Rapid Inventory of Earthquake Damage (RIED)

Assessment of the damage of the 25 January 1999 Earthquake in

Armenia and Pereira, Colombia

Objectives

- Rapid assessment of the damage inflicted by the earthquake
- To make recommendations for the reconstruction of the buildings and structures in the damaged areas

Means

- High resolution aerial photographs
- Integration of existing and new data in an information technology environment to allow fast analyses and visualization for reconstruction

Organizations Involved

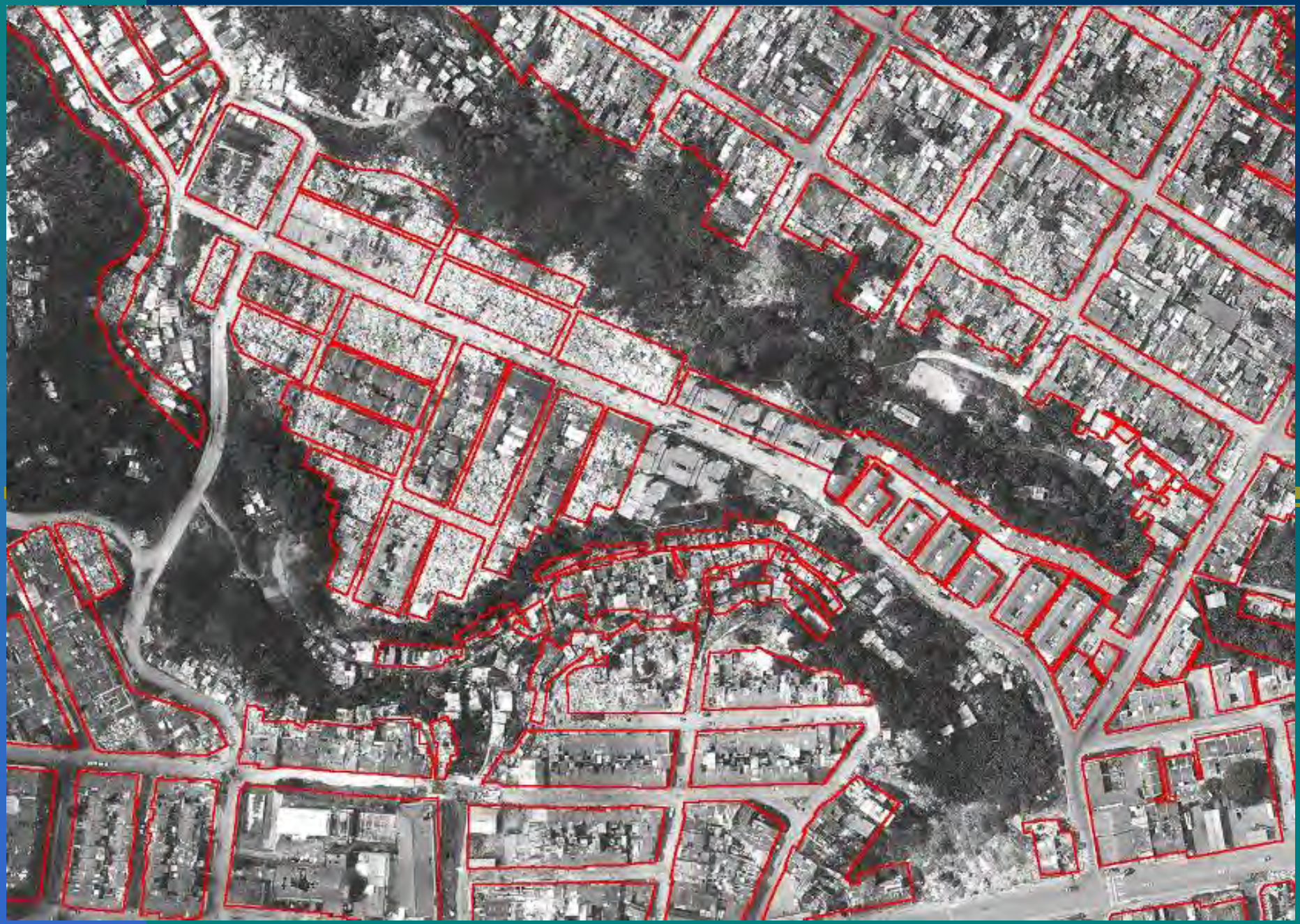
- Ministry of Foreign Affairs, Netherlands
- Ministerio del Medio Ambiente, Colombia

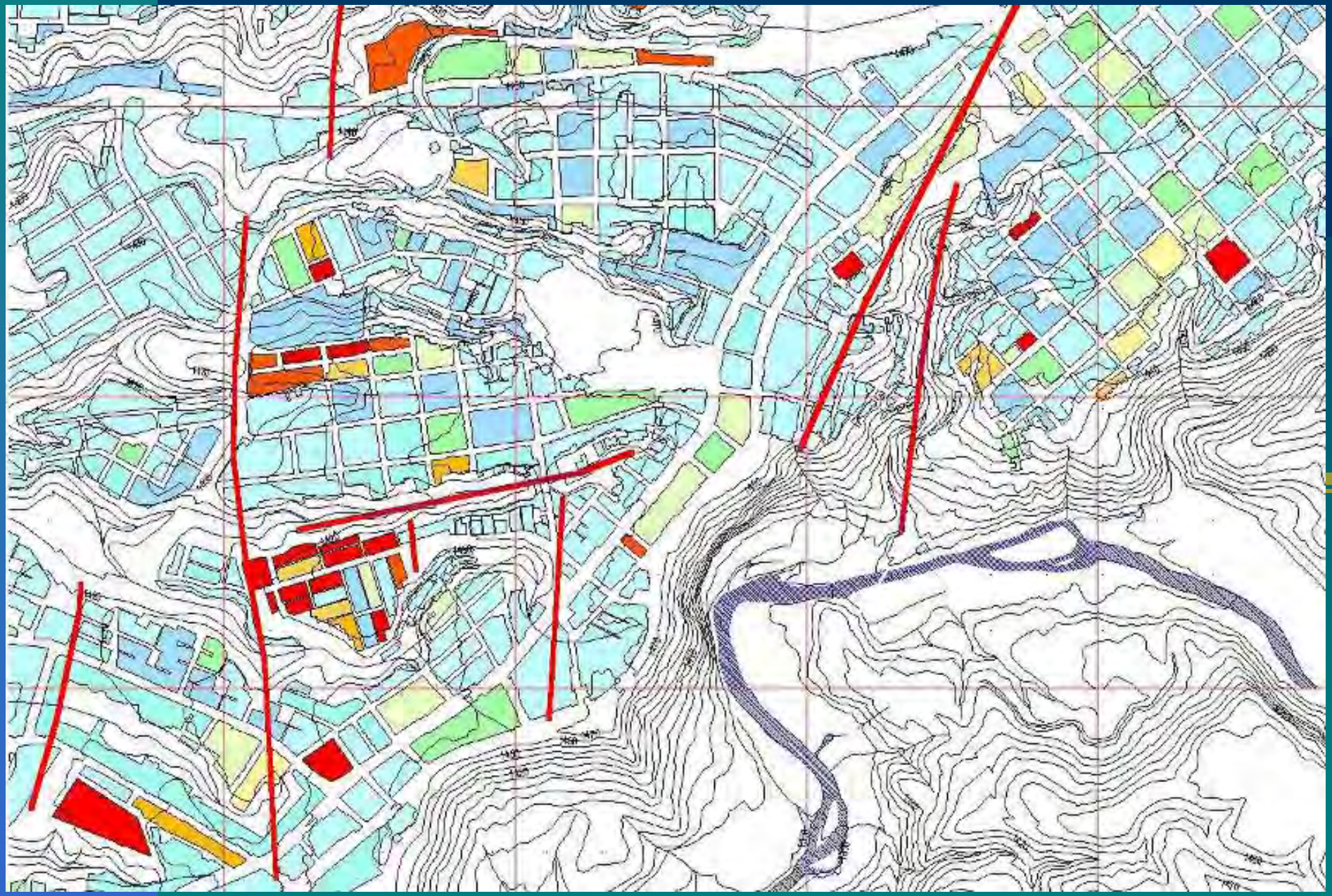
Organisations Involved (cont.)

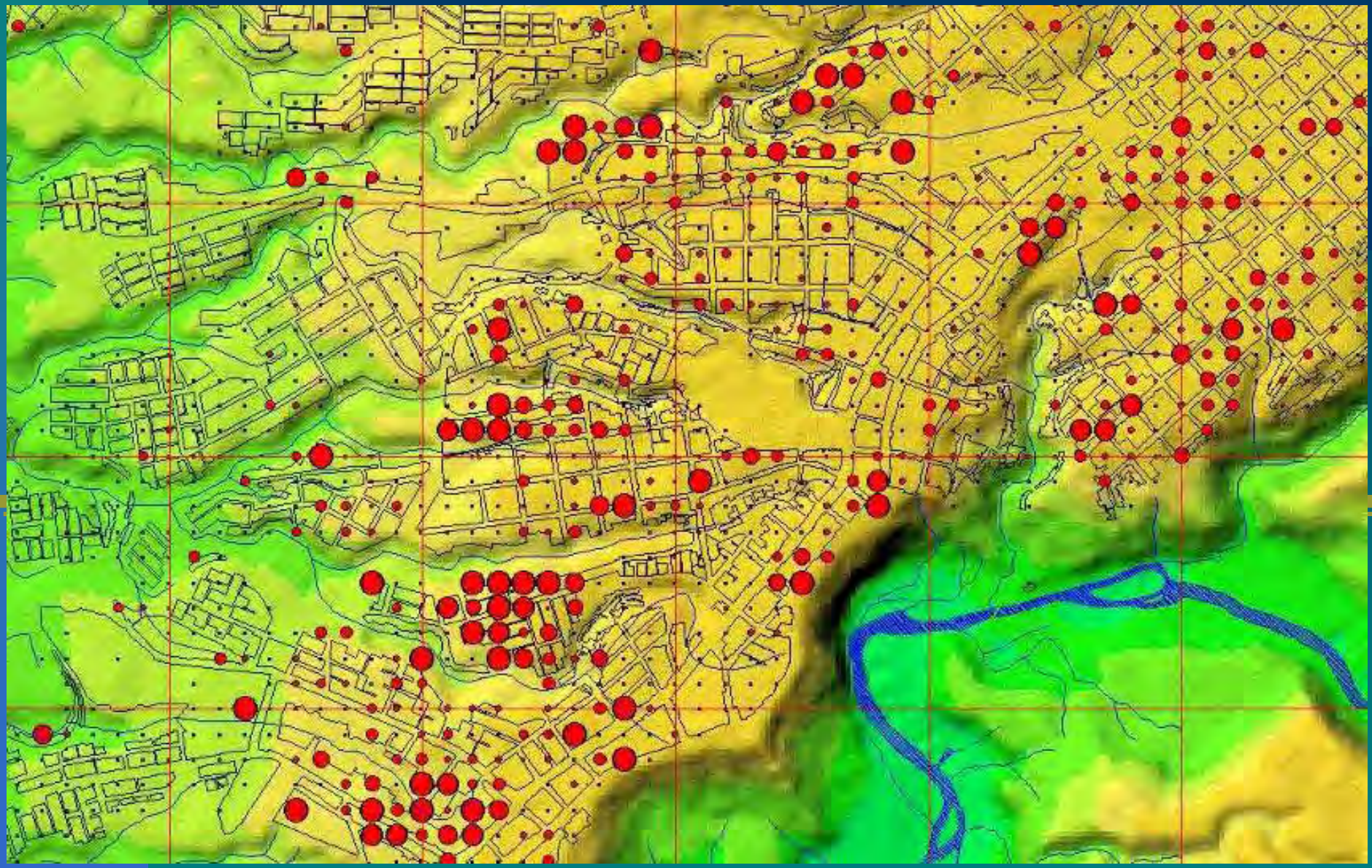
- Coorporacion Autonoma Regional de Risaralda (CARDER)
- Corporacion Regional del Quindio (CRQ)
- Fondo para la Reconstruccion y Desarollo Social del Eje Cafetero (Reconstruction Fund), Armenia
- Instituto Geografico Agustin Codazzi (IGAC)
- Ingeominas
- Int. Inst. For Aerospace Survey and Earth Sciences (ITC)
- Delft University of Technology (TU Delft)

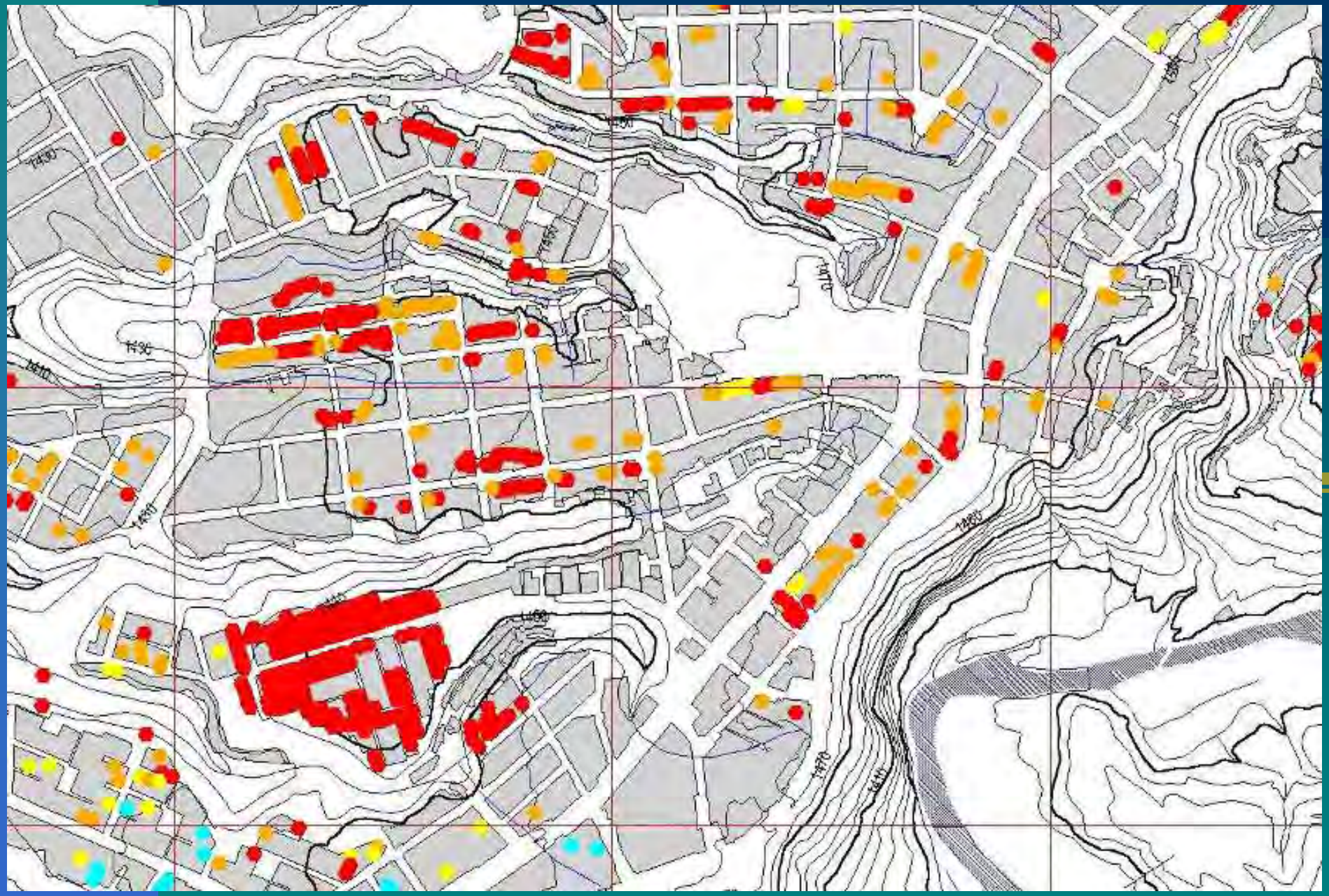
Earthquake damage inventory by aerial photographs

- Structures on aerial photographs were marked in 4 classes
  - Total Collapse
  - Roof Collapse
  - Roof Partly Damaged
  - No Damage Visible but Rubble in the Street
  - No Damage Visible









Comparison Aerial Survey – Ground Survey

- Reasonable correlation for the highly damaged structures such as structures that completely collapsed or for structures of which roof and partially the walls collapsed.
- Less correlation for structures with less severe damage. (This is understandable because cracks in facades and sidewalls of structures are not observed in aerial photographs because of the angle of observation and the resolution of the photographs.)

Results Aerial Photographs Damage Inventory

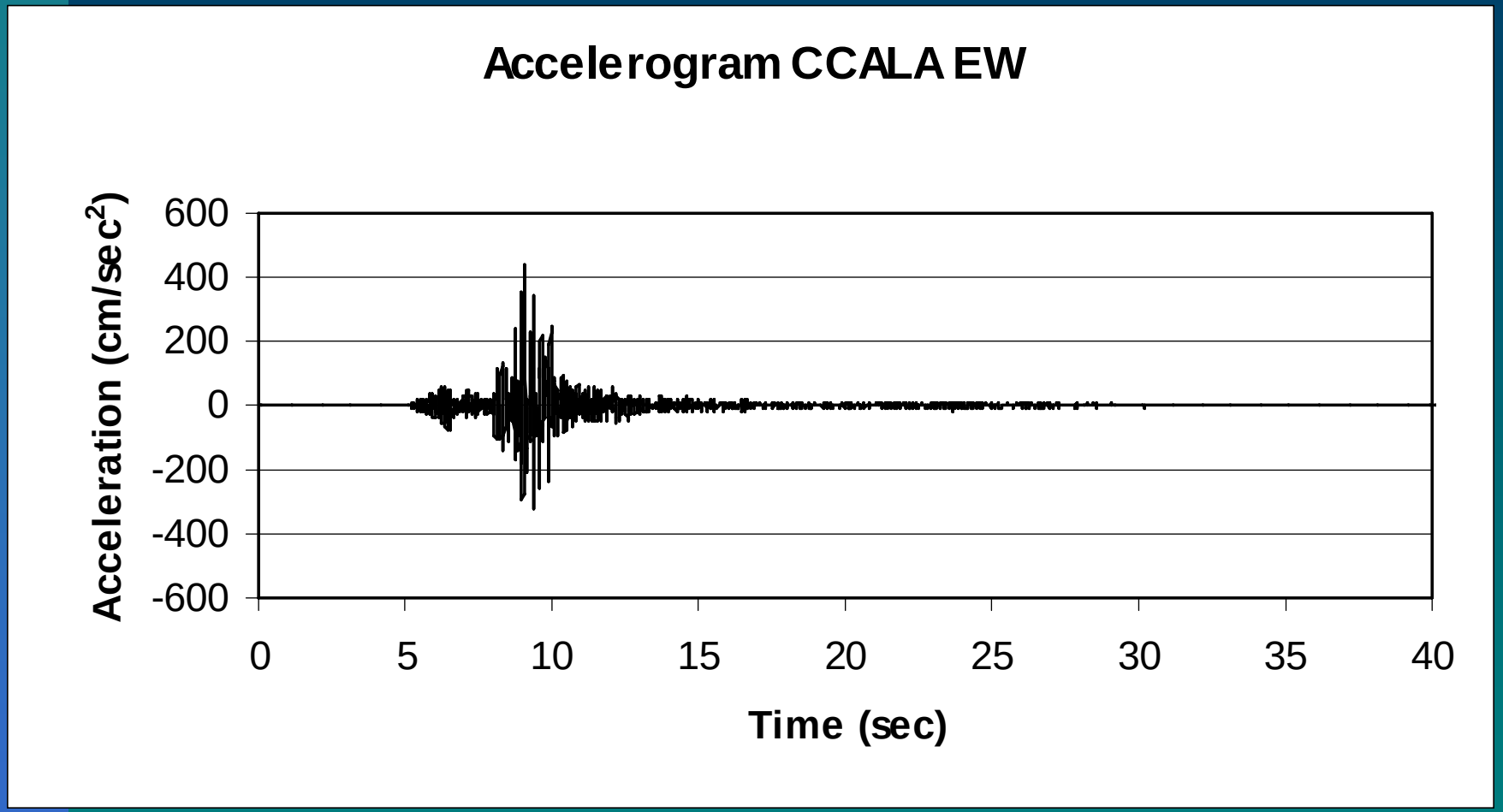
- For reconstruction purposes the inventory gives a good impression of the damage and of major geological, geotechnical, and morphological features that have influenced the damage inflicted on surface structures The presence of such features can then be considered in the planning for reconstruction.

Results Aerial Photographs Damage Inventory (Cont.)

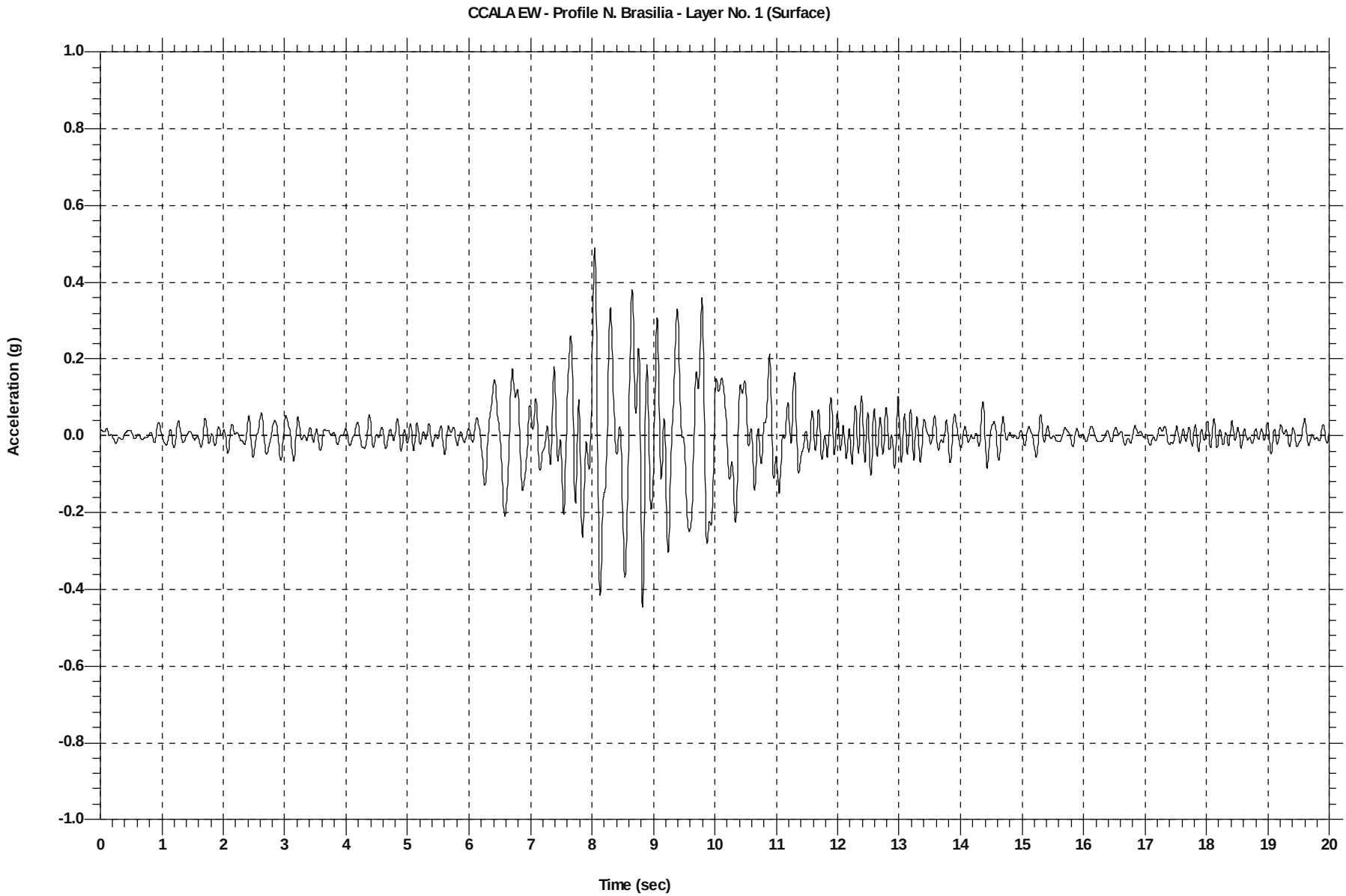
The results of an inventory of damage by aerial photographs can be available more rapidly after an earthquake, as compared to a ground survey. This is of great benefit for relief operations and for reconstruction planning.

1D Ground response analysis

- Test case Brasilia site

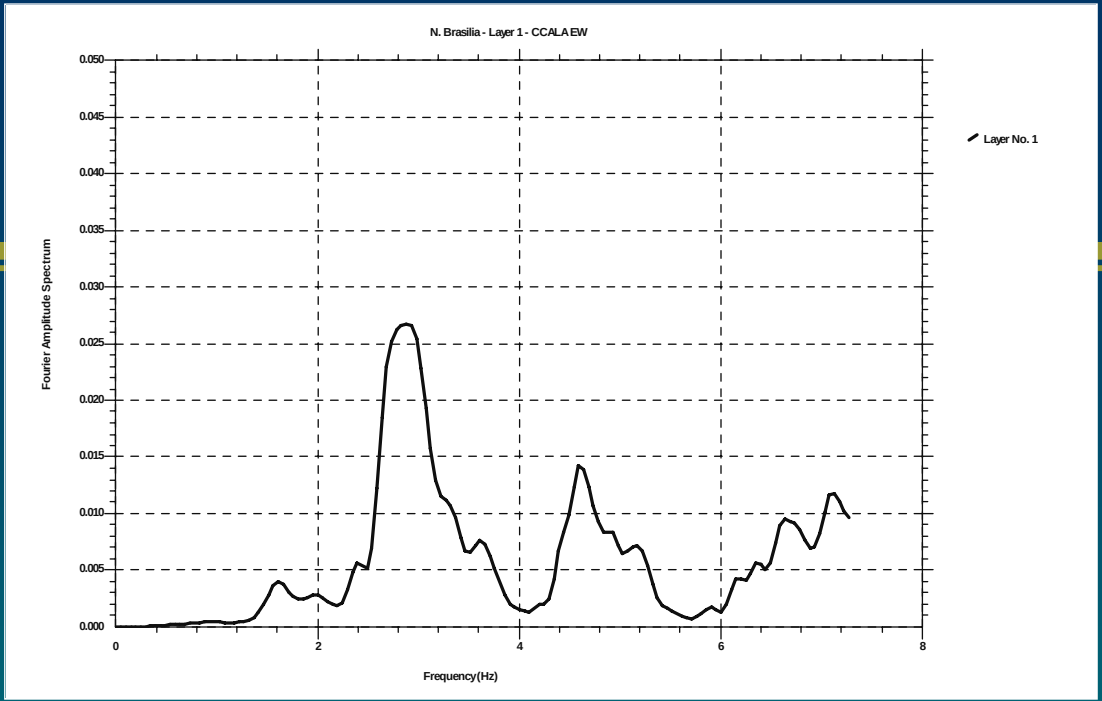


Base level (input) signal

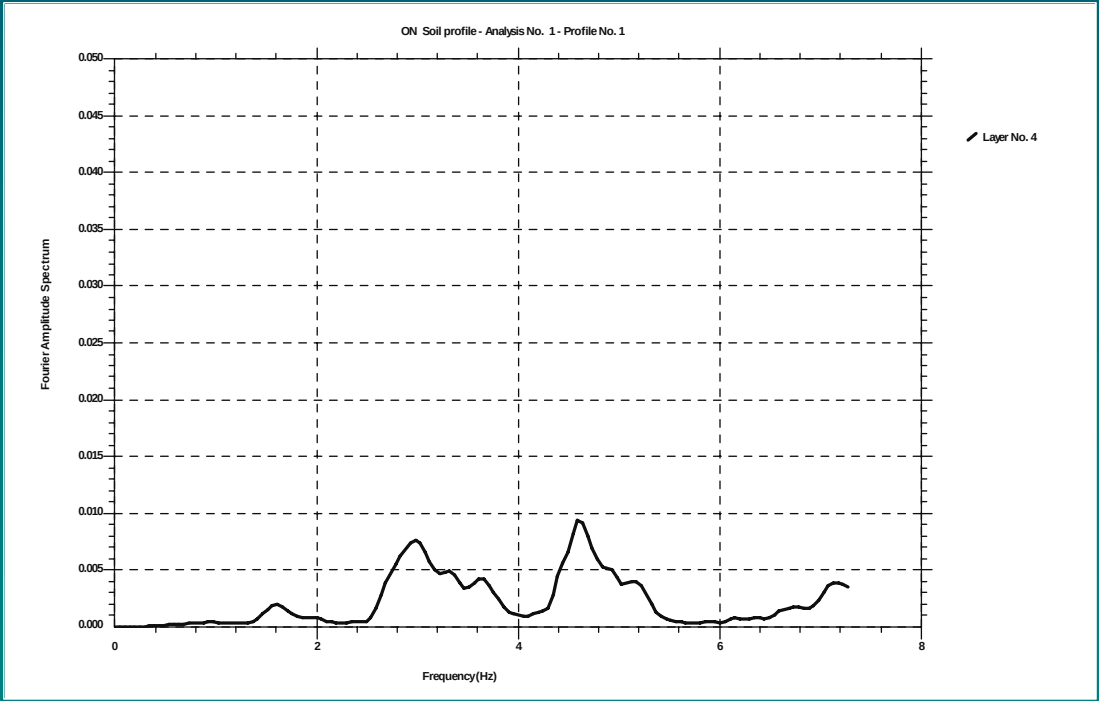


Surface (output) signal

Frequency analysis (Fourier analyses)

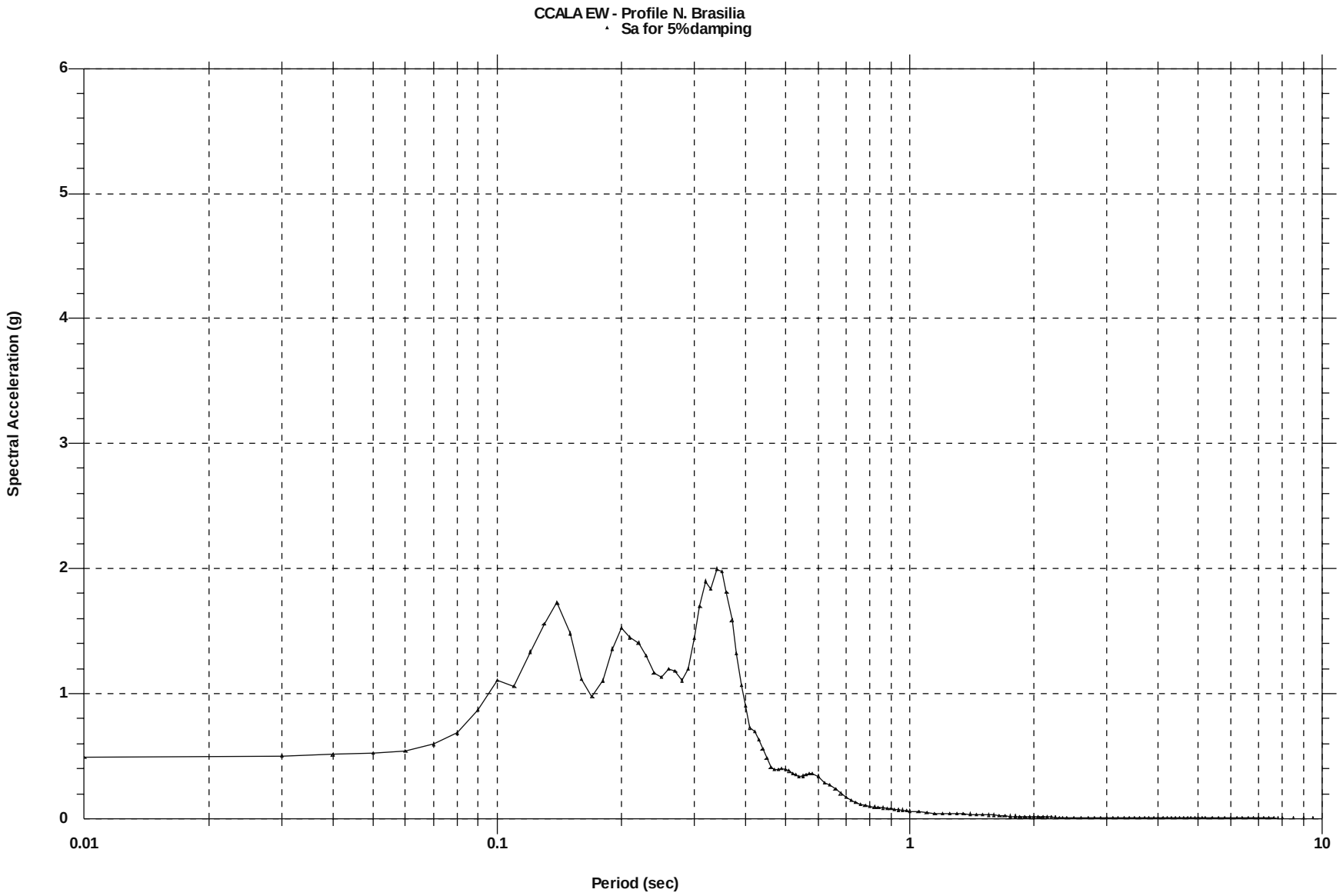


Surface (output) signal



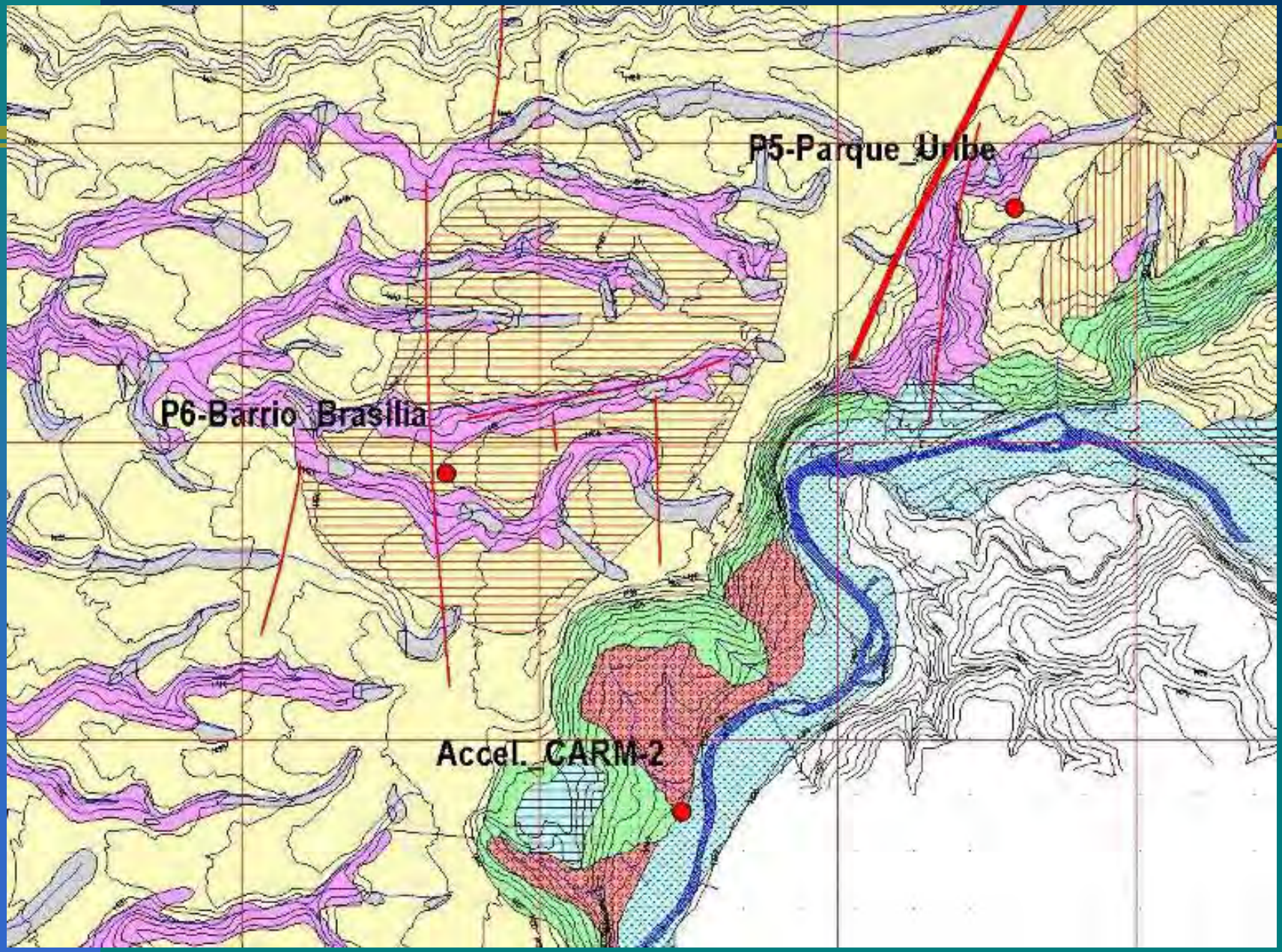
Base level (input) signal

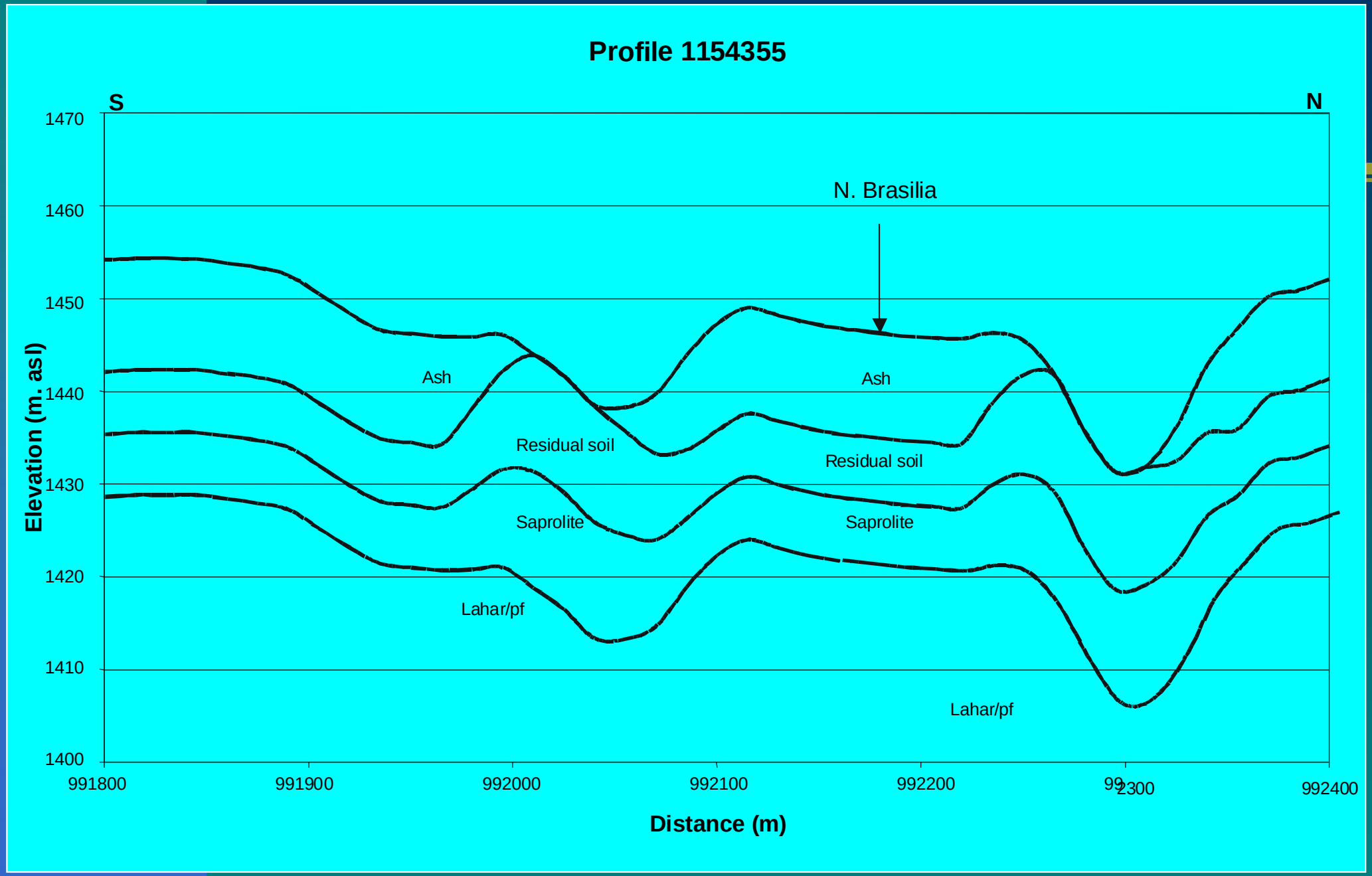
Response spectrum (at surface)

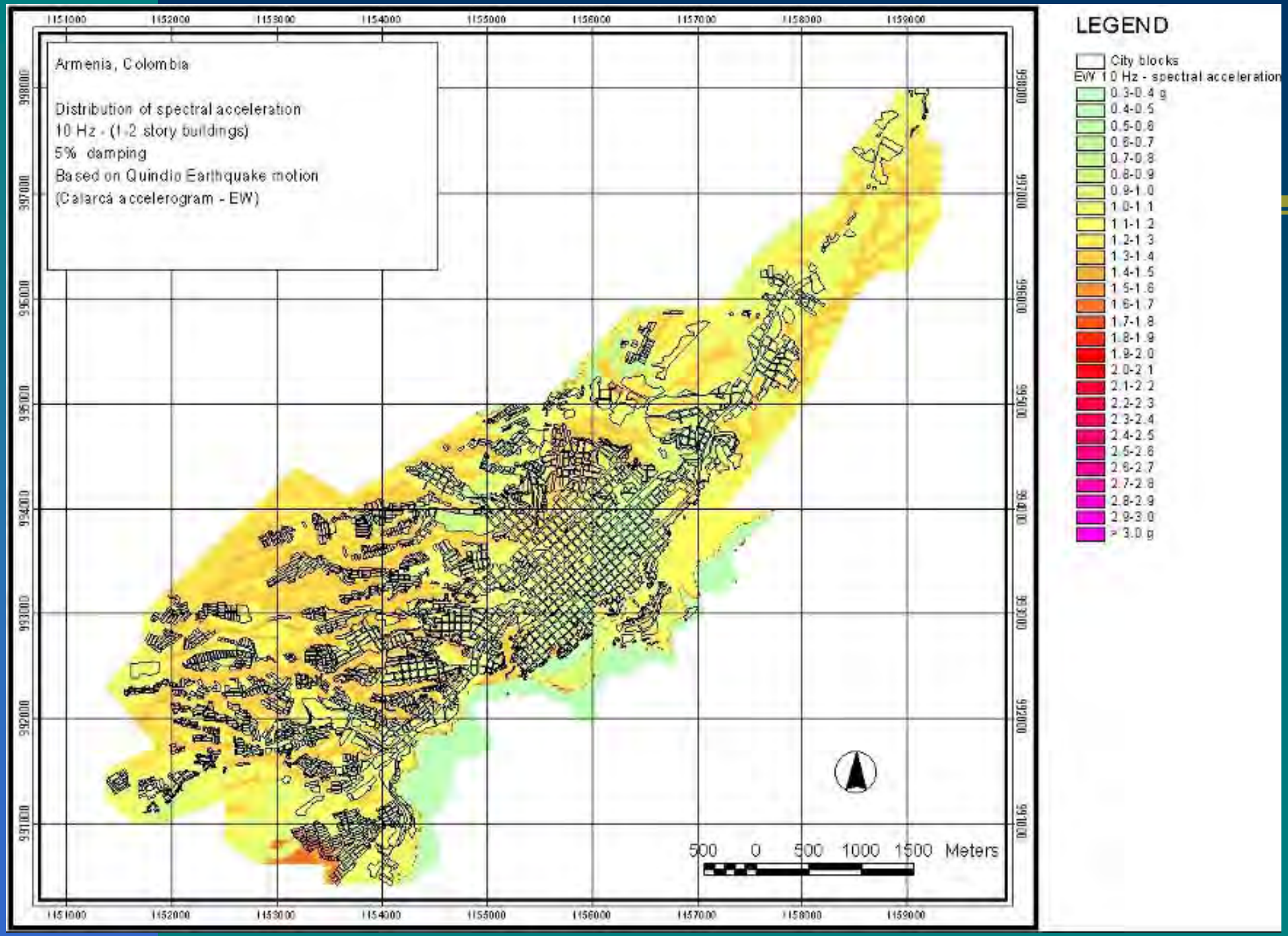


Microzonation of Armenia

- **Microzonation of Armenia**
  - Microzonation based on geotechnical model of sub-surface
  - Coupling between GIS and Shake
  - Automatic response calculation for each grid cell
  - Dimensions grid cells 15 x 15 m

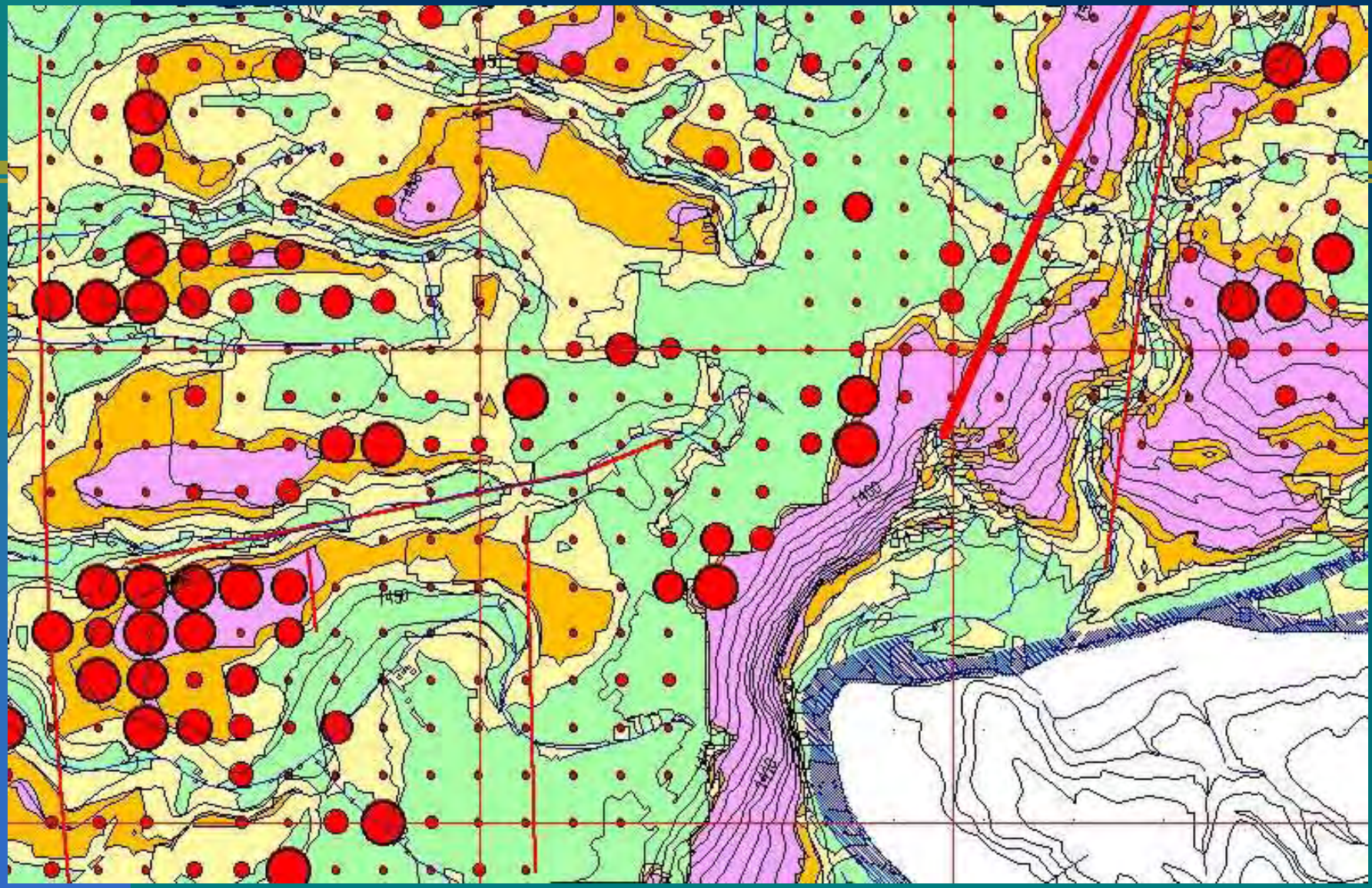

P5-Parque_Uribe
P6-Barrio_Brasilia
Accel_CARM-2


Profile 1154355
S
N
1470
1460
1450
1440
1430
1420
1410
1400
Elevation (m. asl)
N. Brasilia
Ash
Ash
Residual soil
Residual soil
Saprolite
Saprolite
Lahar/pf
Lahar/pf
991800
991900
992000
992100
992200
992300
992400
Distance (m)


Armenia, Colombia
Distribution of spectral acceleration
10 Hz - (1-2 story buildings)
5% damping
Based on Quindio Earthquake motion
(Calarcá accelerogram - EW)
LEGEND
City blocks
EW 10 Hz - spectral acceleration
0.3-0.4 g
0.4-0.5
0.5-0.6
0.6-0.7
0.7-0.8
0.8-0.9
0.9-1.0
1.0-1.1
1.1-1.2
1.2-1.3
1.3-1.4
1.4-1.5
1.5-1.6
1.6-1.7
1.7-1.8
1.8-1.9
1.9-2.0
2.0-2.1
2.1-2.2
2.2-2.3
2.3-2.4
2.4-2.5
2.5-2.6
2.6-2.7
2.7-2.8
2.8-2.9
2.9-3.0
> 3.0 g
500 0 500 1000 1500 Meters

Two-dimensional Topographic Effects

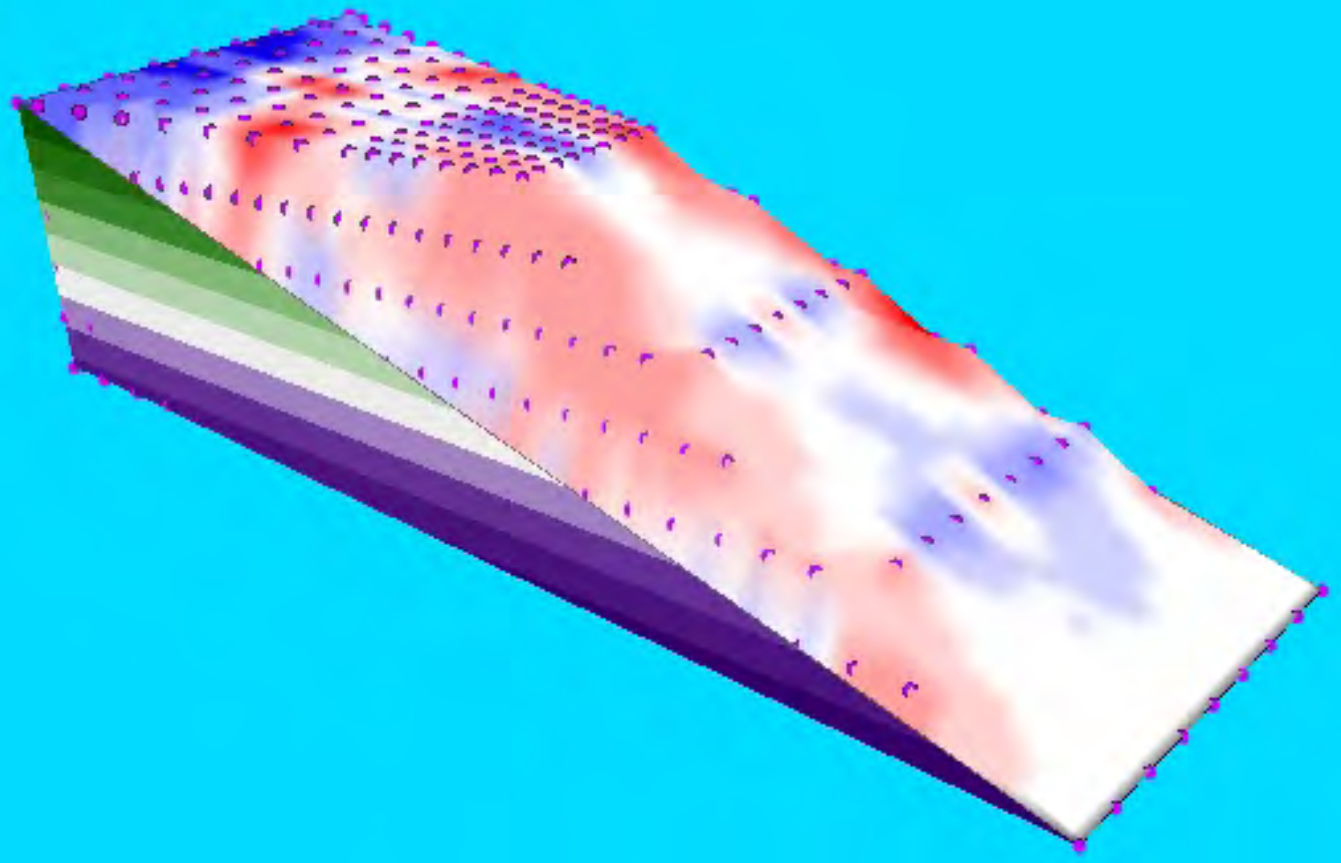
- Qualitative calculation topographic effects
- Correlated with damage pattern



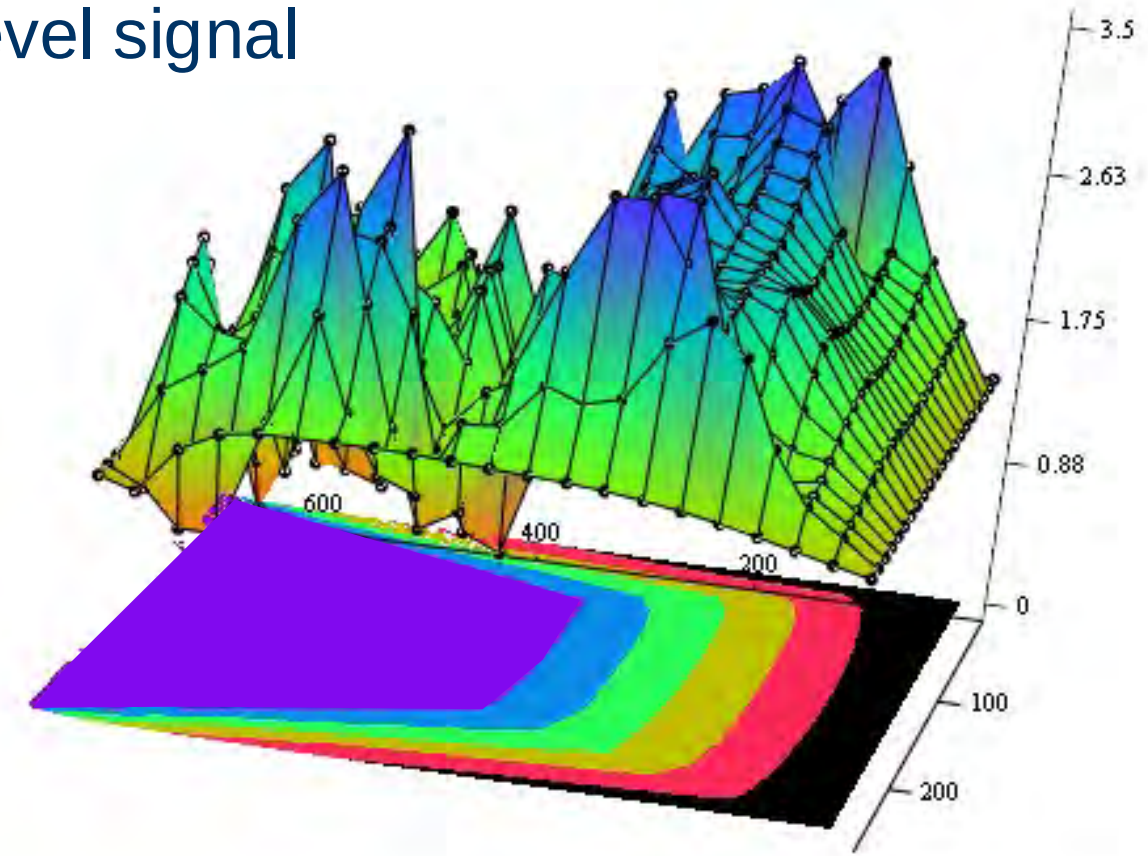
Three-dimensional Effects

- Three-dimensional modeling of topographic effects – Brasilia area
- Surface accelerations are up to 2 to 4 times the base level (input) accelerations

Surface acceleration as result of 3D modeling: red is high; blue is low acceleration



Surface acceleration as result of 3D modeling: maximum acceleration ≈ 3 m/s2 which is about 3 to 4 times the maximum in the base level signal

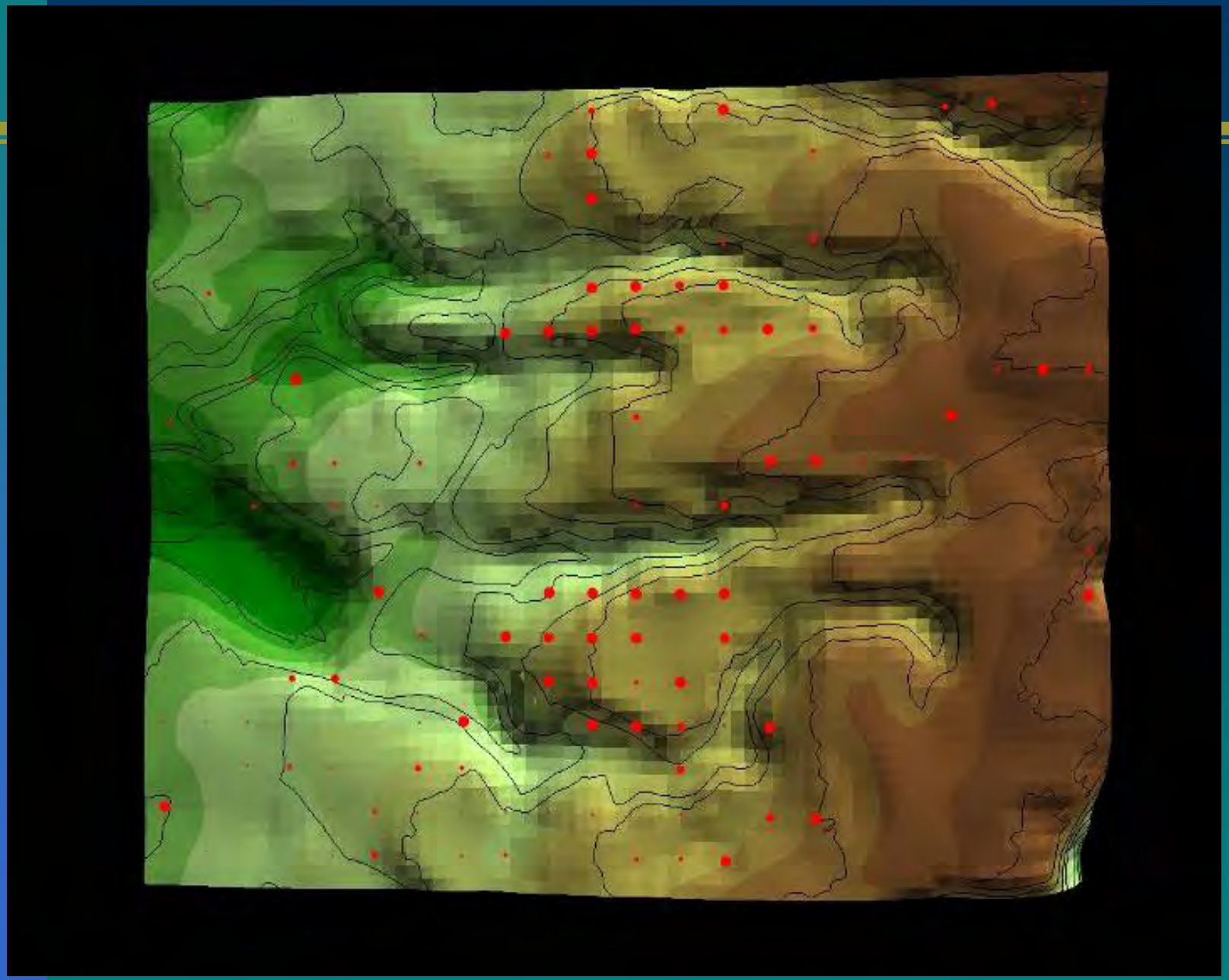


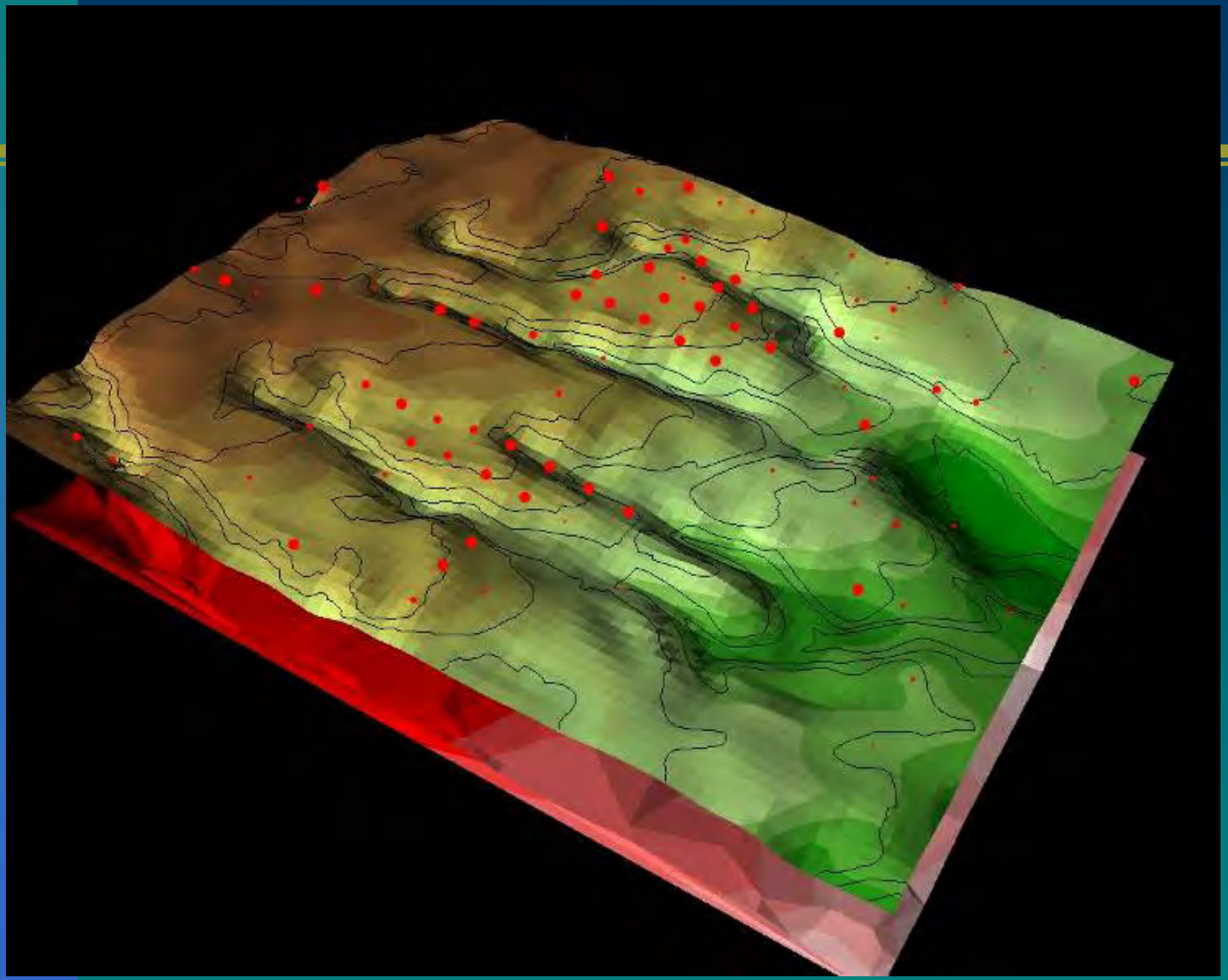
Limitations

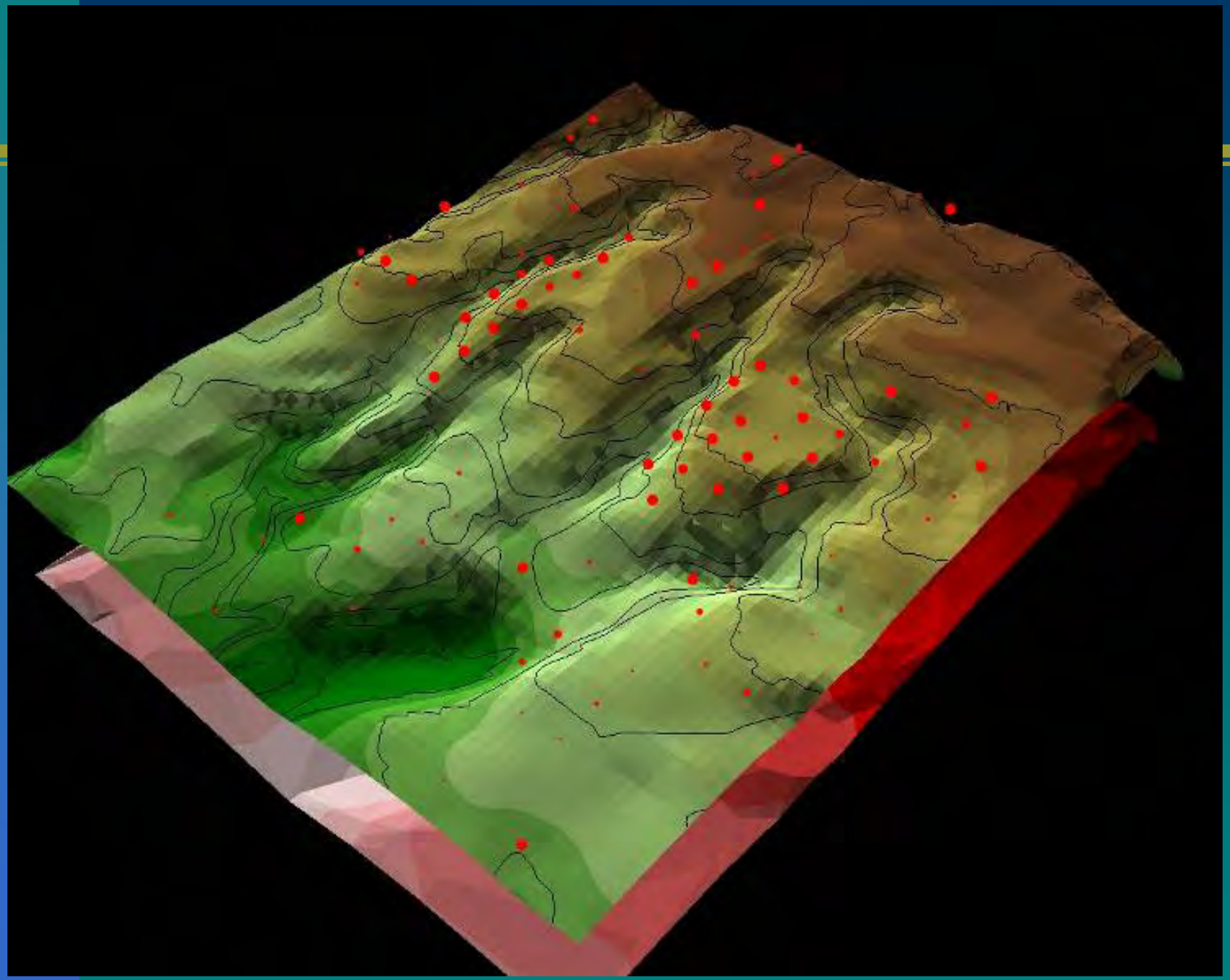
- Few data on sub-surface available
- Simplified model
- Only for the characteristics of the 25 January 1999 earthquake

Information Technology

- The development of an information technology environment for Pereira and Armenia will allow fast analyses, visualization, and production of damage inventory, for recommendations for reconstruction after future earthquakes







Structural Observations

- Visual structural analyses:
  - Flat slabs on columns
  - Torsional buildings
  - Lateral reinforcement in columns
  - Short-columns
  - Masonry in-fills
  - Soft-stories
  - Concrete quality

Flat Slabs and Columns

This structural system has been known to be a non-ductile system since the only available energy-dissipating members are the columns.

Solution is weak-beams-strong-columns methodology, usually known as capacity design.

Torsional Resistance

The severe column damages in the columns at the periphery of the building is a strong indication of lack of torsional resistance.

Shear Reinforcement and Lateral Ties

Columns had failed in shear at the points of maximum bending moment due to not adequately anchored shear reinforcement. Frequently, buckling of the main reinforcing bars was also evident. **Lateral ties** were not adequate in providing lateral support to the main bars causing the concrete to be crushed to rubble

Short-columns

Some typical cases of short-column behaviour were observed. In all of these the reason was the interaction of the column with adjacent (non-structural) elements.

Masonry In-fill

Workmanship problems were observed in the majority of damaged masonry in-fills. As a result, collapse of the in-fill prevented failure of the adjacent columns. In all cases it was observed that the in-fill was constructed totally against the column.

Embedded Utilities

Utility items embedded in the body of the masonry wall. These can create planes of weakness in the body of the wall which can then fail by slippage. In one case, slippage failure of the wall had clearly resulted to shear failure of the adjacent column.

Soft-stories

Soft-storeys. The reduction of the stiffness at a certain level of the building, typically at one of the bottom floors, results in severe damage in the top and bottom of vertical structural elements due to lack of lateral reinforcement.

Concrete Quality

In some cases, high sand percentages were observed. Also, the gradation characteristics of the concrete mixes seem to be not complete. Both of these can lead to concrete of inferior strength and reduced ductility.

Conclusions

- Rapid inventory by aerial photographs gives fast and decent input for reconstruction planning
- Information technology environment gives possibilities for rapid analyses, visualization and production of maps
- Measures (often simple and cheap measures) in structural engineering will avoid large damage in future

Recommendations

- Seismology investigation to determine frequency of occurrence and characteristics of future earthquakes
- Public awareness campaign