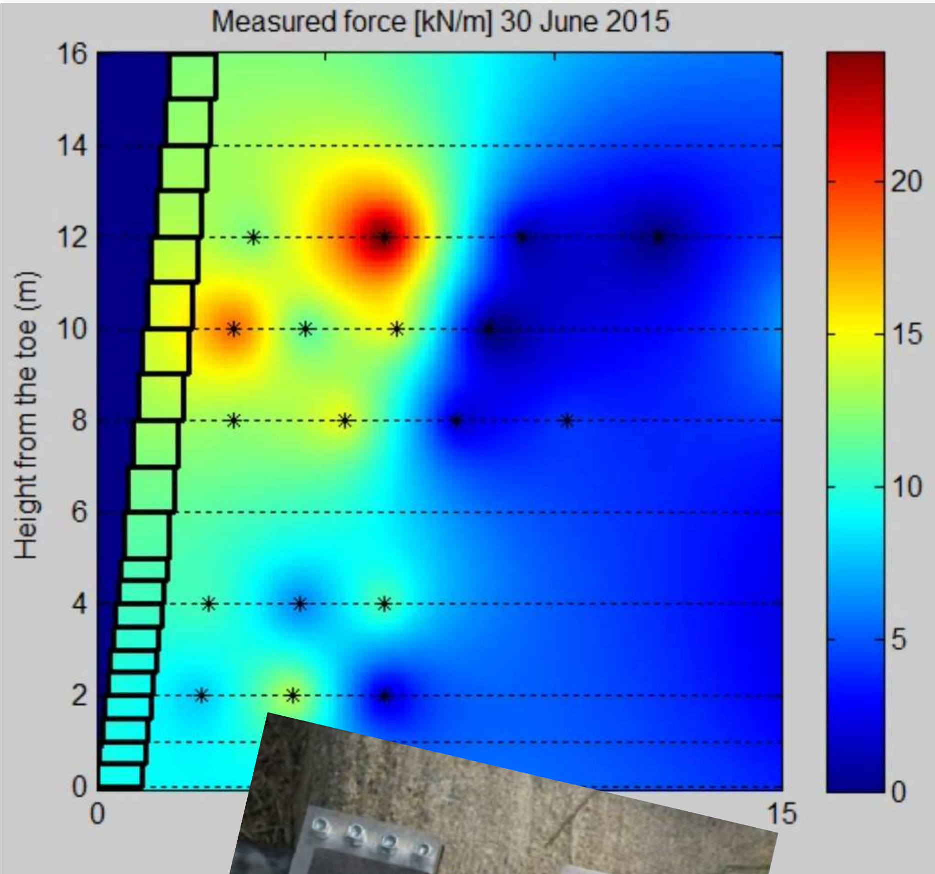
Figure 8 Horizontal Movement Section 2 Station 0+410, 2 m Vertical Spacing

Instrumented Full-Scale Wall – Soil Displacement

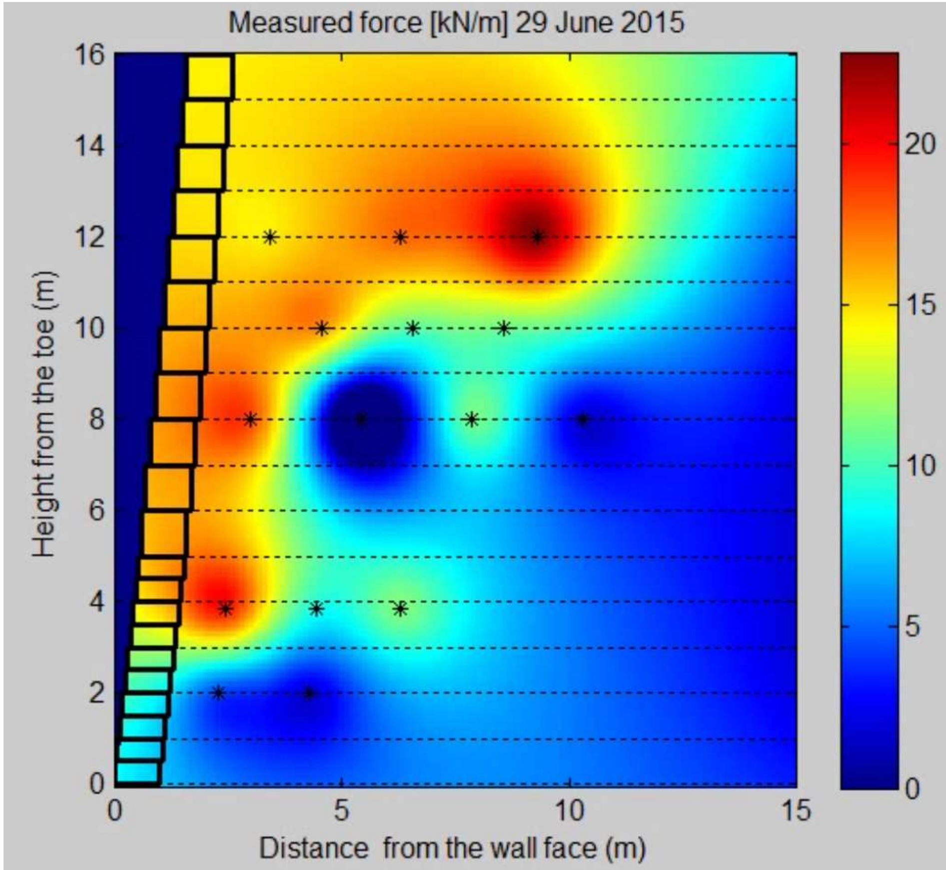
Figure 9 4 bar Extensometer



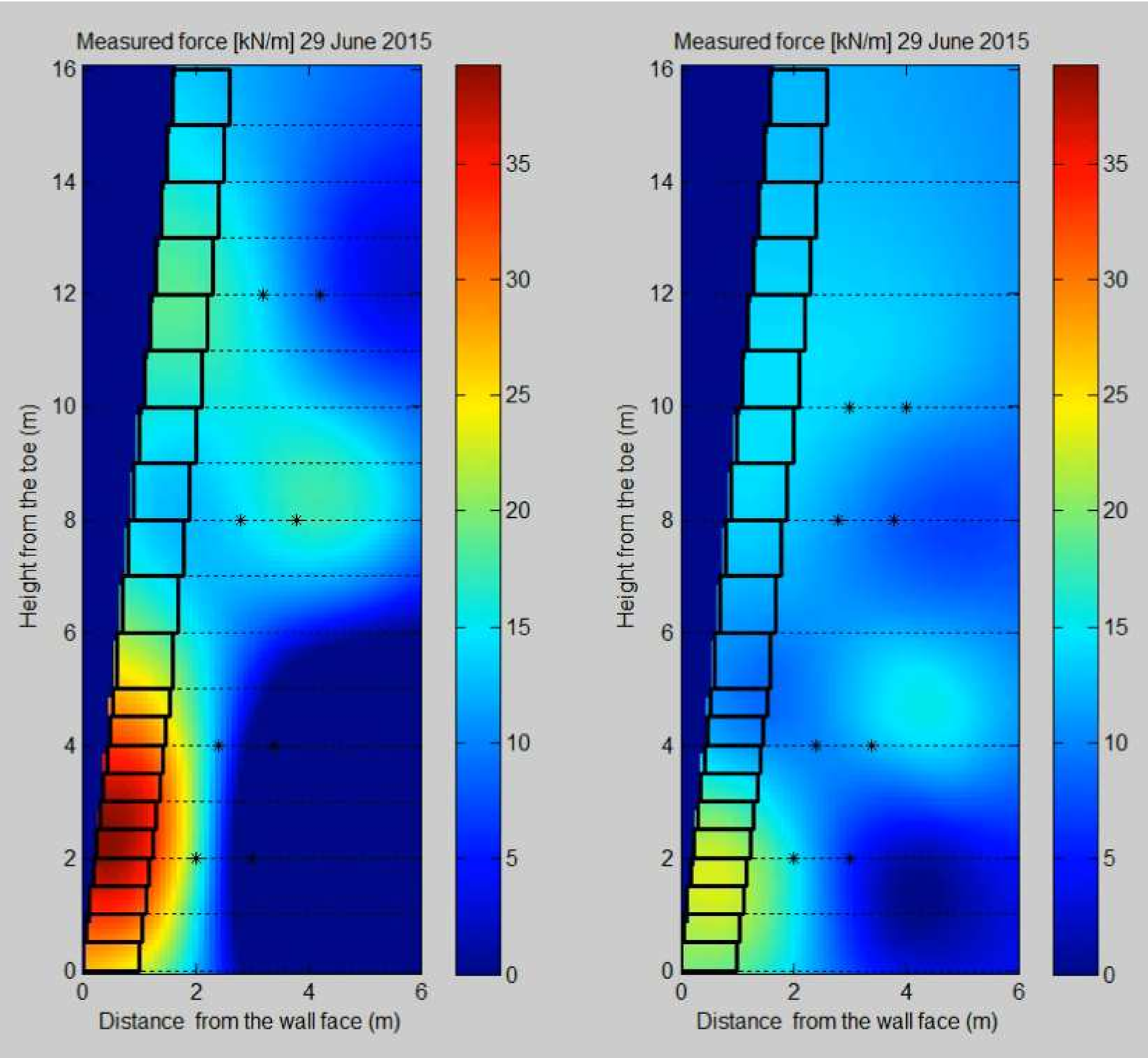
Instrumented Full-Scale Wall – Tension in Geogrids



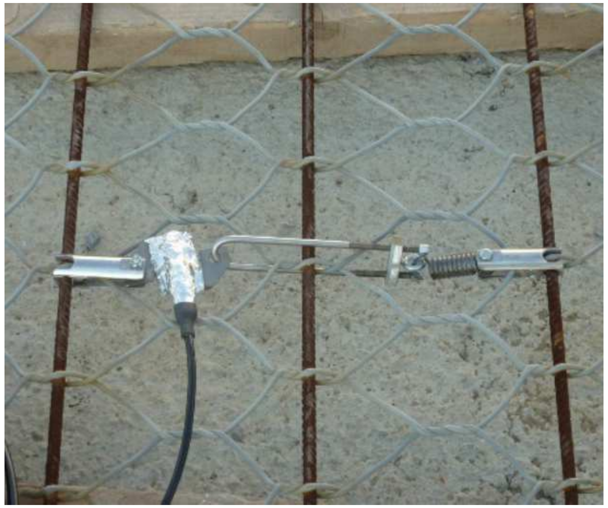
The purpose of the load cells was to determine the critical internal failure surface of the structure



Instrumented Full-Scale Wall – Tension in Wire Mesh



The wire mesh load cells were calibrated to determine
the deformation and modulus characteristics.



BACKGROUND RESEARCHES - Collins et al.

Instrumented Full-Scale Wall – Tension in Geogrids VS Mesh

1 m spacing – Load on wire → 11 ÷ 19 kN/m

2 m spacing – Load on wire → 11 ÷ 13 kN/m

1 m spacing – Load on geogrids at face → Max. 19 kN/m

2 m spacing – Load on geogrids at face → Max. 18 kN/m

Results: the tension in the geogrid at the face in a 2m vertical spacing configuration is much higher than the tension measured in the tail

Instrumented Full-Scale Wall – Numerical modeling

T_{max} estimated from design by AASHTO **VS** T_{max} measured from the field

Analysis 1: Section 0+392, Sv = 1 m, and $\varphi_{reinforced}$= 42.9 deg
as determined from numerical analyses

Analysis 2: Section 0+392, Sv = 1 m, $\varphi_{reinforced}$ = 40 deg
as limited by AASHTO LRFD design method

Analysis 3: Section 0+401, Sv = 2 m, $\varphi_{reinforced}$ = 42.9 deg
as determined from numerical analyses

Analysis 4: Section 0+401, Sv= 2 m, $\varphi_{reinforced}$ = 40 deg
as limited by AASHTO LRFD design method

Instrumented Full-Scale Wall – Numerical modeling

RESULTS:

1. *In all four (4) analysis the walls appear to behave as EXTENSIBLE*
2. *The reinforcement length exceeds the required length for pullout*
3. *The **line of maximum tensile strains** for both 1 and 2m vertical spacing configurations is **close to RANKINE failure line**.*

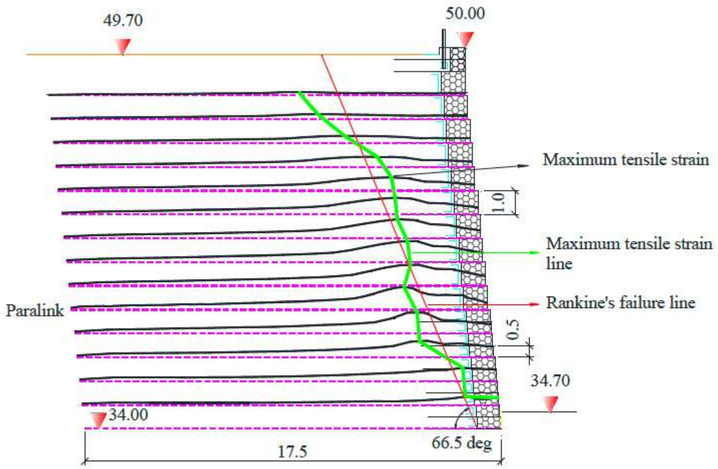


Figure 49 Maximum strain lines for 1 m reinforcement spacing.

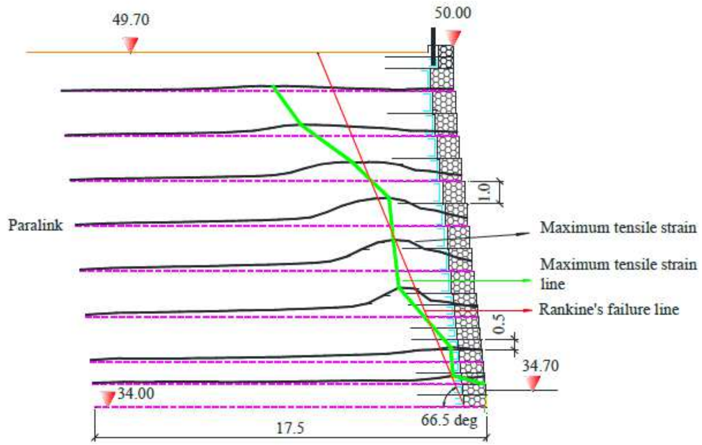


Figure 50 Maximum strain lines for 2 m reinforcement spacing.

Instrumented Full-Scale Wall – Conclusions

- *Hybrid MSE structures with* ***1m vertical spacing*** *behave in accordance with traditional RE theory →* ***AASHTO 2014*** *states:*

  "A vertical spacing, Sv, greater than 2.7 ft should not be used without full scale wall data that support the acceptability of larger vertical spacing, except for MSE wall systems with facing units equal to or greater than 2.7 ft high with a minimum facing unit width, Wu equal to or greater than the facing unit height. For these larger facing units the maximum spacing, Sv, shall not exceed the width of the facing unit, Wu, or 3.3 ft, whichever is less."

- *Hybrid MSE structures, like Izmir walls, behave as an extensible MSE wall system*

Instrumented Full-Scale Wall – Conclusions

- *Locus of max. strains → TIE-BACK WEDGE method*

  However, the locus of max. strains is closer to the face than it would be for a $\Phi_{backfill}$=39 deg → high strenght geogrids + toe restrain + gabion massive face produce an increased of the equivalent shear stiffness of soil= larger apparent friction angle

Hybrid structures should be modeled as per tie-back wedge method but with increased reinforced soil friction angle

From the best fit lines it results: β = 66.5°,

hence from the Rankine formula

$\beta = \arctan(45° + \varphi_{fill}^* / 2)$

$\varphi_{fill}^* = 43°$

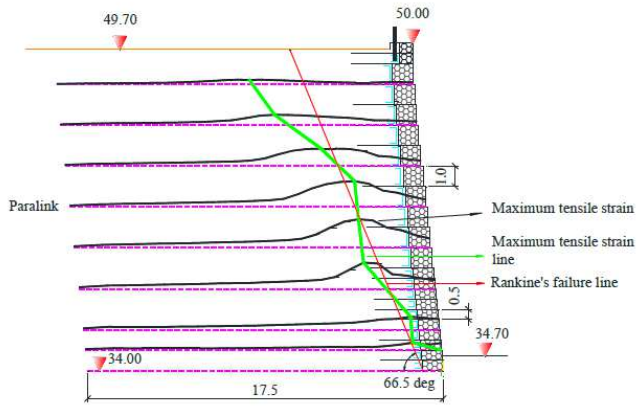
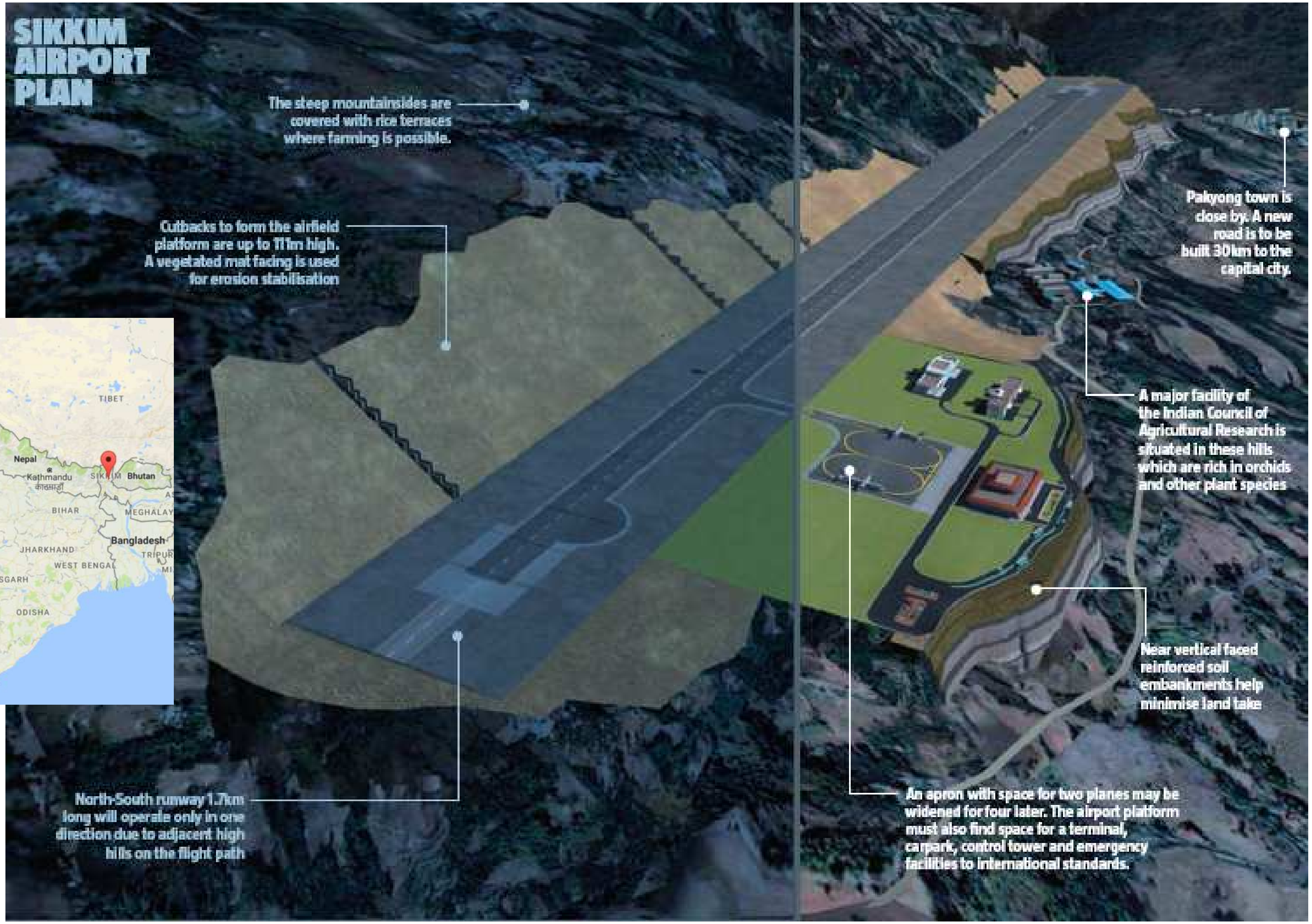


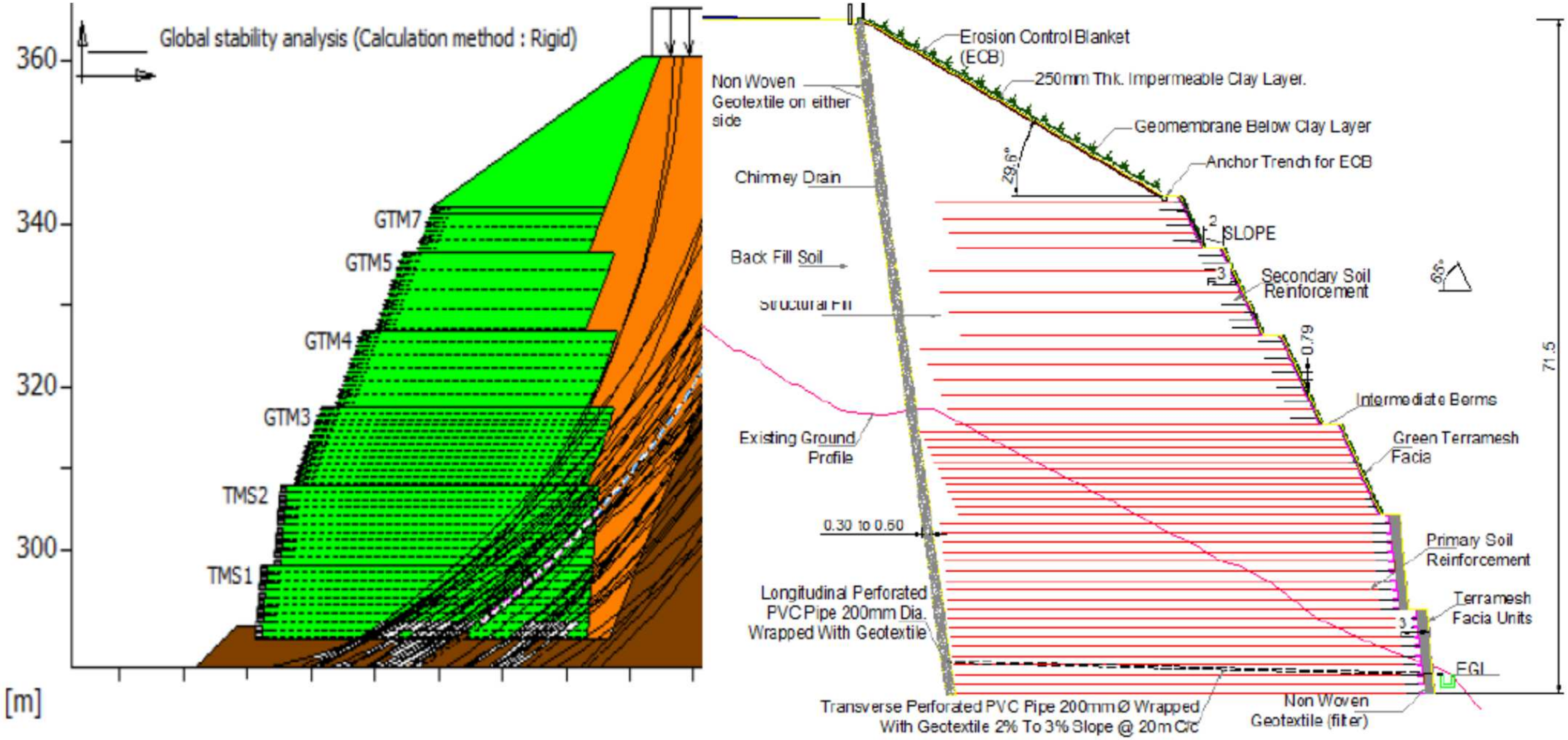
Figure 50 Maximum strain lines for 2 m reinforcement spacing.

Sikkim Airport, India



Sikkim Airport, India

- BS 8006 / FHWA
- Seismic Zone IV(recent 6,9 magnitude earthquake)



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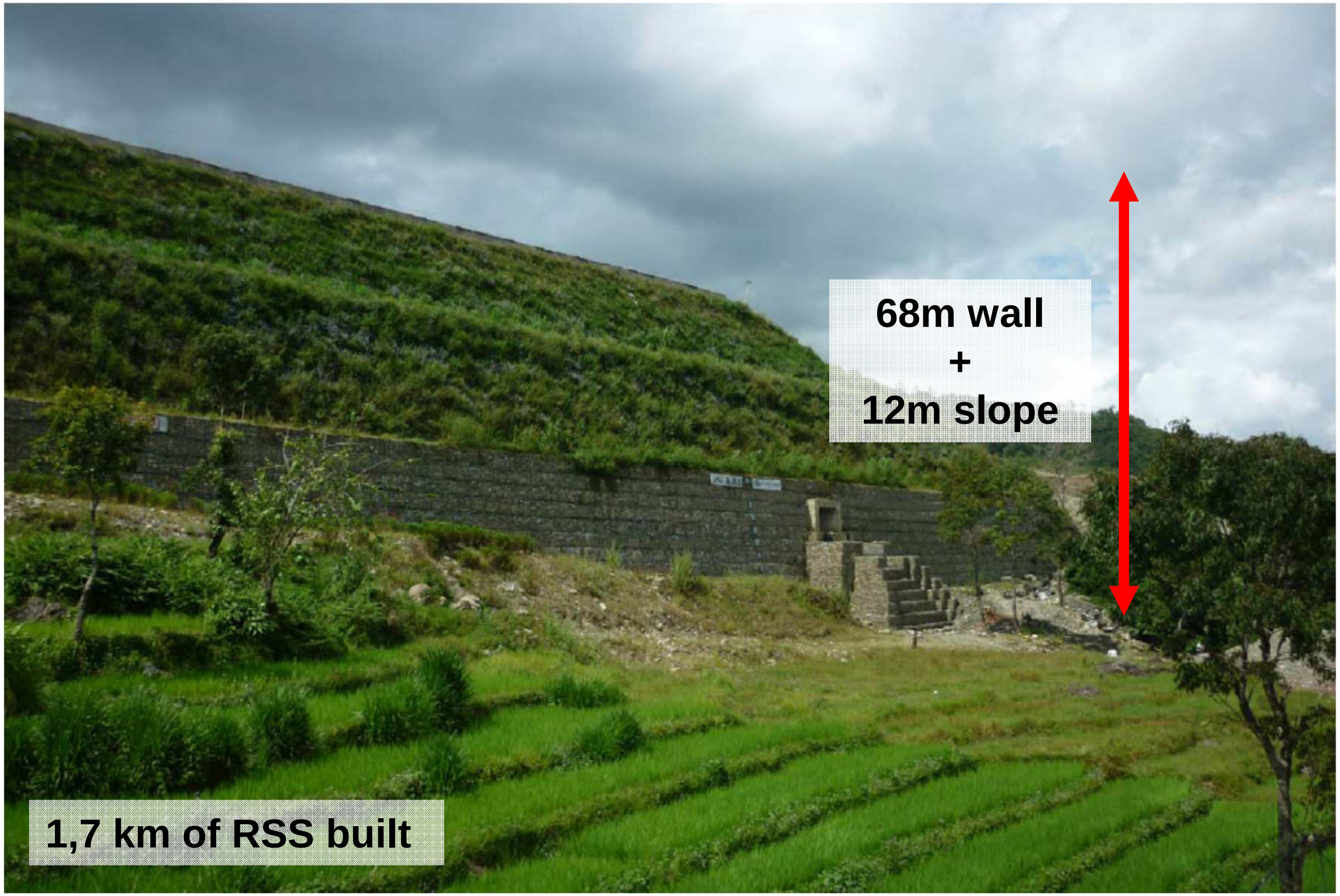
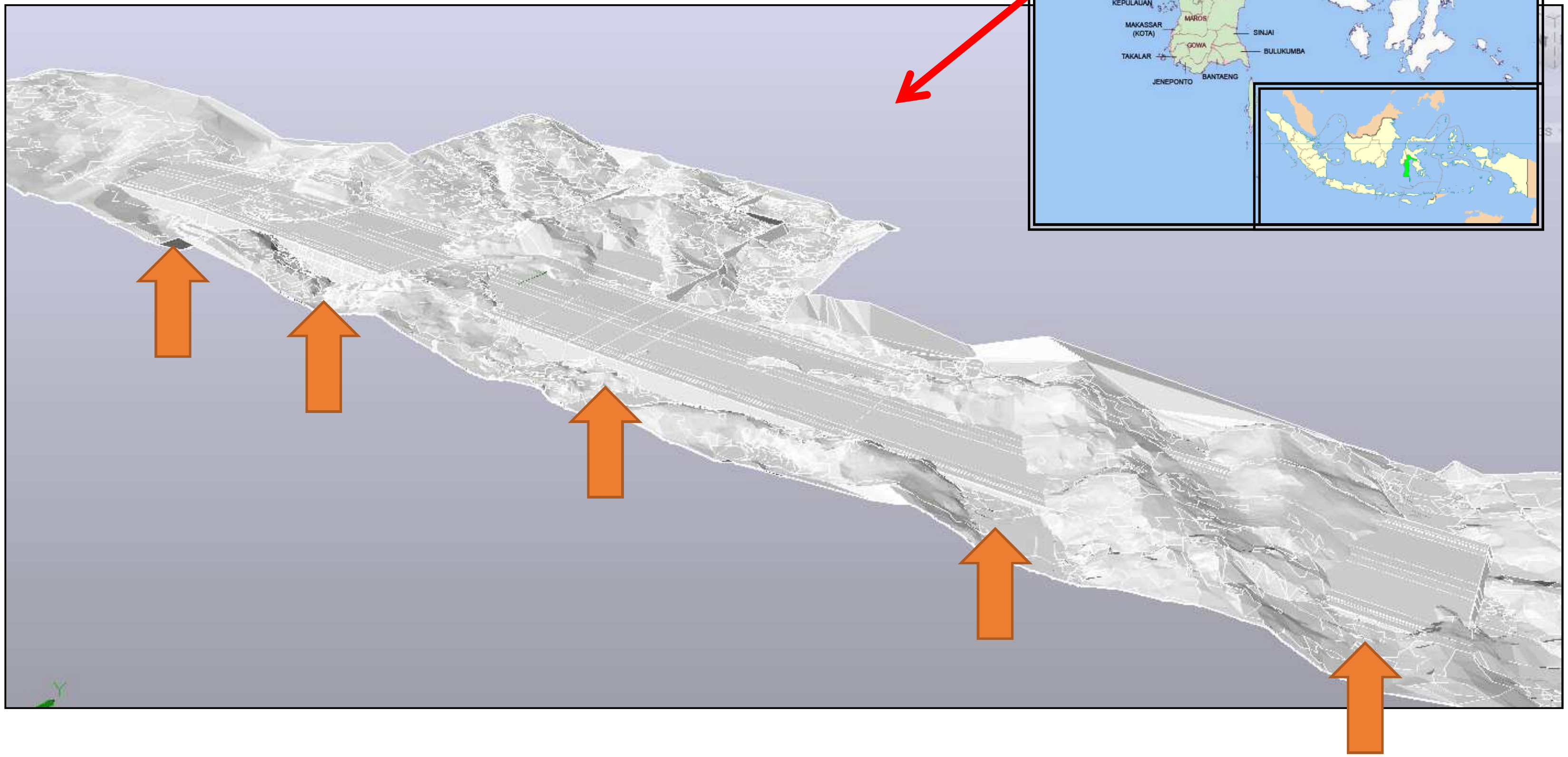


Tana Toraja Airport, Indonesia

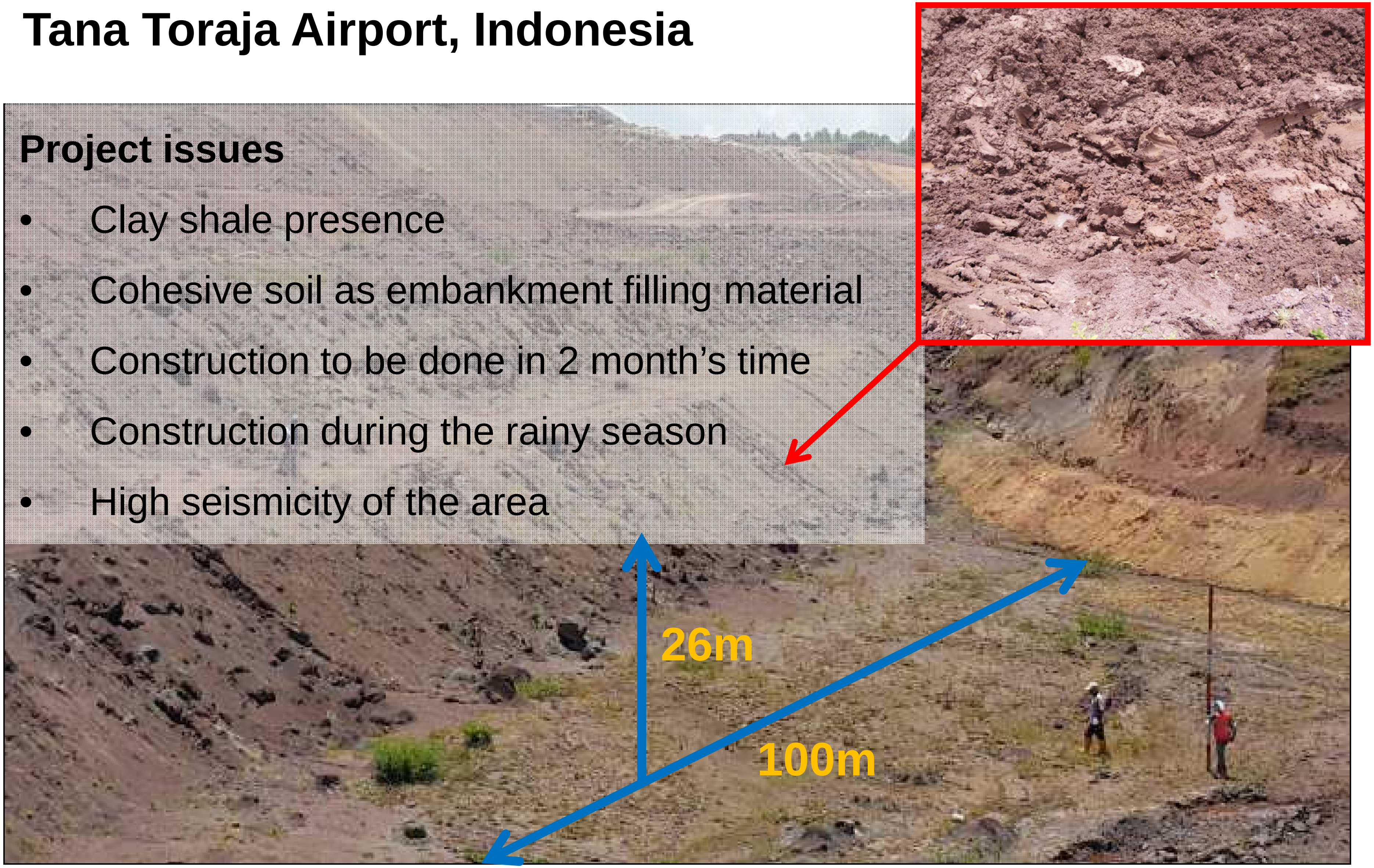
- RUNWAY: 2 km long and approx. 210 m wide
- Massive cut and fill earth works have to be undertaken. Max embankment height = 35m



Tana Toraja Airport, Indonesia

Project issues

- Clay shale presence
- Cohesive soil as embankment filling material
- Construction to be done in 2 month’s time
- Construction during the rainy season
- High seismicity of the area



Tana Toraja Airport, Indonesia

Solution

1. Dewatering of the saturated superficial foundation portion (approx. first 2m) and soil stripping to reach a layer with a Su > 100 kPa
2. Basal reinforcement
3. Temporary and permanent drainage systems
4. Replacement of weathered clay shale with selected compacted soil
5. Fast excavation and backfilling (avoiding the rainy hours)

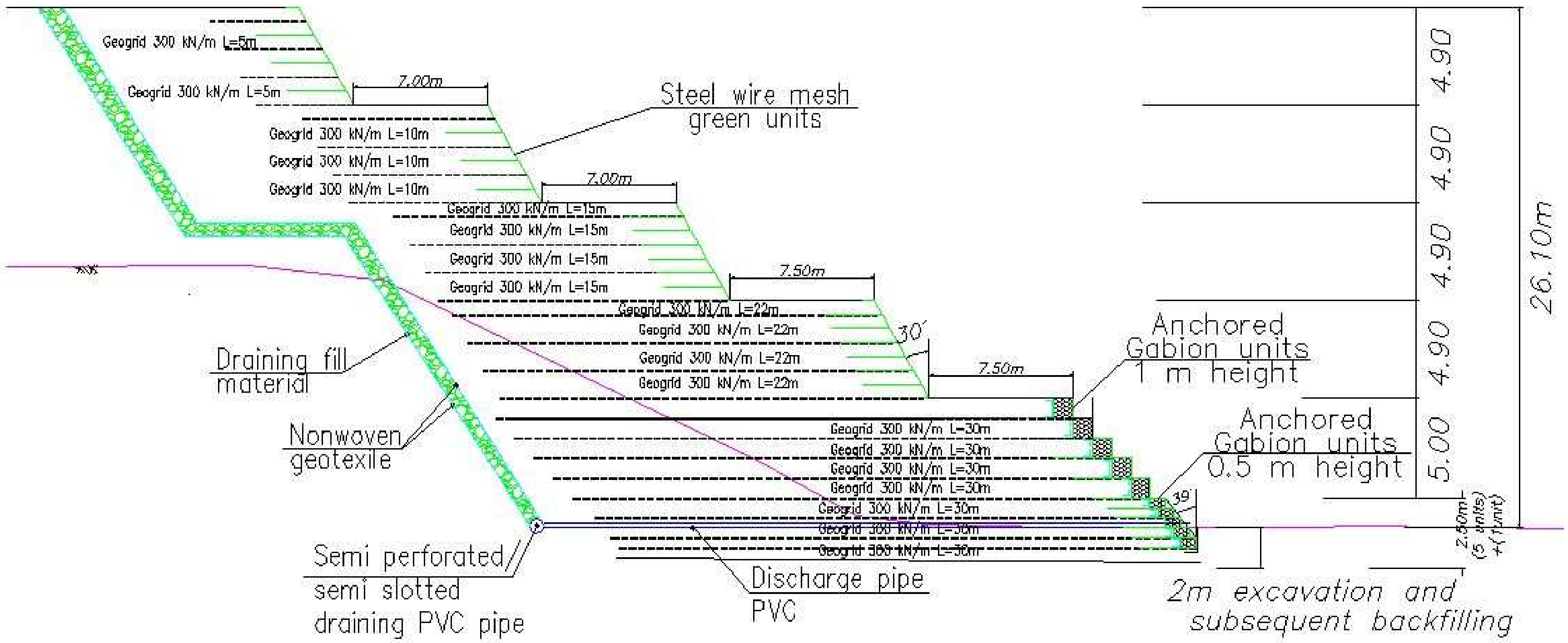
Tana Toraja Airport, Indonesia

Runway retaining structure - Adopted solution

The selection criteria were:

- Permeability
- Flexibility
- Construction schedule
- Overall cost
- Local manpower involvement

Hybrid RSS *combining anchored gabion units and geogrids*



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During construction

1 month after construction

Conclusions

- ✓ *Hybrid RSS can lead to significant advantages if compared to traditional retaining structures as concrete walls, bored piles and natural slopes*

- ✓ *Hybrid RSS with geogrids as primary reinforcement and wire mesh units as facing and secondary reinforcements were used for 40 ÷ 80 m high RSS in several Countries.*

- ✓ *As long as it is properly designed and carefully executed, RSS can be built also on clay shales and using cohesive materials as backfilling material*

- ✓ *The use of high strength and large vertical spacing (Sv) have the advantages of rapid construction and economy, compared to low strength and small vertical spacing arrangement.*

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THANK YOU FOR YOUR ATTENTION

ANY QUESTION?

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