The 2023 Kahramanmaras earthquakes of February 6th in Turkey

Los terremotos de Kahramanmaras de 2023 del 6 de Febrero en Turquía

Evangelia GARINI and **George GAZETAS**

School of Civil Engineering, Geotechnical Department

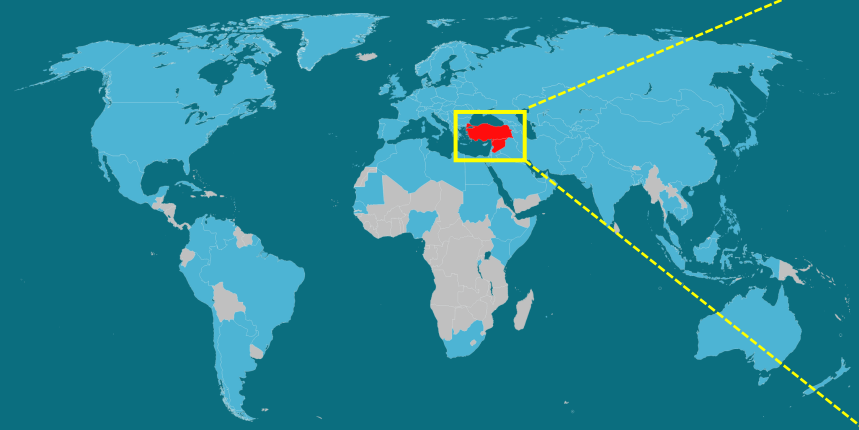
National Technical University of Athens, Greece

A journey from Hispaniola to Turkey

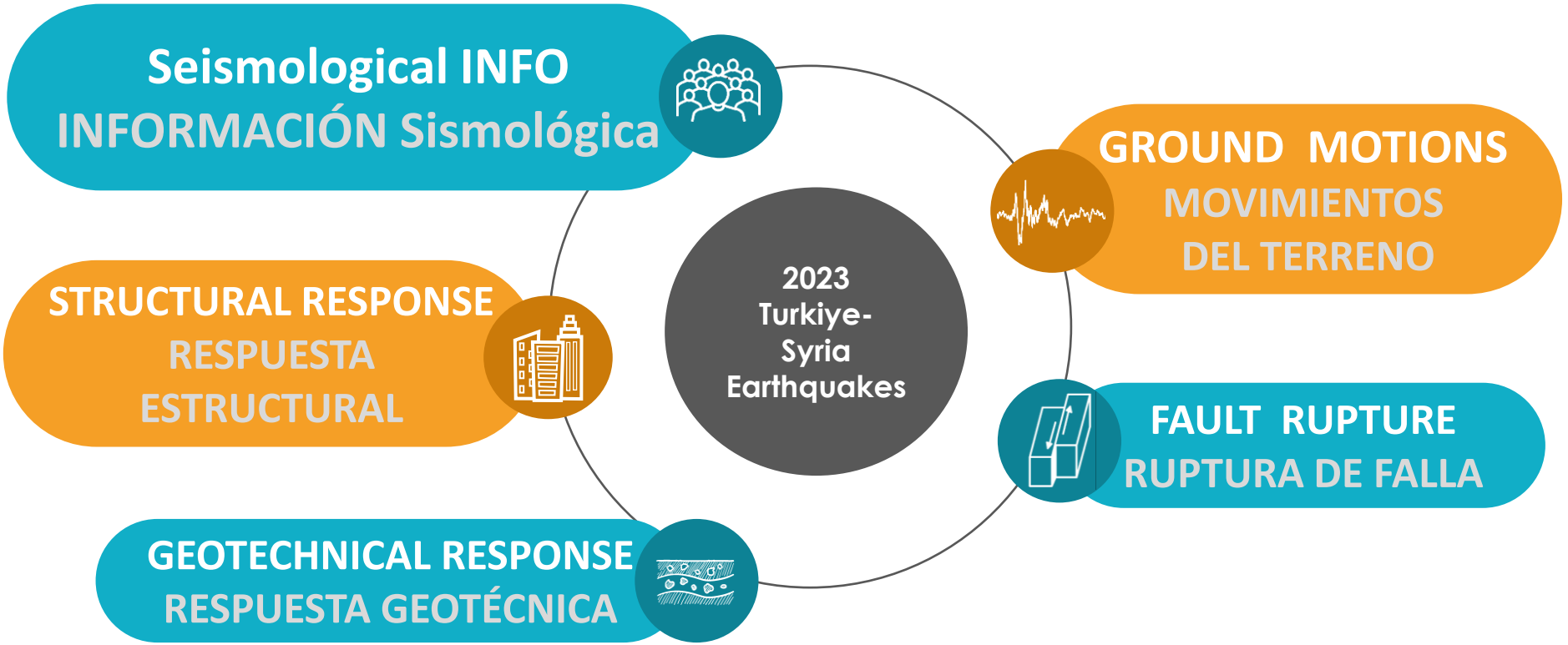
Un viaje de La Española a Turquía

THE 2023 TURKIYE-SYRIA EARTHQUAKES

LOS TERREMOTOS DE 2023 EN TURQUÍA Y SIRIA



Glance over


Seismological INFO
INFORMACIÓN Sismológica
GROUND MOTIONS
MOVIMIENTOS DEL TERRENO
2023 Turkiye-Syria Earthquakes
STRUCTURAL RESPONSE
RESPUESTA ESTRUCTURAL
FAULT RUPTURE
RUPTURA DE FALLA
GEOTECHNICAL RESPONSE
RESPUESTA GEOTÉCNICA

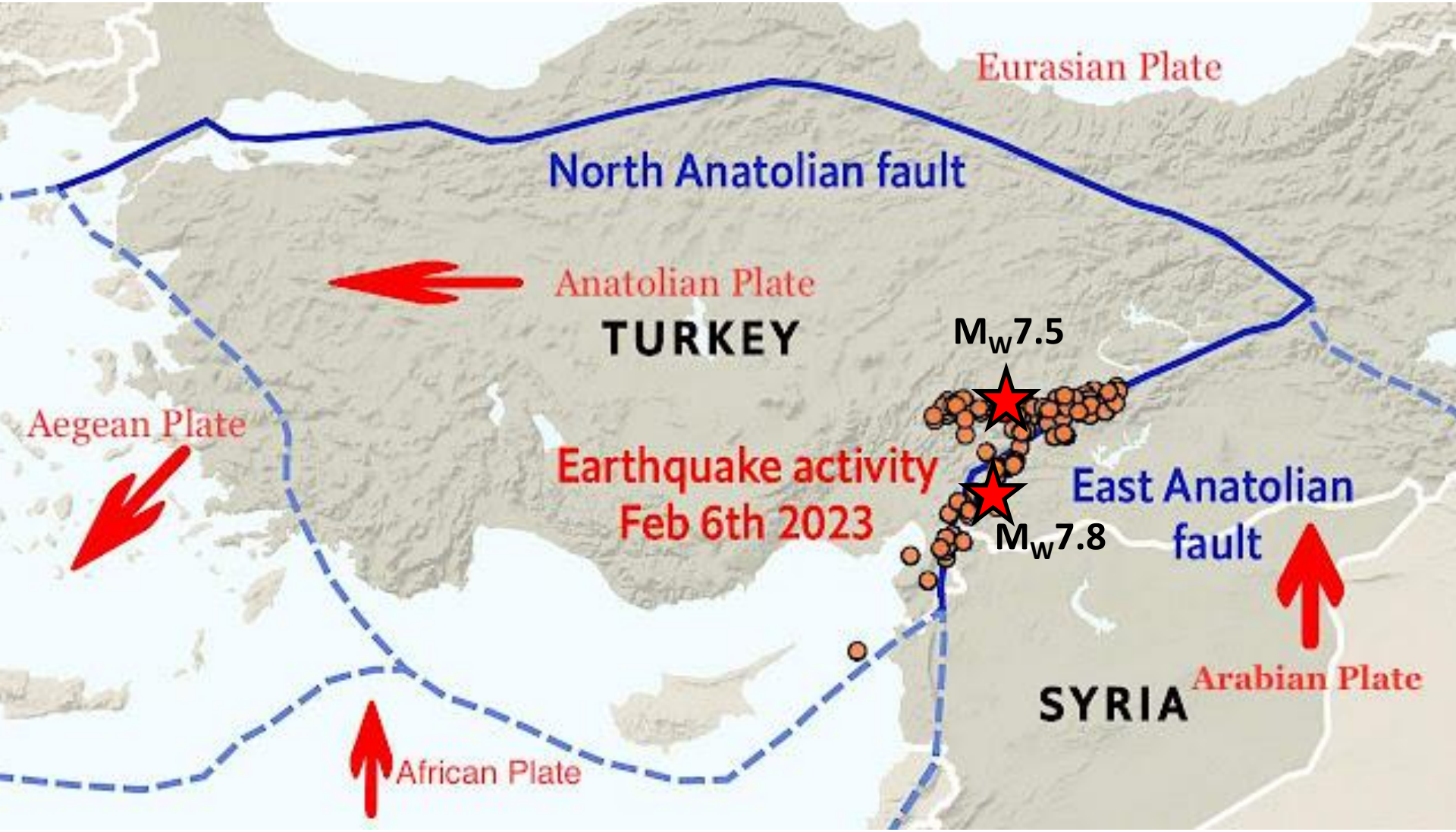
Glance over

Seismological INFO
INFORMACIÓN Sismológica

2023 Turkiye-Syria Earthquakes

Seismotectonic Map of Anatolian Plate

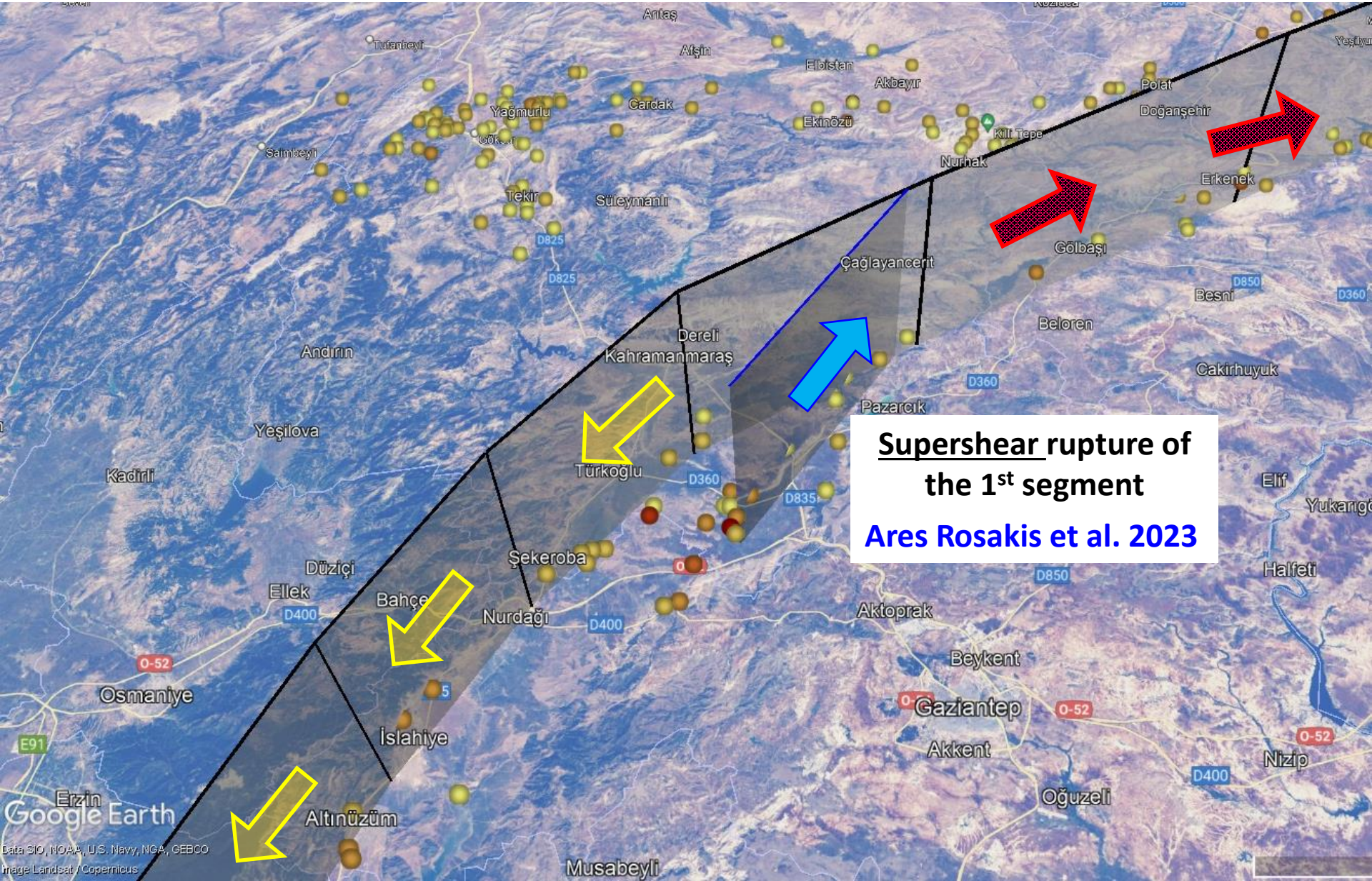
Mapa sismotectónico de la placa de Anatolia



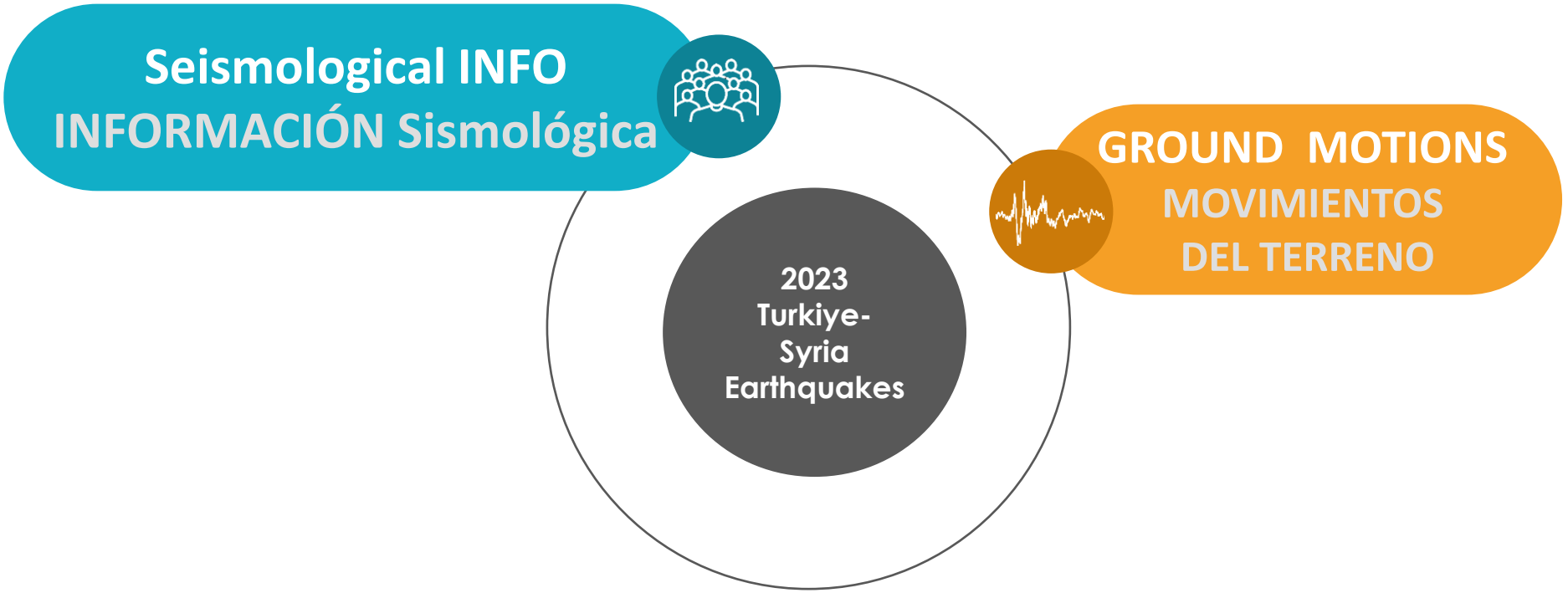
Kayseri
Elâzığ
Malatya
Afşin
Elbistan
Diyarbakır
M_W 7.5
Adıyaman
Siverek
Kahramanmaraş
M_W 6.7
M_W 7.8
Şanlıurfa
O-52
Osmaniye
Gaziantep
Nizip
Adana
O-52
Kilis
İskenderun
M4
M4
Antakya
Ar Raqqah
M_W 6.5
M4
M5

Seismotectonic Phenomena observed in the M_W 7.8 earthquake

Fenómenos sismotectónicos observados en el sismo de M_W 7.8



Glance over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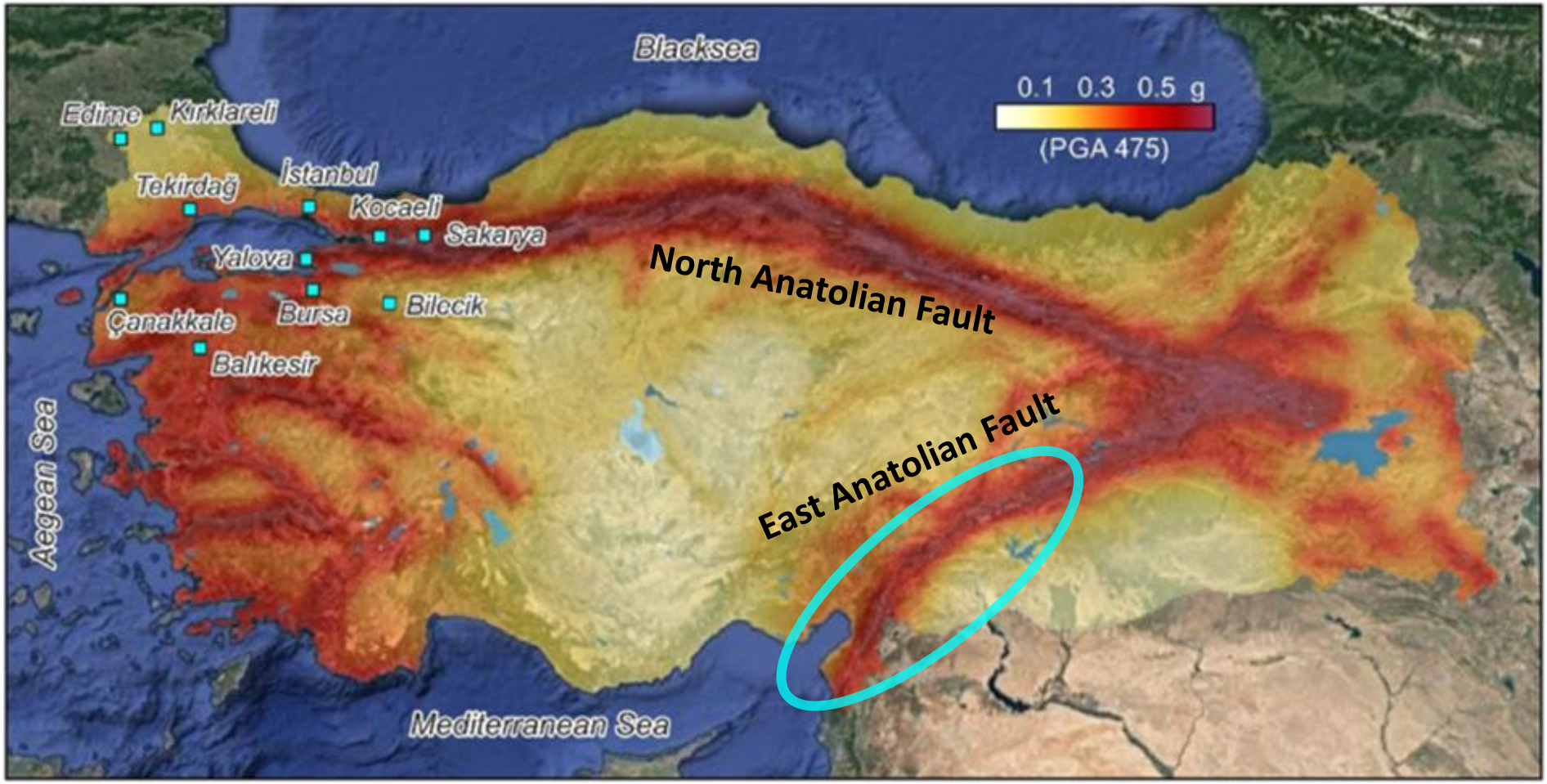
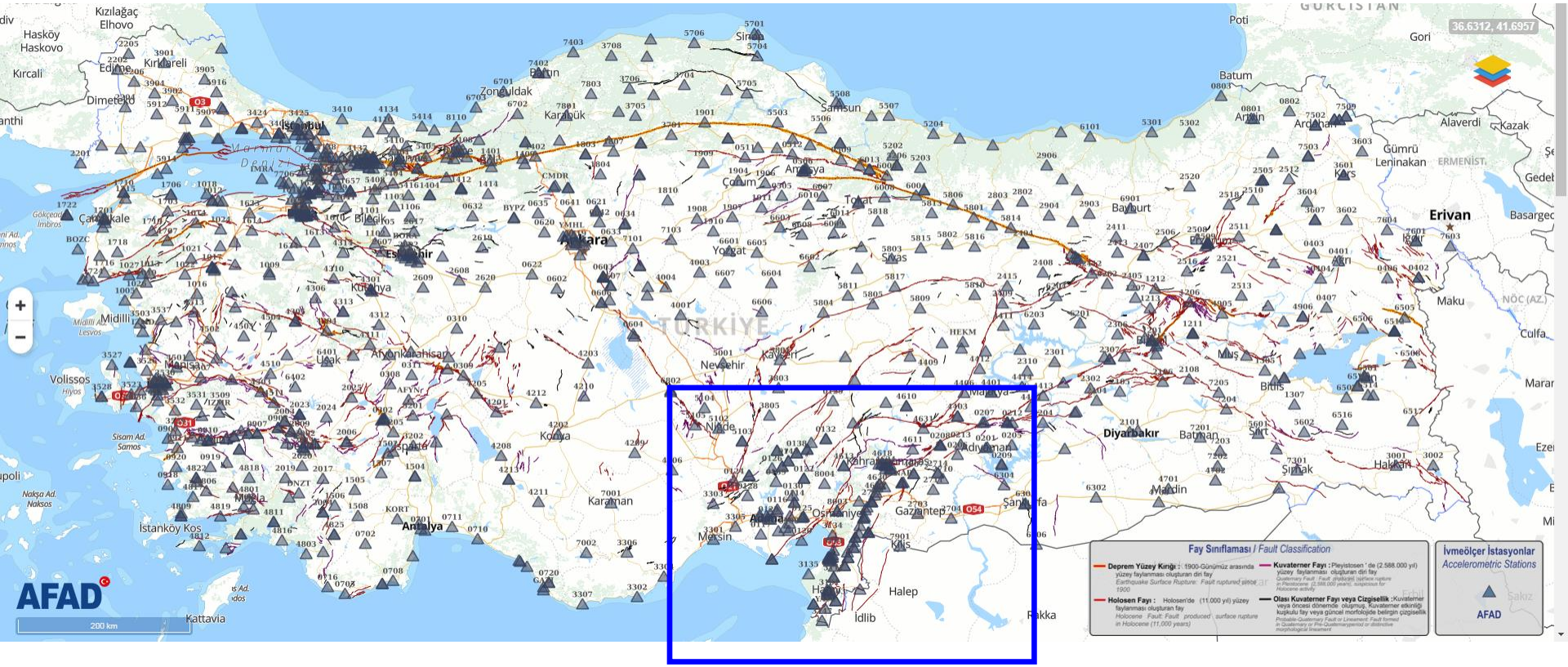
The NEW Turkish Seismic Code 2018 (TBEC-2018)

El NUEVO Código Sísmico Turco 2018



The outstanding Strong Motion Network of Turkey

La Excelente Red de Movimientos Fuerte de Turquía

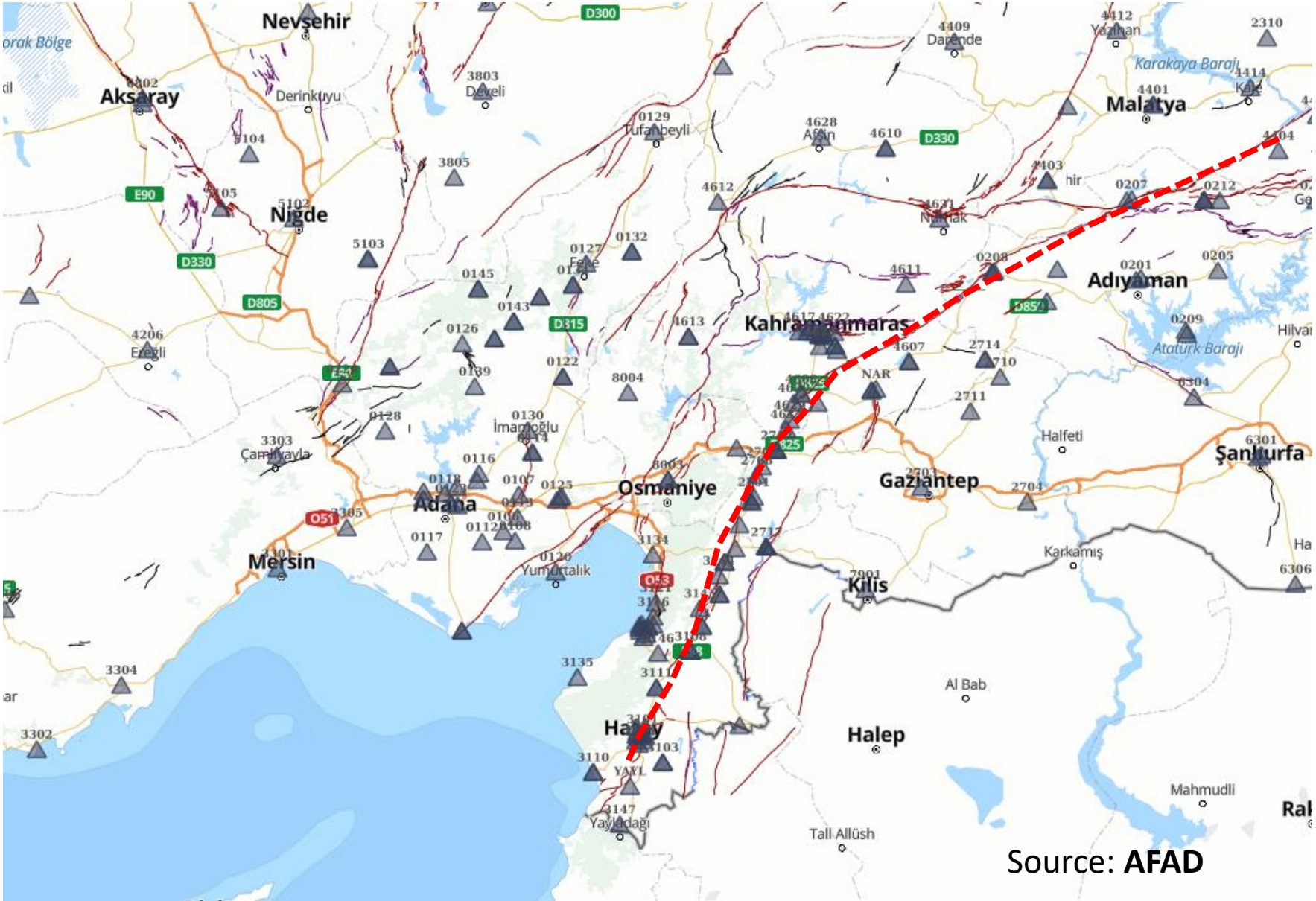


Total: 857 recording stations !!!

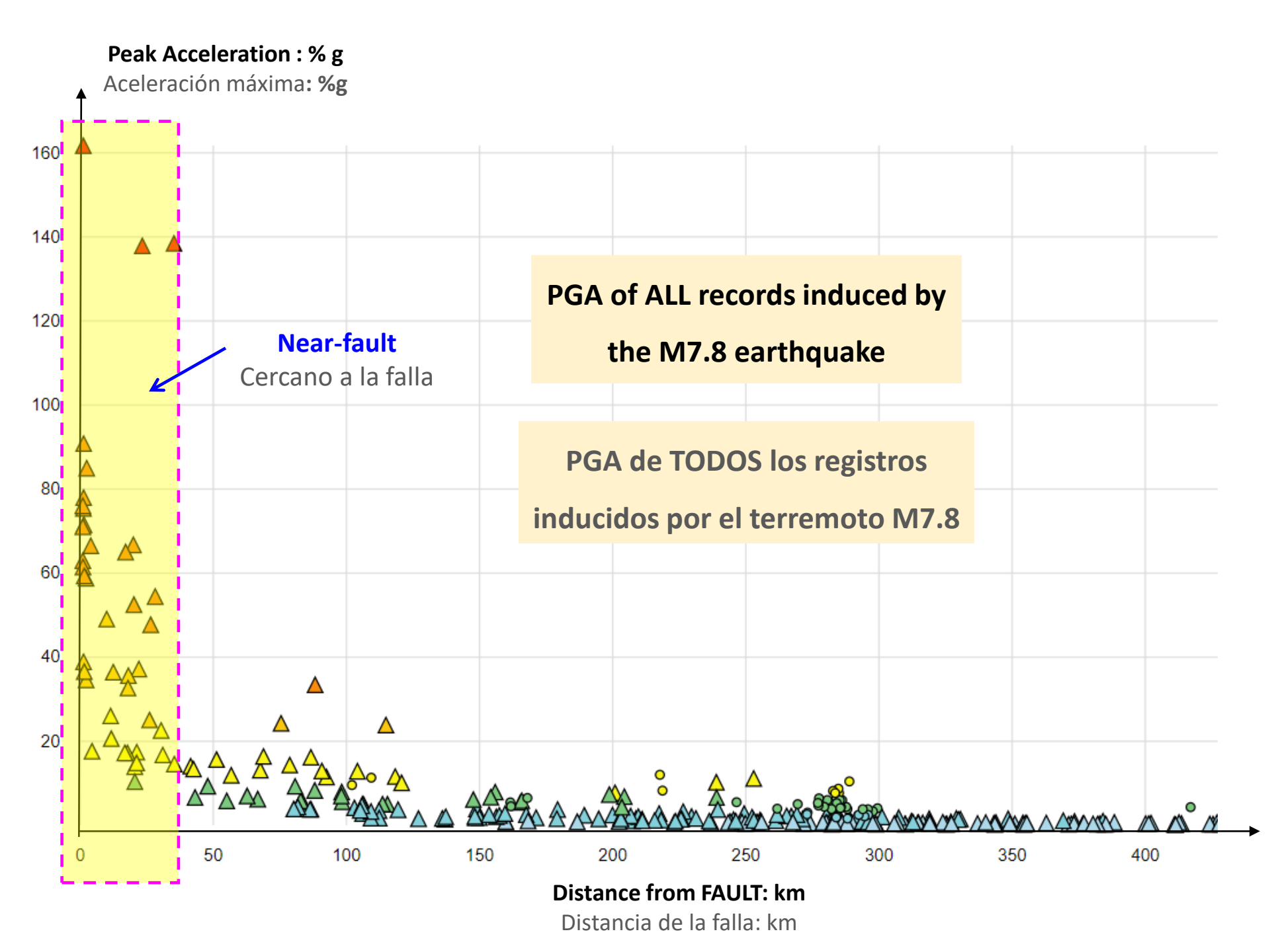
Total: ¡¡¡857 estaciones de grabación!!!

Turkish Strong Ground Motion Network

Red turca de movimientos fuertes

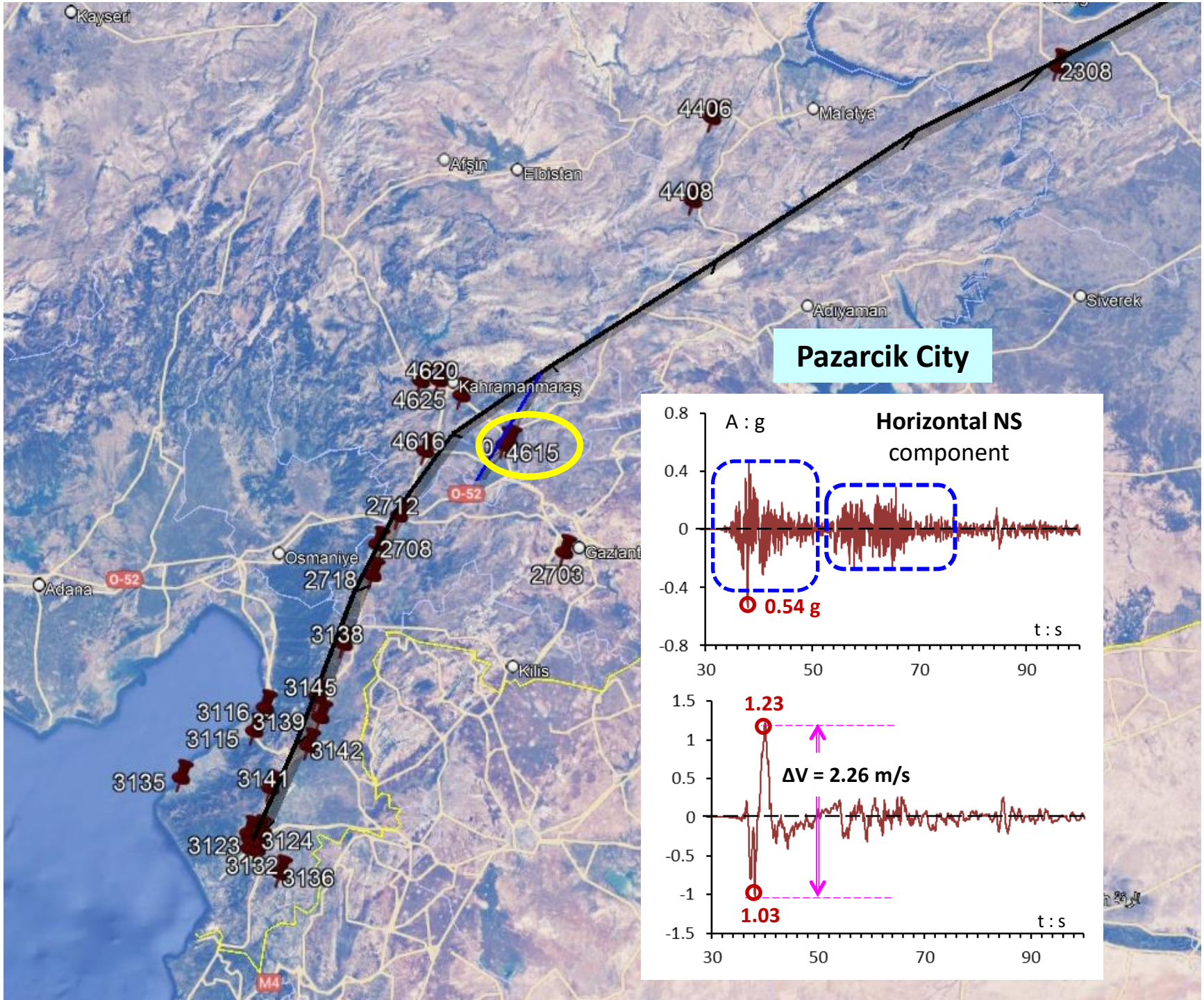


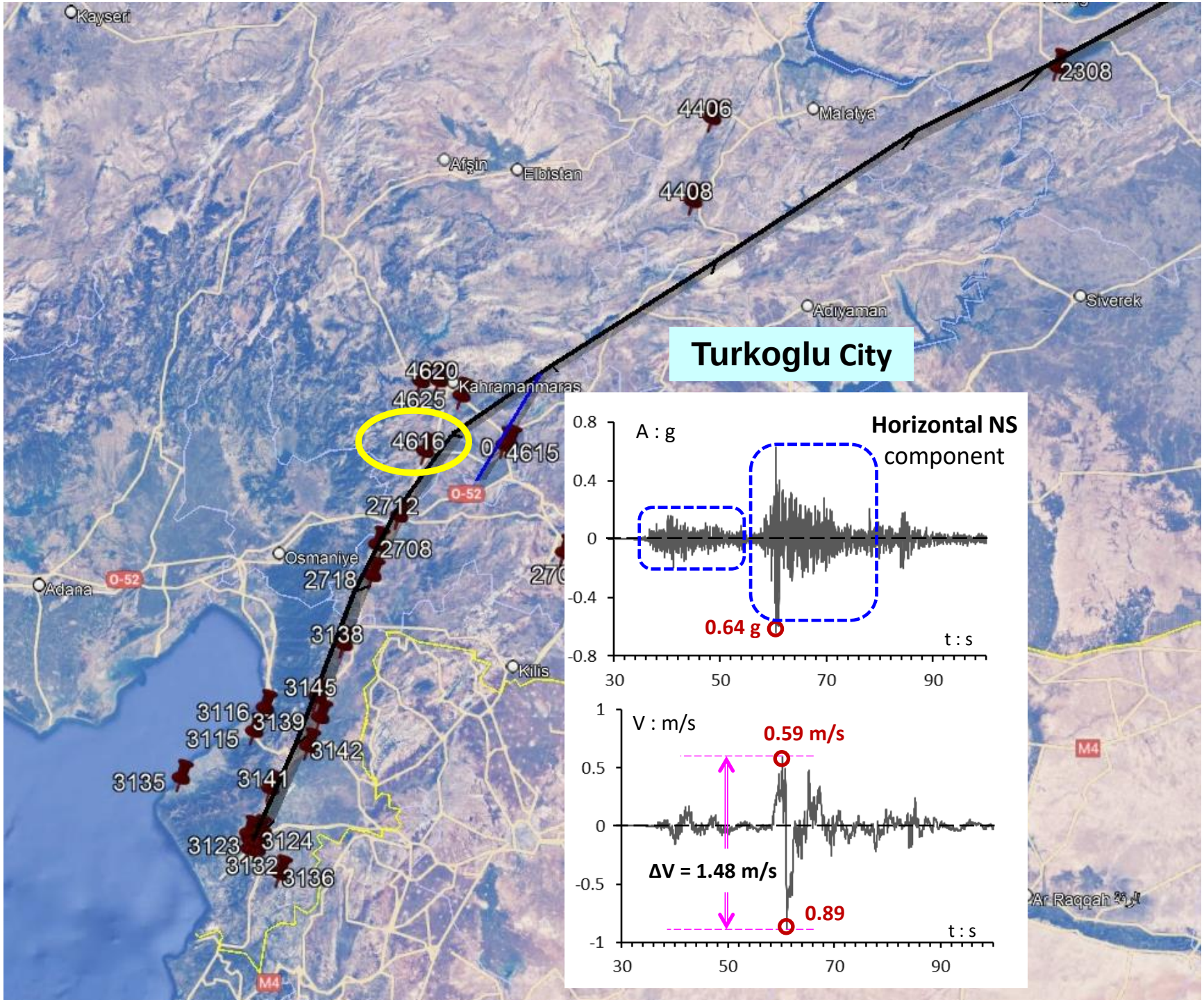
Source: **AFAD**


Peak Acceleration : % g
Aceleración máxima: %g
160
140
120
100
80
60
40
20
Near-fault
Cercano a la falla
PGA of ALL records induced by the M7.8 earthquake
PGA de TODOS los registros inducidos por el terremoto M7.8
0
50
100
150
200
250
300
350
400
Distance from FAULT: km
Distancia de la falla: km

Strong Ground Motions along the Fault Rupture

Movimientos fuertes a lo largo de la ruptura de la falla


Kayseri
2308
4406
Malatya
Afşin
Elbistan
4408
Adıyaman
Siverek
Pazarcik City
4620
Kahramanmaraş
4625
4616
4615
O-52
2712
2708
Osmaniye
Gaziant
2703
Adana
O-52
2718
3138
Kilis
3145
3116
3139
3115
3142
3135
3141
3123
3124
3132
3136
M4
Horizontal NS component
A : g
0.8
0.4
0
-0.4
-0.8
0.54 g
t : s
30
50
70
90
1.5
1
0.5
0
-0.5
-1
-1.5
1.23
ΔV = 2.26 m/s
1.03
t : s
30
50
70
90


Turkoglu City
Horizontal NS component
A : g
0.64 g
t : s
V : m/s
0.59 m/s
ΔV = 1.48 m/s
0.89
t : s
Kayseri
Malatya
Afşin
Elbistan
Adıyaman
Siverek
Kahramanmaraş
Osmaniye
Adana
Kilis
Ar Raqqah
2308
4406
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4620
4625
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4615
2712
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2718
3138
3145
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3139
3115
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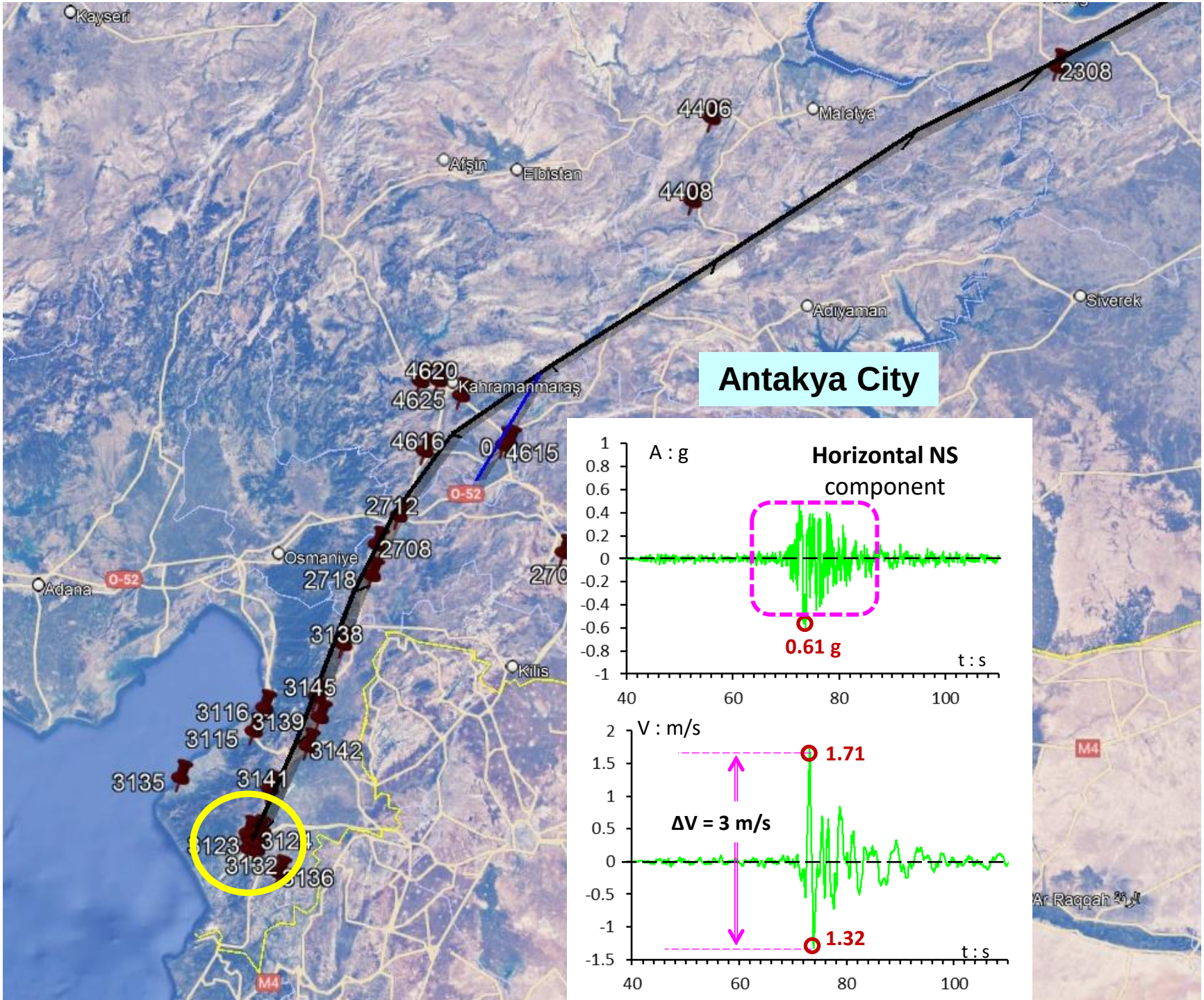
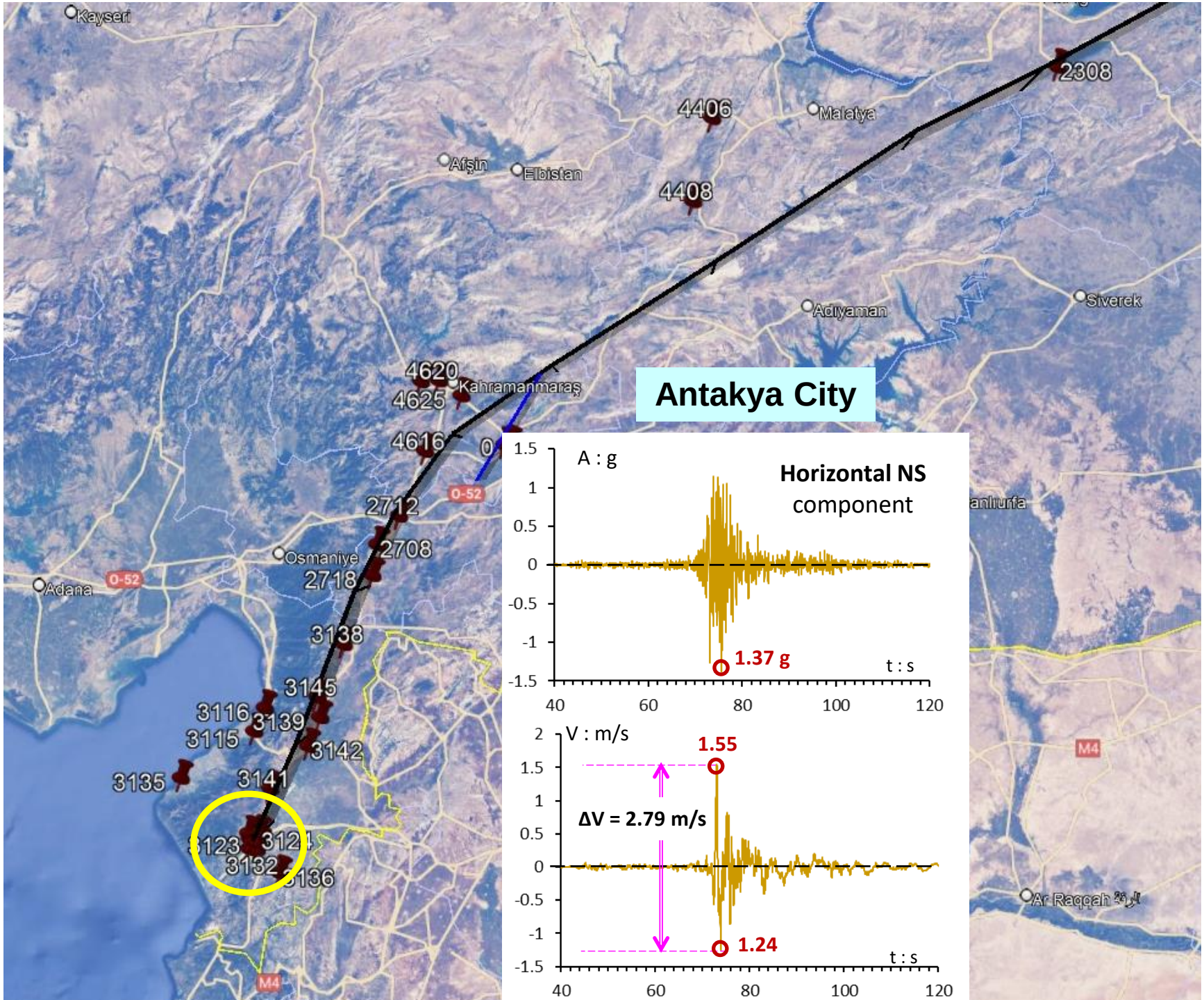
3141
3123
3124
3132
3136
O-52
M4


Kayseri
2308
4406
Malatya
Afşin
Elbistan
4408
Adıyaman
Siverek
Antakya City
4620
Kahramanmaraş
4625
4616
0
4615
O-52
2712
2708
Osmaniye
2718
Adana
O-52
3138
Kilis
3145
3116
3139
3115
3142
3135
3141
3123
3124
3132
3136
M4
M4
Ar Raqqah
A : g
Horizontal NS component
0.61 g
t : s
V : m/s
1.71
ΔV = 3 m/s
1.32
t : s


Kayseri
2308
4406
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4620
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4625
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0
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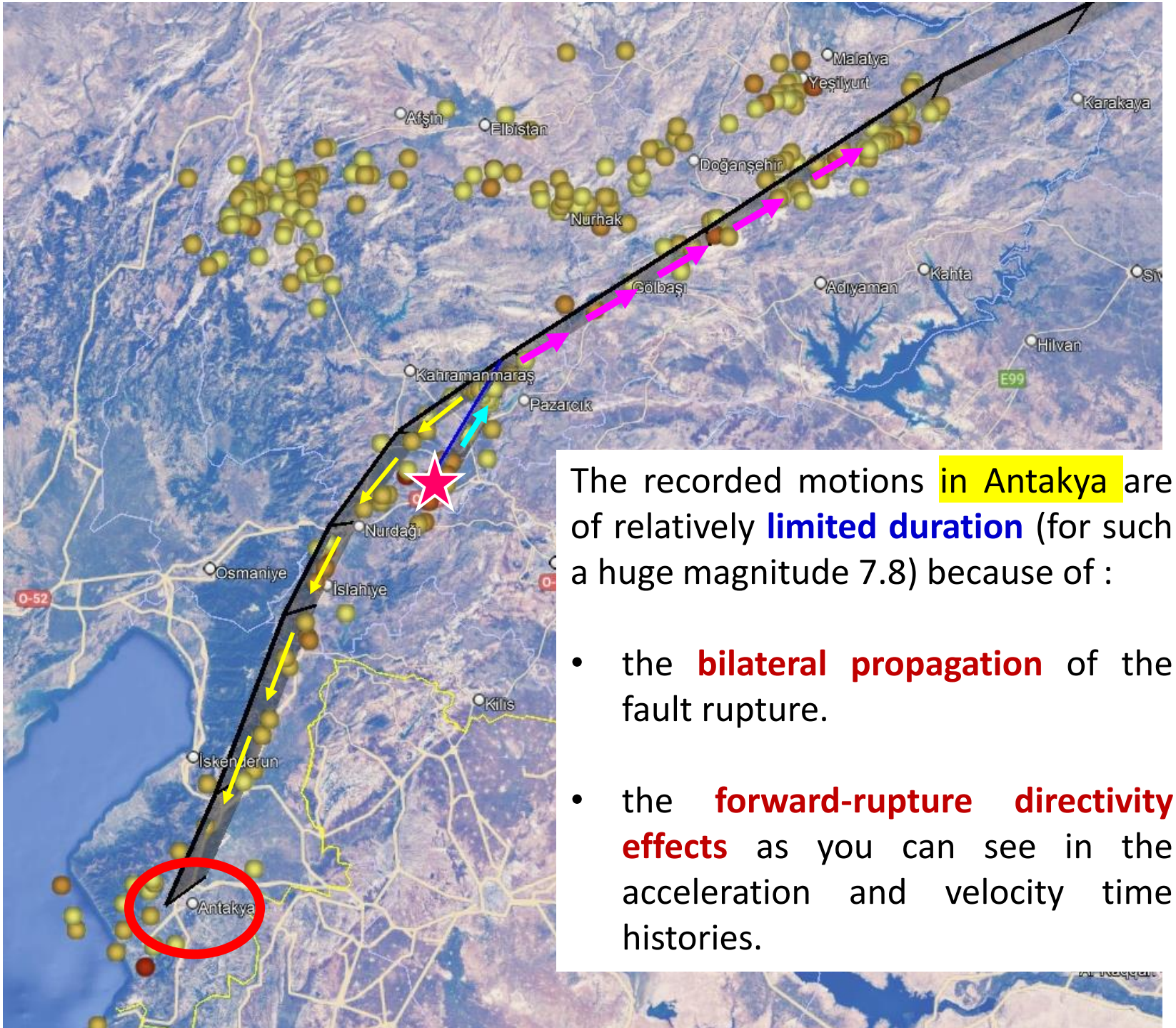
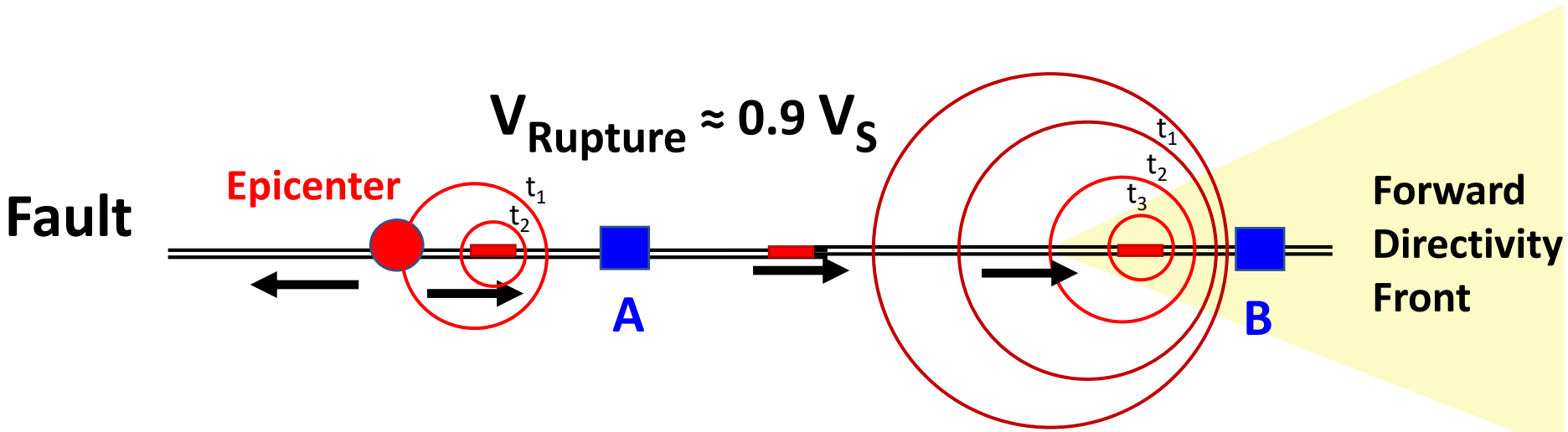
2718
Adana
O-52
3138
3145
3116
3139
3115
3142
3135
3141
3123
3124
3132
3136
M4
Antakya City
A : g
Horizontal NS component
1.37 g
t : s
V : m/s
1.55
ΔV = 2.79 m/s
1.24
t : s
M4
Ar Raqqah



The recorded motions in Antakya are of relatively **limited duration** (for such a huge magnitude 7.8) because of :

- the **bilateral propagation** of the fault rupture.
- the **forward-rupture directivity effects** as you can see in the acceleration and velocity time histories.

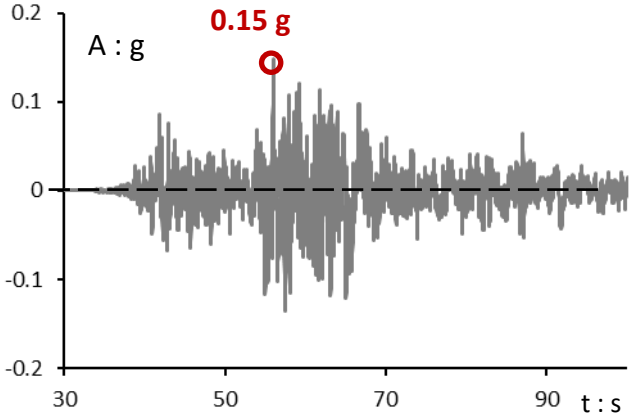
What is the forward directivity effect?



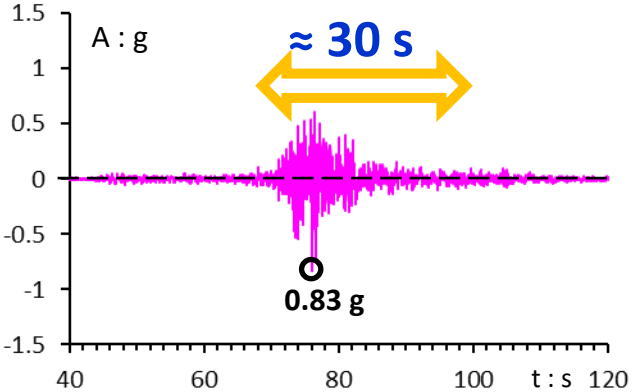
Result: the wave fronts *generated at different time instances* arrive on **site B** at the same time ⇨

⇨ **constructive interference of waves**

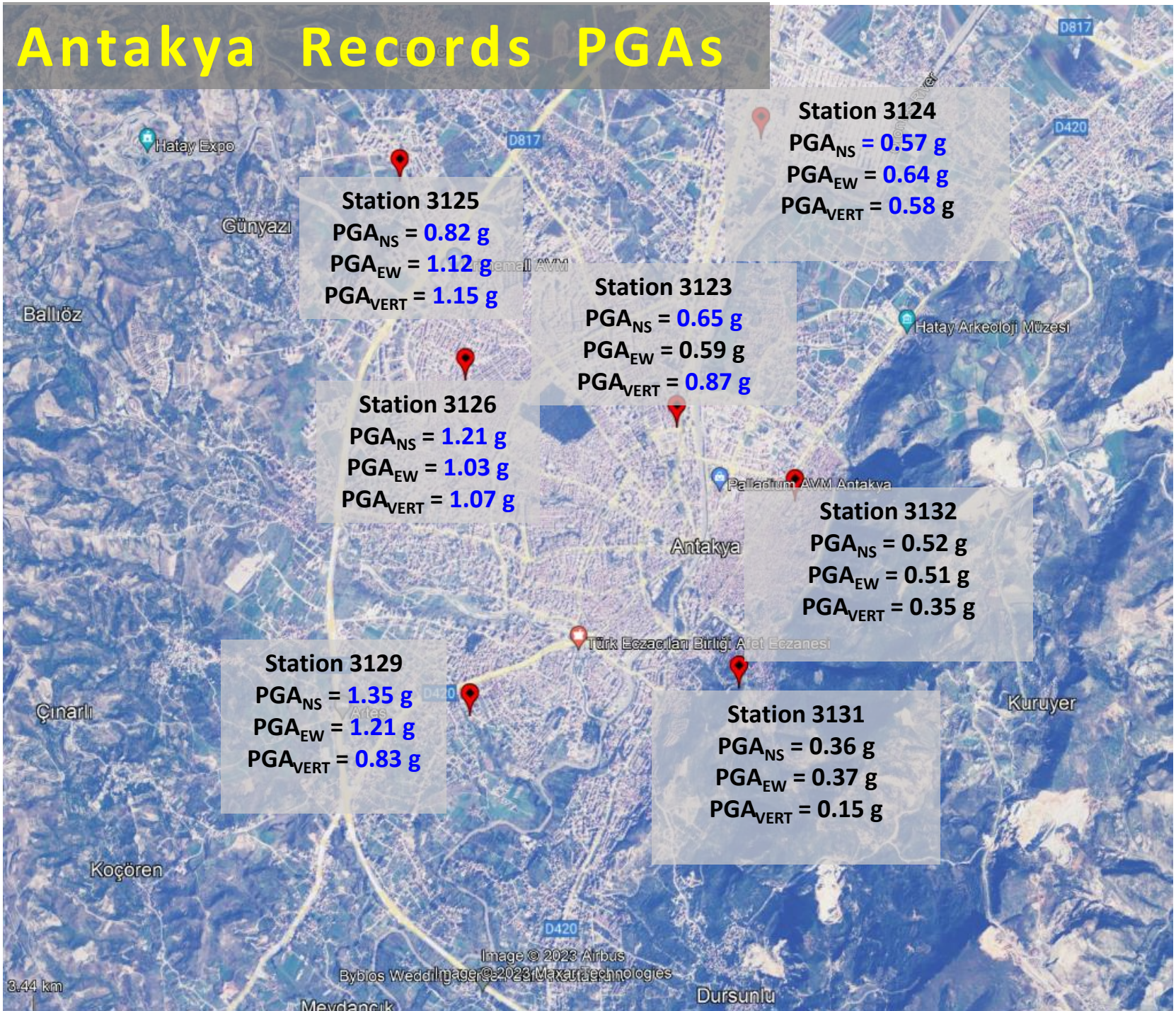
A duration ≈ 60-70 s



B short duration ≈ 30 s but 0.83 g !!

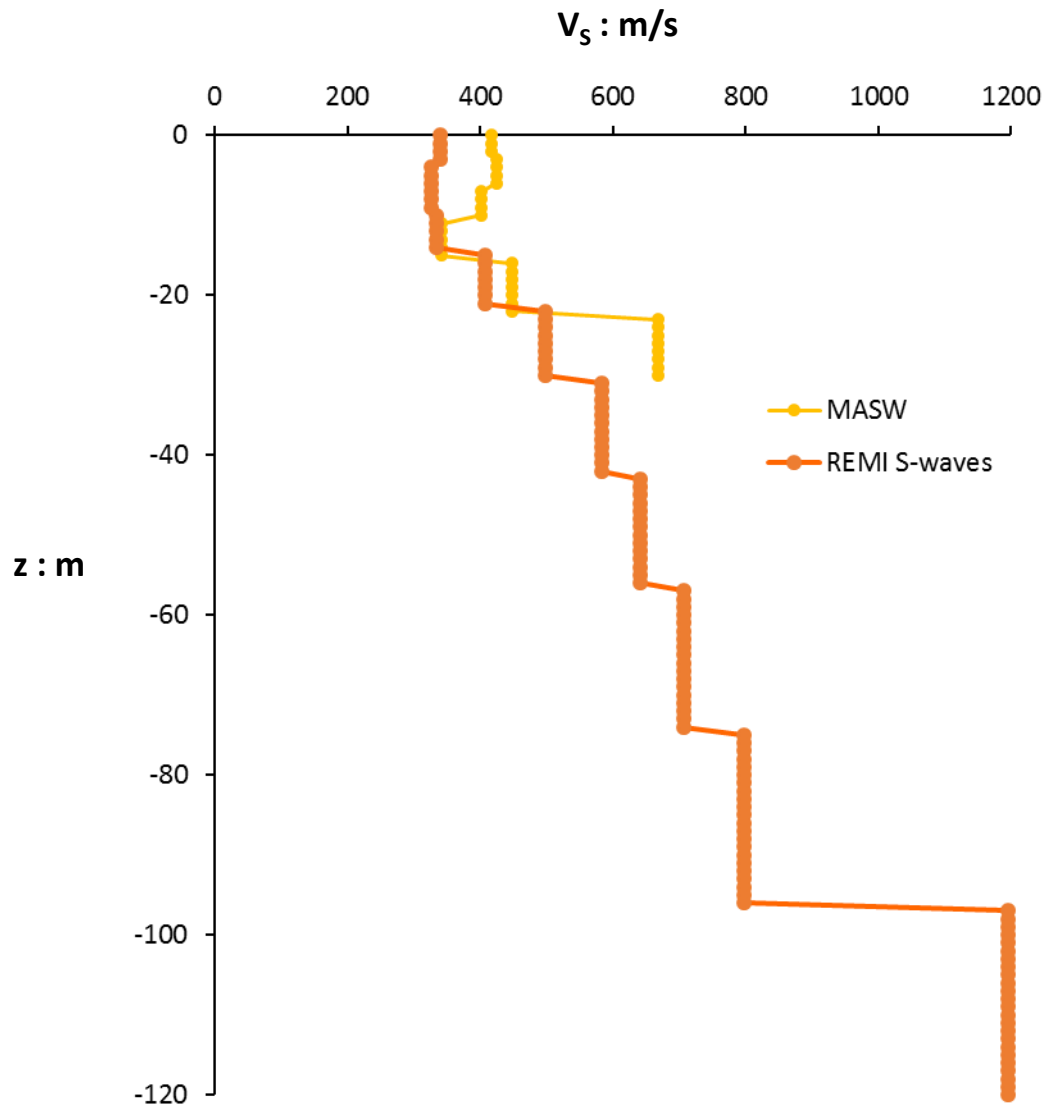


Antakya Records PGAs



Station 3129: V_{S30} = 447 m/s

Source: AFAD



Earthquake M_W7.8

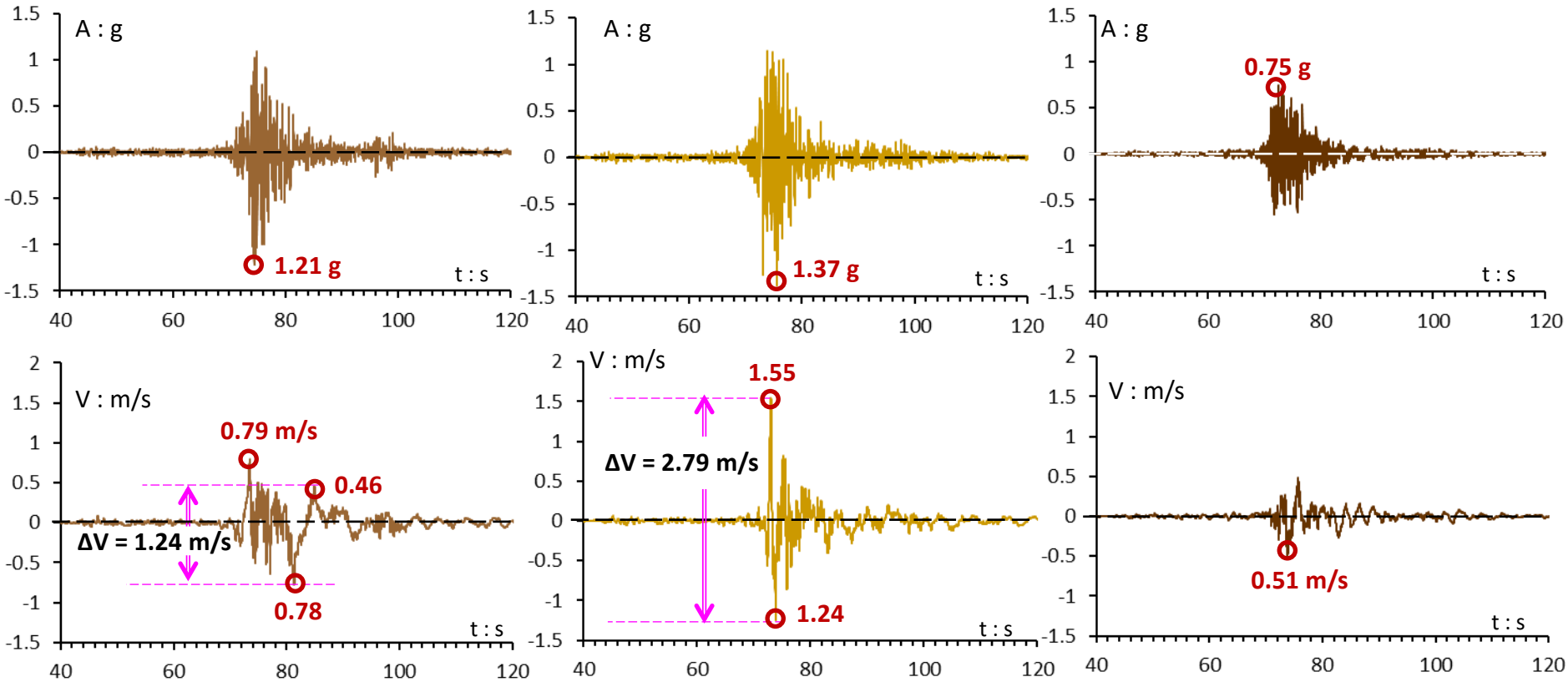
Station 3129: in Daphne, south of Antiochia, Hatay District

on Free field, V_{S30} = 447 m/s (EC8 Type B)

Horizontal EW component

Horizontal NS component

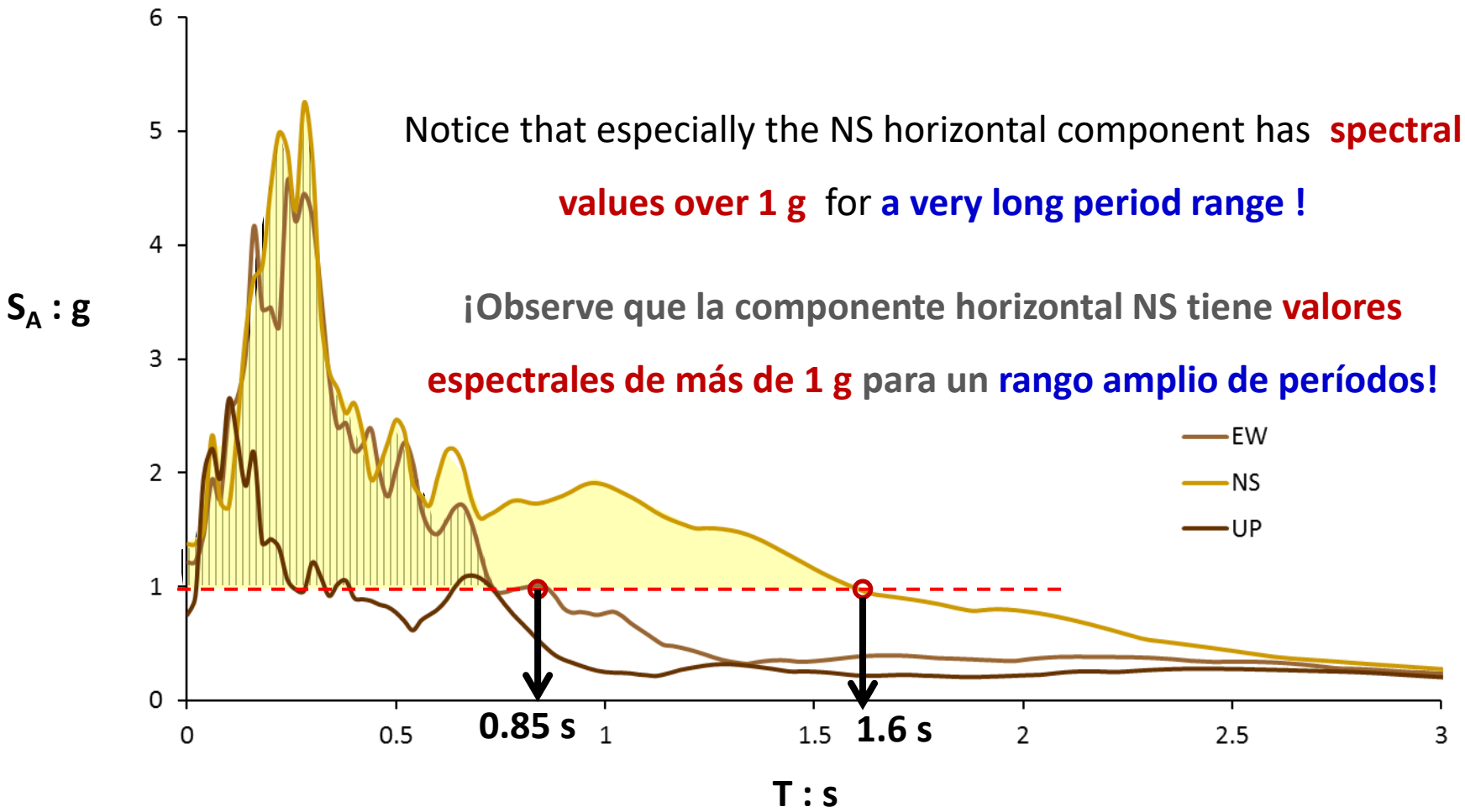
Vertical component



Earthquake M_W7.8

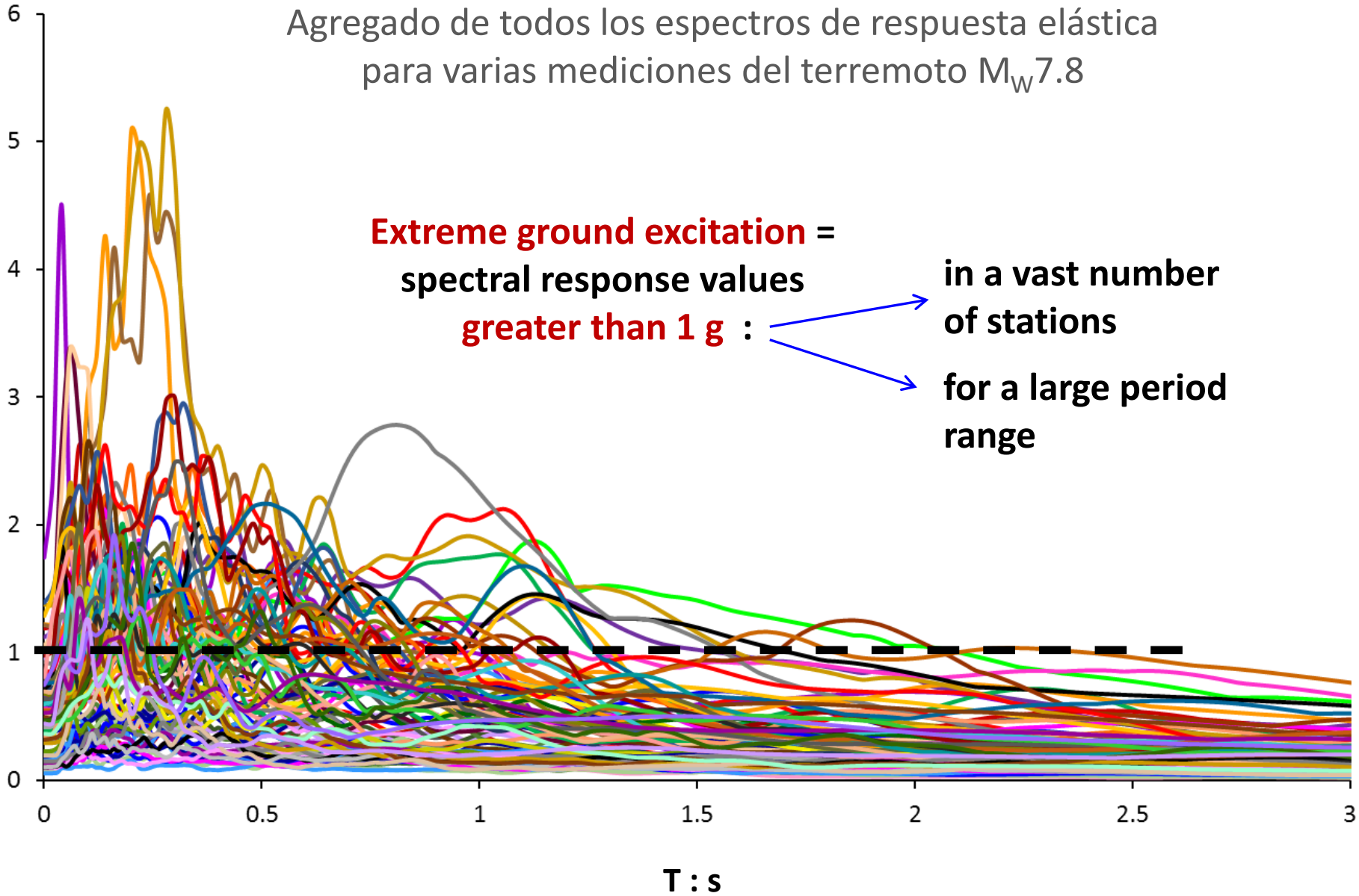
Station 3129: in Daphne, south of Antiochia, Hatay District

on Free field, V_{S30} = 447 m/s (EC8 Type B)



Aggregate of all elastic response spectra for several recordings from the M_W7.8 earthquake

Agregado de todos los espectros de respuesta elástica para varias mediciones del terremoto M_W7.8



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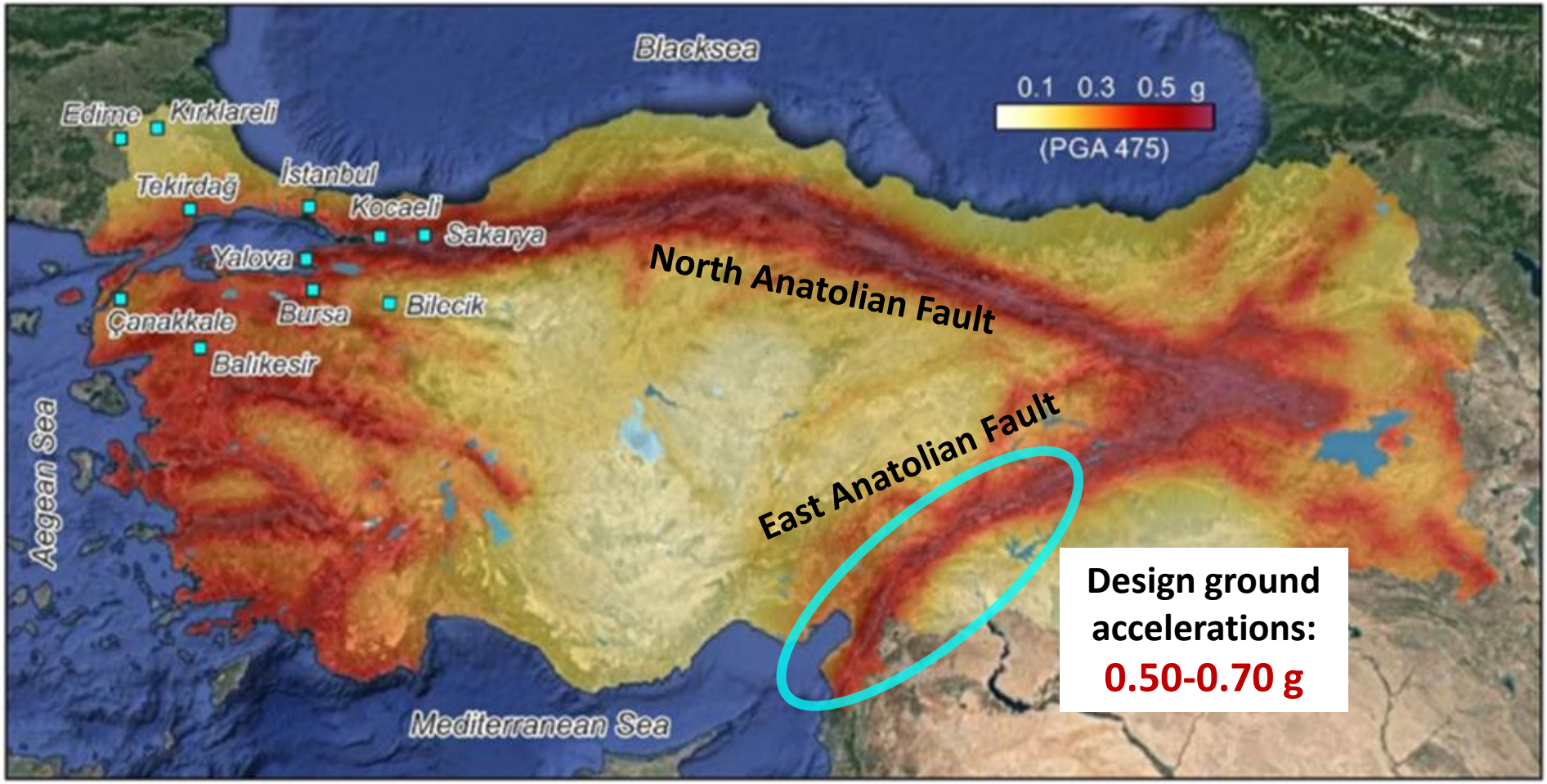
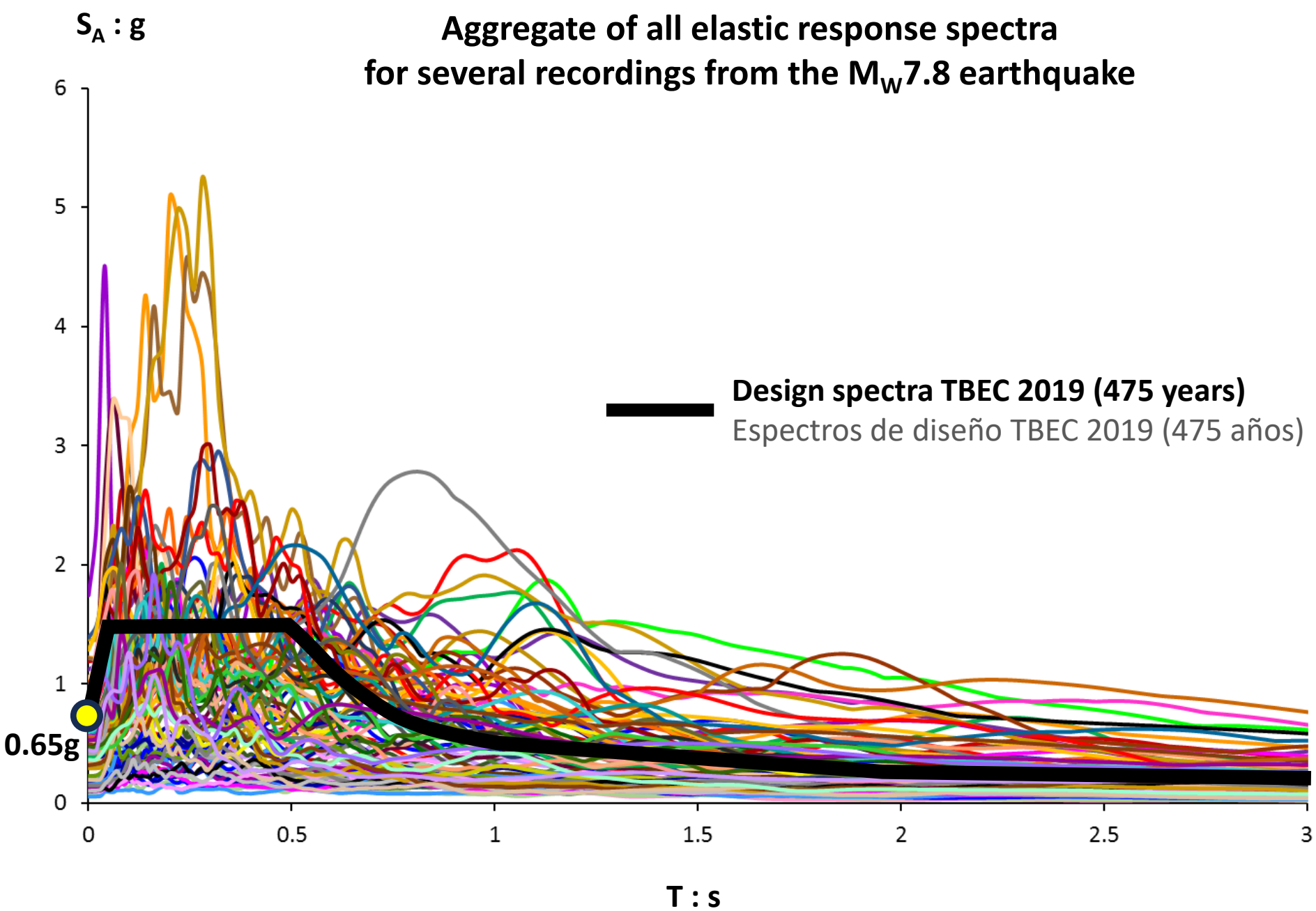
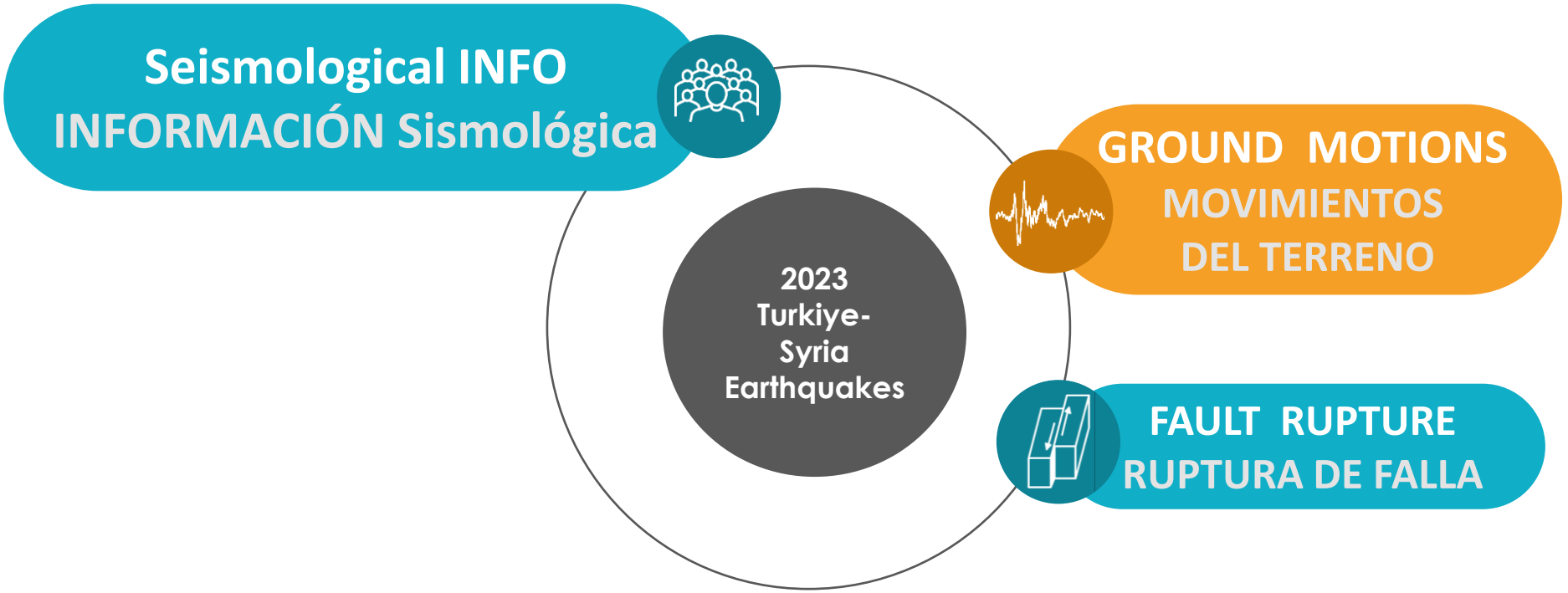
El NUEVO Código Sísmico Turco 2018




S_A : g
Aggregate of all elastic response spectra
for several recordings from the M_W7.8 earthquake
6
5
4
3
2
1
0.65g
0
0
0.5
1
1.5
2
2.5
3
T : s
Design spectra TBEC 2019 (475 years)
Espectros de diseño TBEC 2019 (475 años)

Glance over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EMERGENCE OF FAULT ON SURFACE

a permanent marc of 250 km on earth's skin

APARICIÓN DE FALLA EN LA SUPERFICIE

una marca permanente de 250 km en la superficie

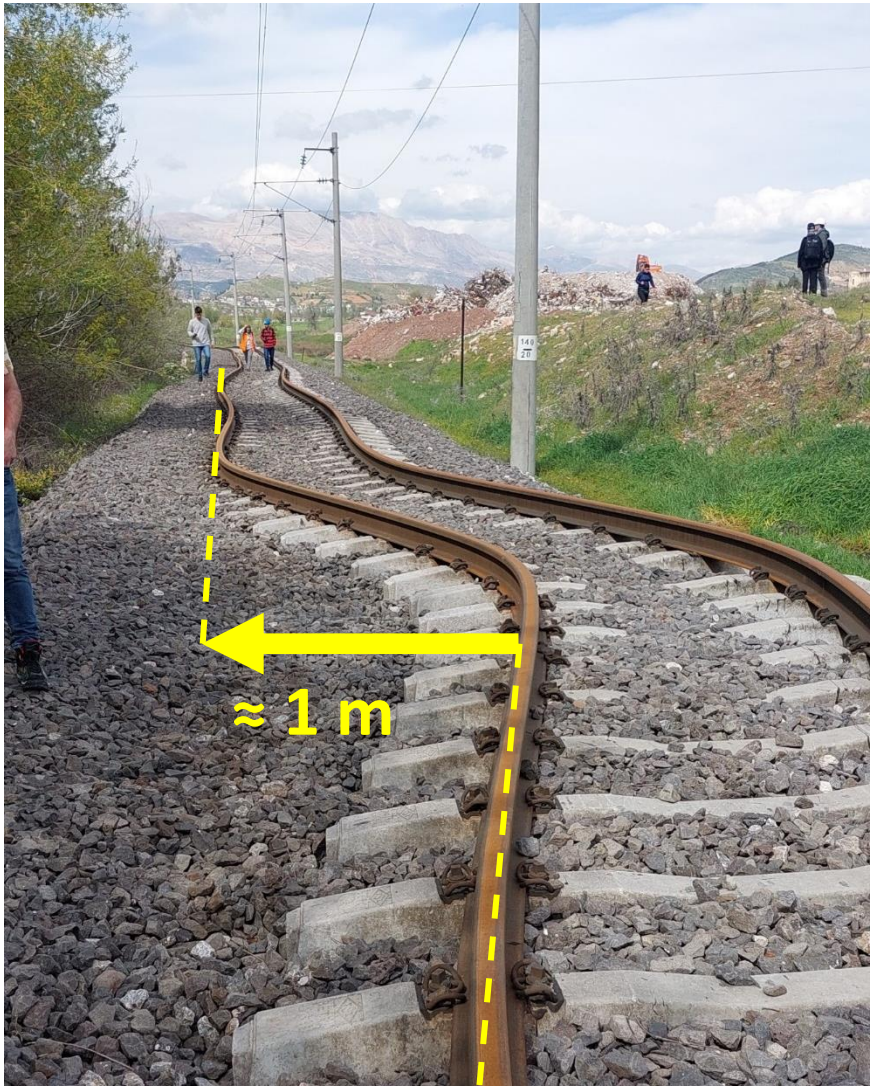
Anadolu Agency

The strike-slip fault emerging at acute angle to the rails causes them to buckle.

La falla emerge en ángulo agudo a los rieles y hace que se doblen.

Source: **Cengiz Zabci** @CengizZabci

Gölbaşi
≈ 1 m


≈ 1 m

Source: **https://twitter.com/Panthalassa_Z/status/1623040975848280107**

Photo: **H. Serdar Akyüz**

Glance over

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KEY FIGURES

VALORES CLAVES

9.6 M	57,300	109,000	2.2 M	3.1 M
People directly AFFECTED by earthquakes (Personas AFECTADAS directamente por los terremotos)	*LIVES officially lost in Turkiye and Syria (VIDAS oficialmente perdidas en Turkiye y Siria)*	*INJURED both in Turkiye and Syria (HERIDOS tanto en Turkiye como en Siria)*	*People displaced from residence (Personas desplazadas de su residencia)*	*Homeless in temporary shelter (Sin hogar en albergue temporal)*

Humanitarian Crisis

Crisis Humanitaria

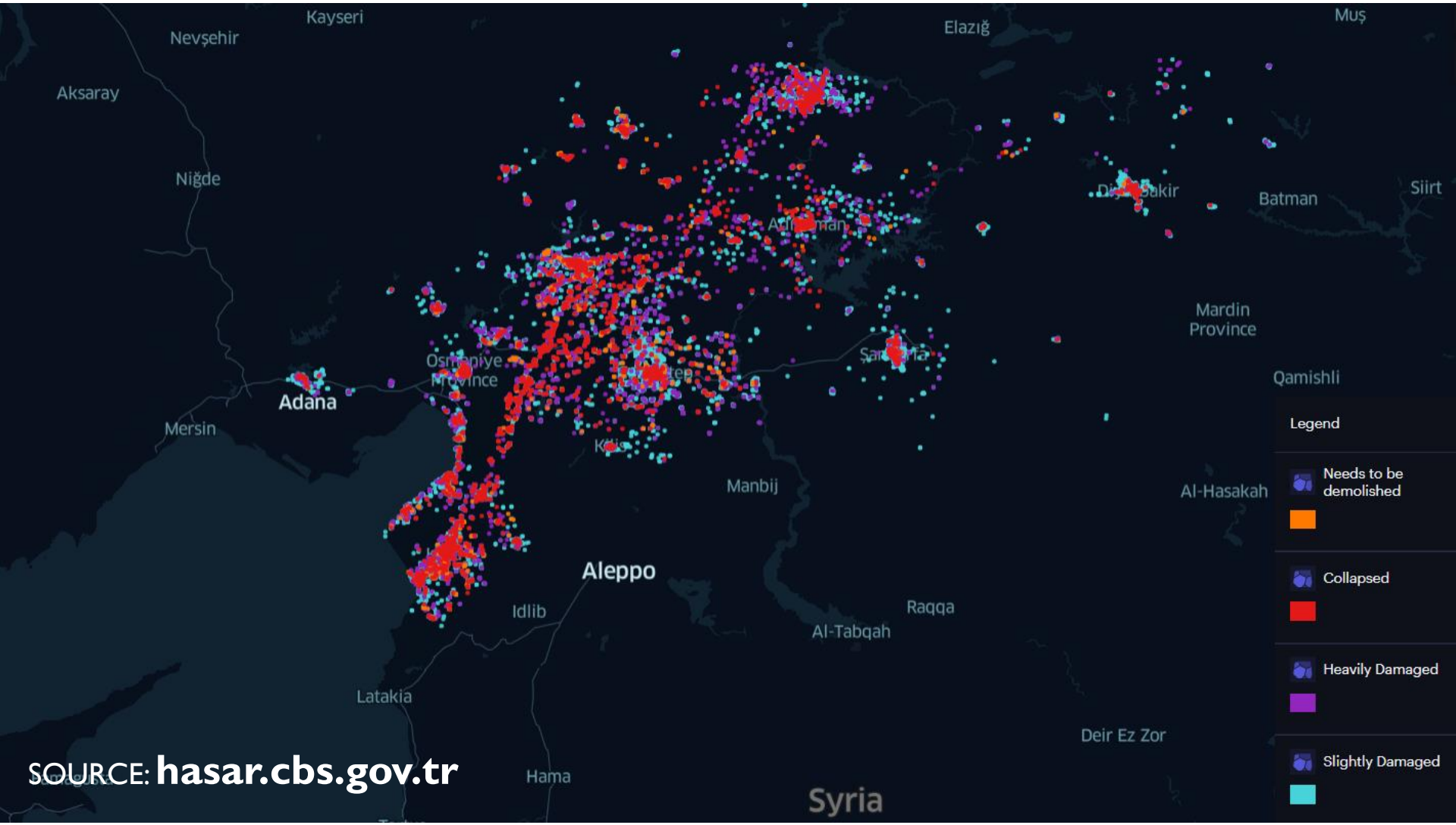
OCHA

Situation Report No. 11, As of 23 March 2023

Source: https://reliefweb.int/report/turkiye/turkiye-2023-earthquakes-situation-report-no-11-23-march-2023

BUILDING DAMAGE ASSESSMENT MAP

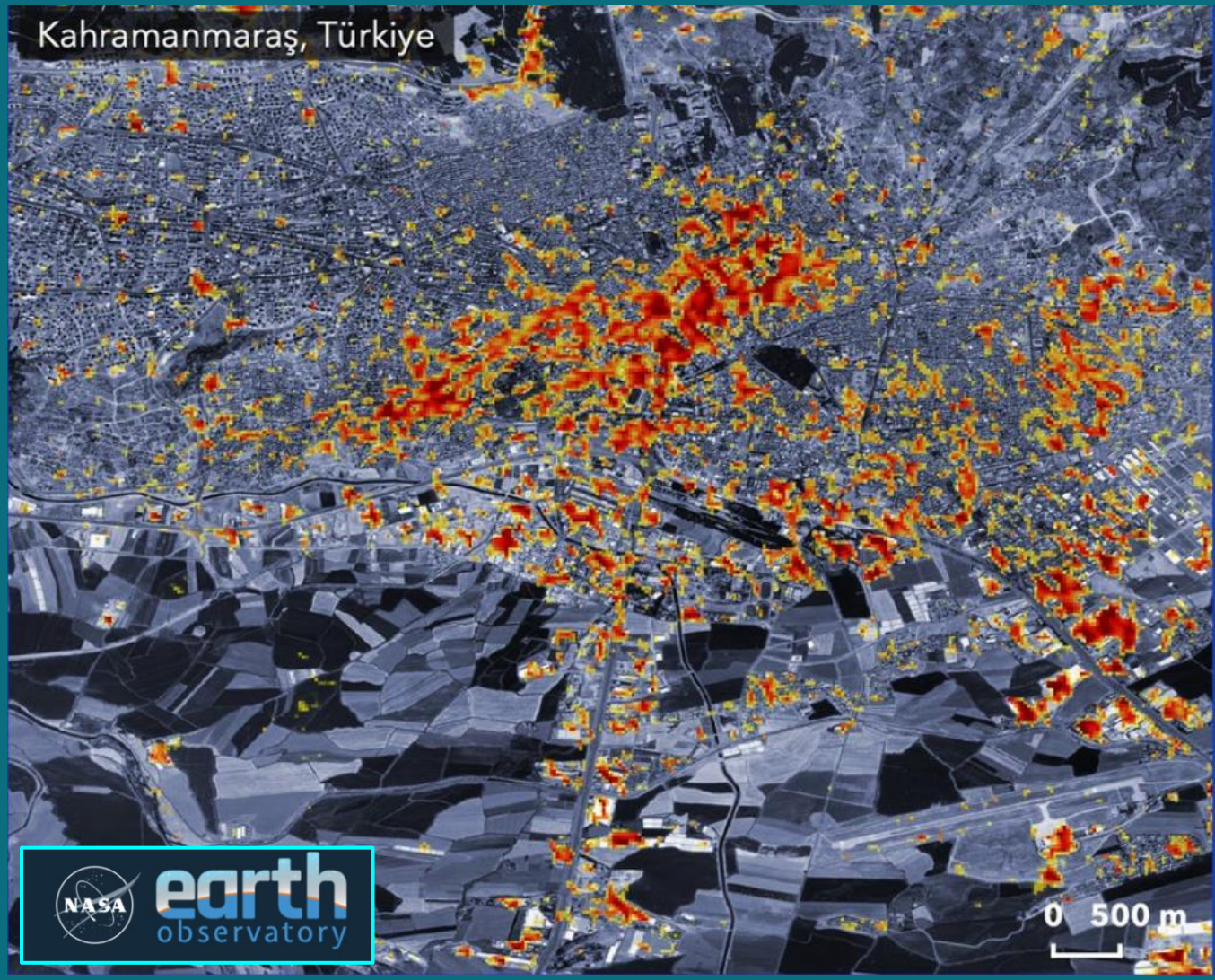
MAPA DE EVALUACIÓN DE DAÑOS EN EDIFICIOS



SOURCE: **hasar.cbs.gov.tr**

Damage distribution through satellite observations

Distribución de daños a través de observaciones satelitales



Antakya, Türkiye
0 500 m
NASA
earth
observatory

STRUCTURAL DAMAGE OVERVIEW

DESCRIPCIÓN GENERAL DEL DAÑO ESTRUCTURAL

Reported by the Turkish State Bureau of Statistics

Informado por la Oficina Estatal de Estadísticas de Turquía

3.9 M	40%	164,000	61,722	$109 B
Building units in the 11 damaged cities (Edificaciones en las 11 ciudades dañadas)	*Built prior to seismic-resistant 2000 design code (Construidas antes del código de diseño sismico 2000)*	*Collapsed or severely damaged buildings (Edificios colapsados o severamente dañados)*	*Buildings to be demolished (Edificios a demoler)*	*REBUILDING cost in all 10 inflicted Prefectures (Costo de RECONSTRUCCIÓN en las 10 prefecturas infligidas)*

Data as on 24 February 2023

Source: https://www.tuik.gov.tr/

© ISSAM ABDALLAH/REUTERS

DAMAGE IN KAHRAMANMARAS

DAÑO EN KAHRAMANMARAS

Photo: **Ihlas News Agency**

Kahramanmaras [SOURCE: STRINGER (REUTERS)]

General view in Kahramanmaras neighborhoods

Vista general en los barrios de Kahramanmaras

Kahramanmaras

9-story RC building

edificio RC de 9 pisos

Structural damage

concentrated on the

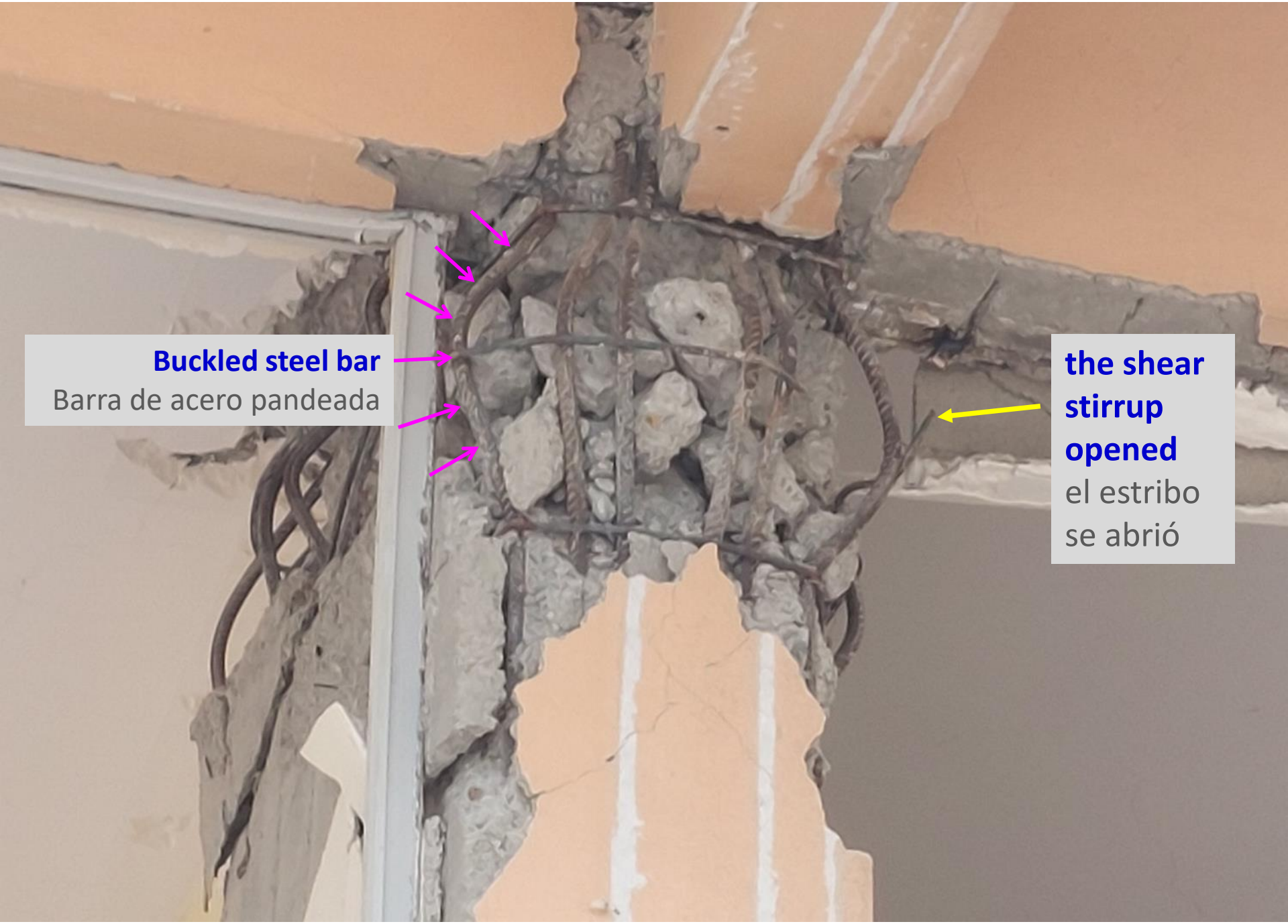
ground and 1st floors

Daños estructurales

concentrados en planta

baja y 1er piso

ÖZYILMAZ
ELEKTRİK VE AVİZE
Plan - Proje - Tesisat - Taahhüt
Dekorasyon - Kumanda Panoları - Aydınlatma
223 09 57-0535 355 45 18 - 0535 656 68 96
Nida
APARTMANI
NO : 12
ELEKTRİK AVİZE
ELEKTRİK AVİZE


Buckled steel bar
Barra de acero pandeada
the shear stirrup opened
el estribo se abrió

ÖZYILMAZ
ELEKTRİK VE AVİZE
Plan - Proje - Tesisat - Taahhüt
Dekorasyon - Kumanda Panoları - Aydınlatma
223 09 57-0535 355 45 18 - 0535 656 68 96
Nida
APARTMANI
NO : 12
ELEKTRİK AVİZE
ELEKTRİK AVİZE

Inadequate shear reinforcement in the joint

Refuerzo de cortante inadecuado en la junta

Longitudinal reinforcement is discontinued in the joint

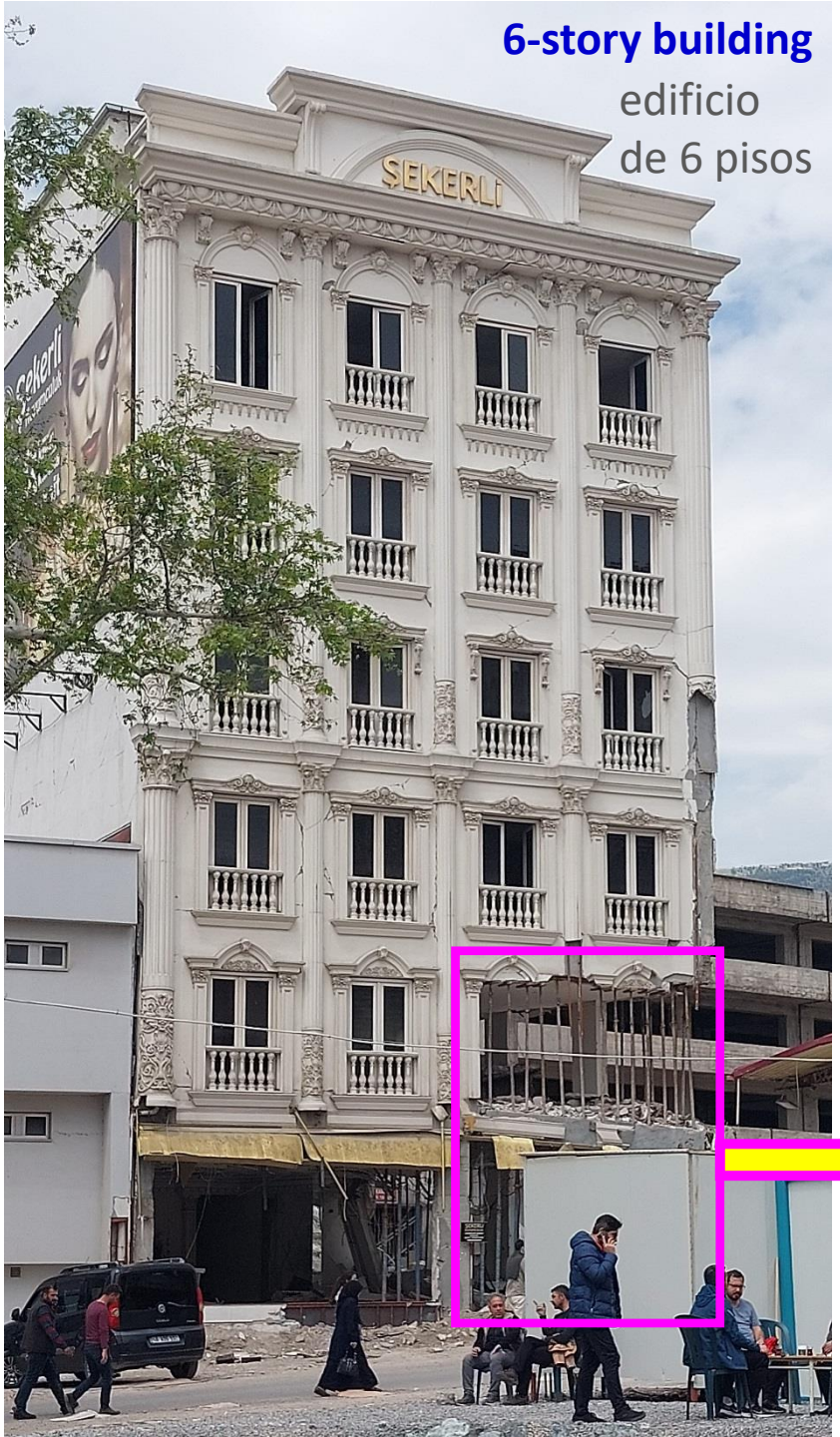
El refuerzo longitudinal se discontinuo en la junta

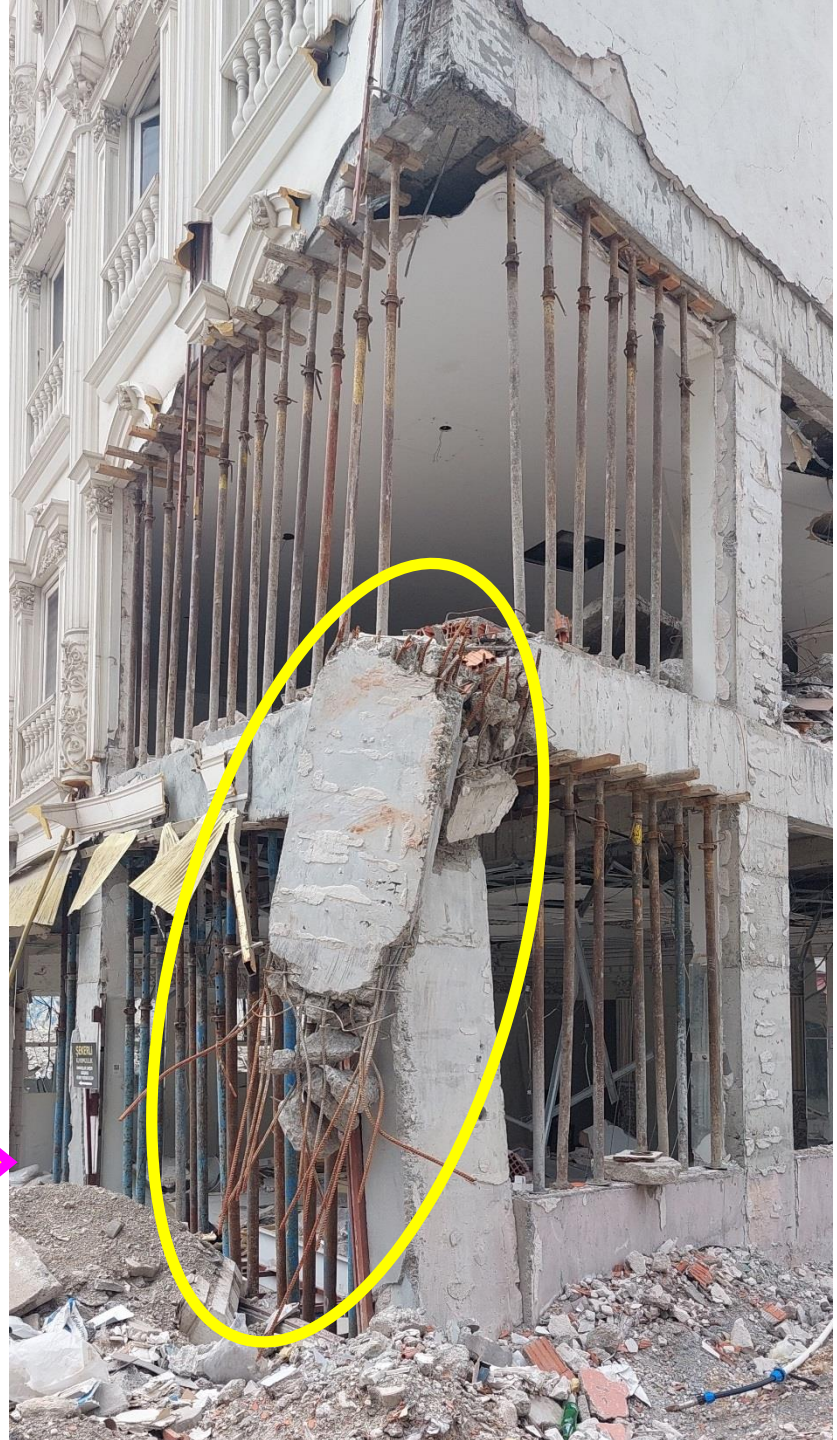
Construction joint in the concrete just above the slab

Junta de construcción en el hormigón justo encima de la losa

General view in Kahramanmaras neighborhoods

Vista general en los barrios de Kahramanmaras


6-story building
edificio
de 6 pisos
ŞEKERLİ

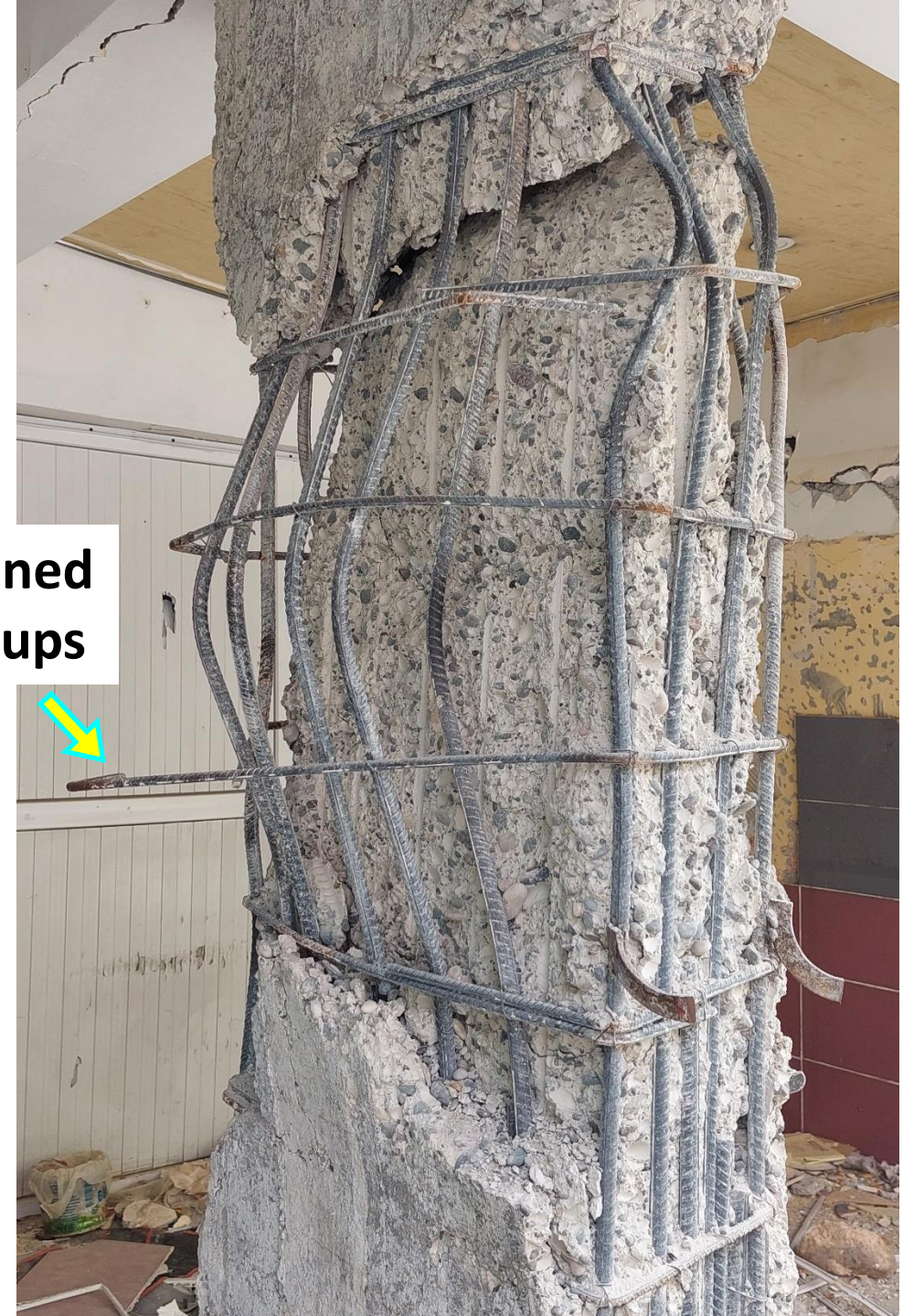


Longitudinal reinforcement is discontinued at the joint

El refuerzo longitudinal se interrumpio en la junta

Stirrups nowhere in the joint…

No hay estribos en ninguna parte del nudo…



Shear wall failure

Falla del muro de corte

- **Not close enough stirrups**
- **Poor concrete quality (large+ rounded aggregates)**
- **Buckled steel rods**

A new base-isolated hospital

outside Kahramanmaras

Un nuevo hospital con base aislada en

las afueras de Kahramanmaras

the new under-construction wing
la nueva ala en construcción

the older hospital wing
el ala del hospital más antigua

View of the new constructed hospital wing

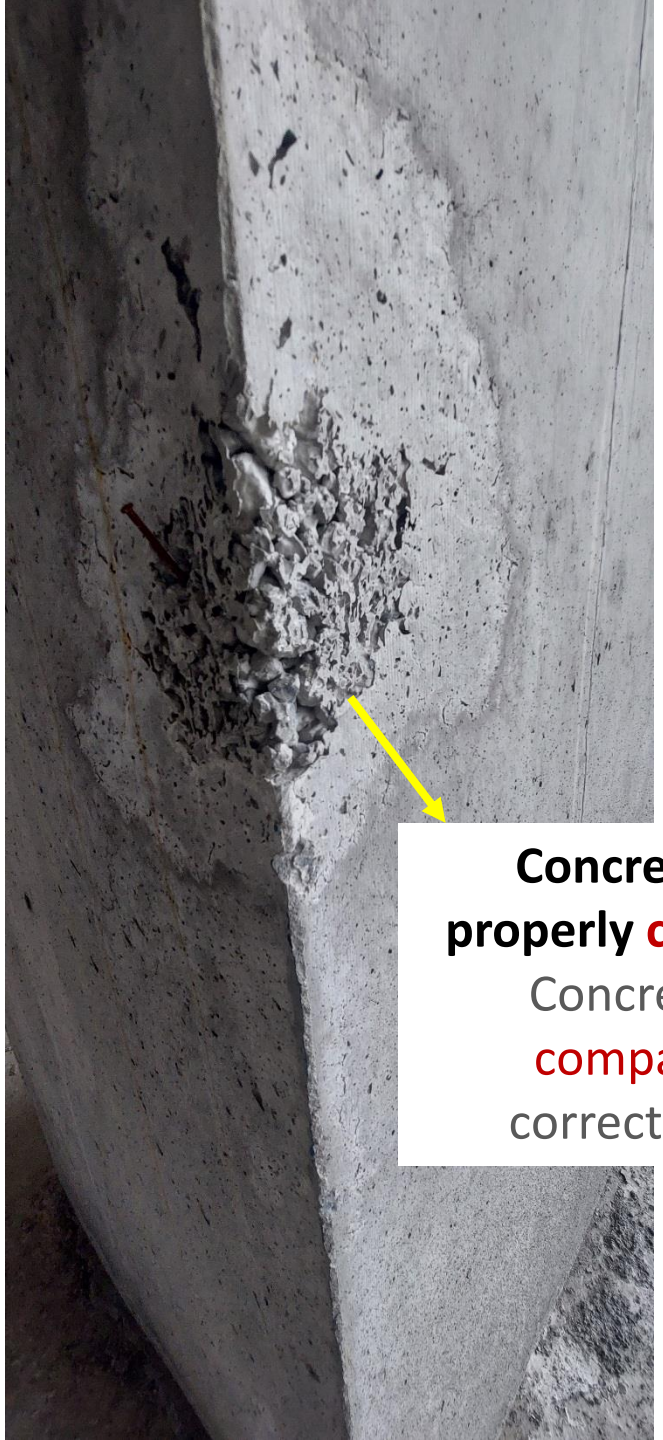
Vista de la nueva ala del hospital construida

The FRICTION pendulum system Isolators

Los aisladores del sistema pendular FRICCION

Everything looks fine …

Todo se ve bien…



Concrete NOT properly compacted

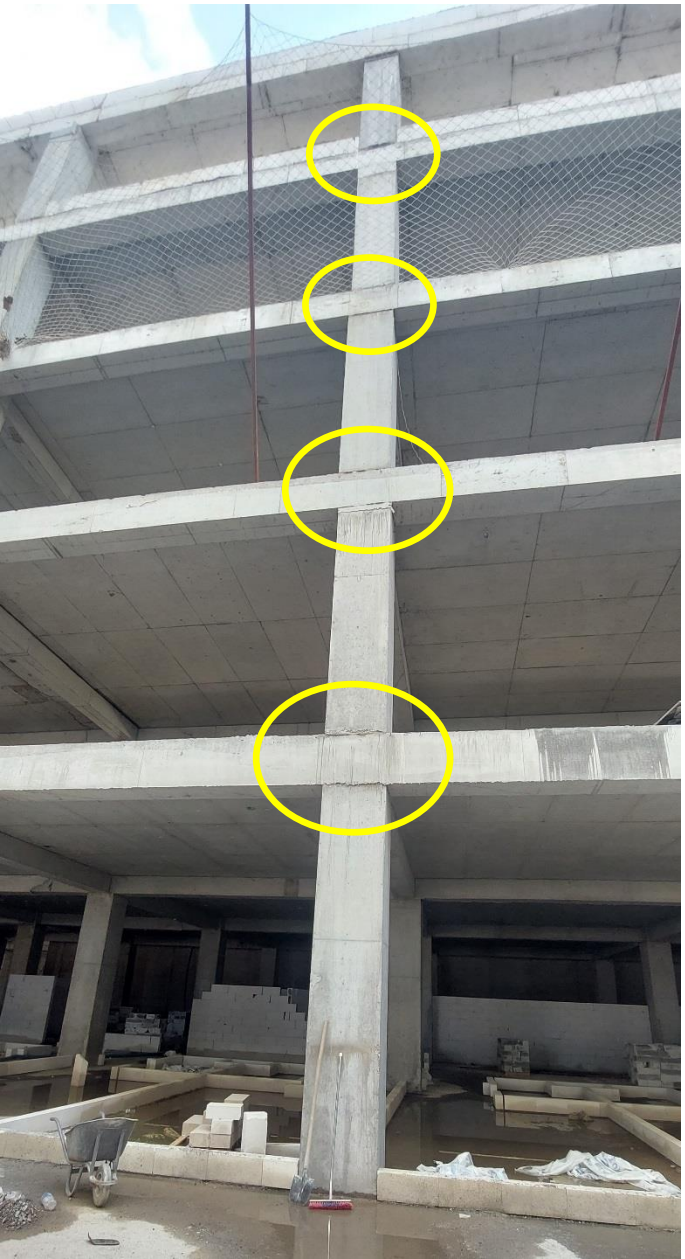
Concreto NO compactado correctamente

At the bottom of a ground floor column

En la parte inferior de una columna de la planta baja

JOINT details

Detalles de nudos



No monolithic joint…

No hay juntas monolíticas…

DAMAGE IN ADIYAMAN

DAÑOS EN ADIYAMAN

Photo: **IRAKLI GEDENIDZE (REUTERS)**

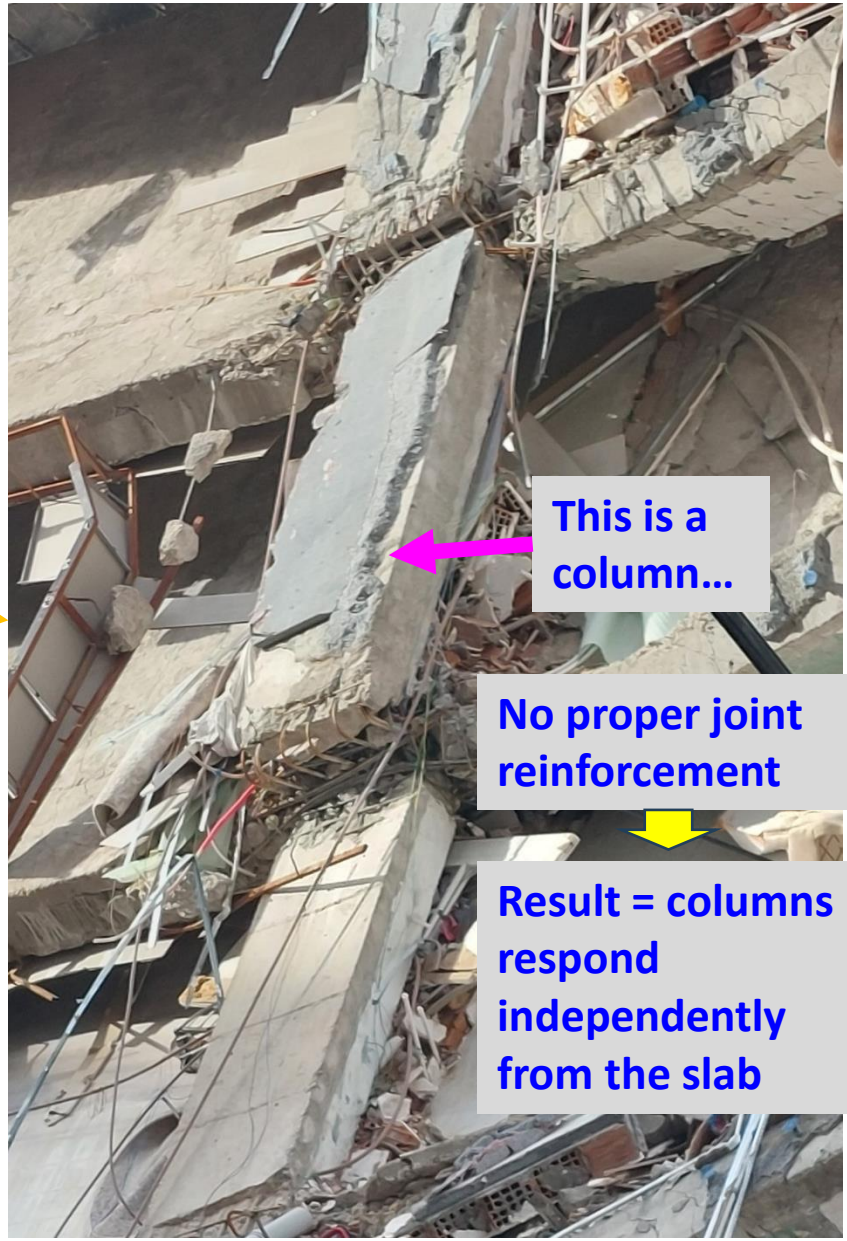
Plastic hinge in a 3-story RC building in Adiyaman

Partial collapse in a 9-story RC building in Adiyaman

Adiyaman

Bending of plate as if
it is simple supported
(no fixity at the joint)

Adiyaman


This is a column…
No proper joint reinforcement
Result = columns respond independently from the slab

Important Fact

Turkey's Ministry of Environment, Urbanization and Climate Change has reported that :

From a total of 20 million buildings in Turkey,

almost 50% were constructed

WITHOUT following the Seismic Code

DAMAGE IN GOLBASI

DAÑOS EN GOLBASI

A toppled building in Golbasi, Adiyaman district

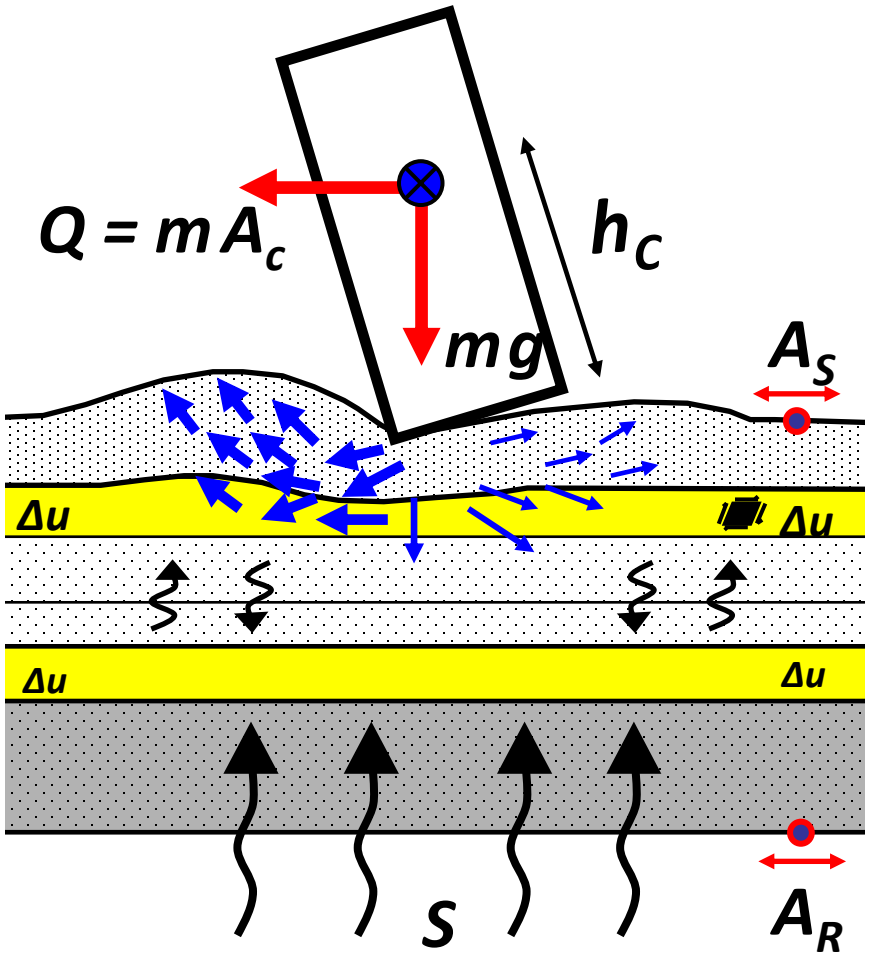
No structural damage

Flat slab foundation: without a crack!

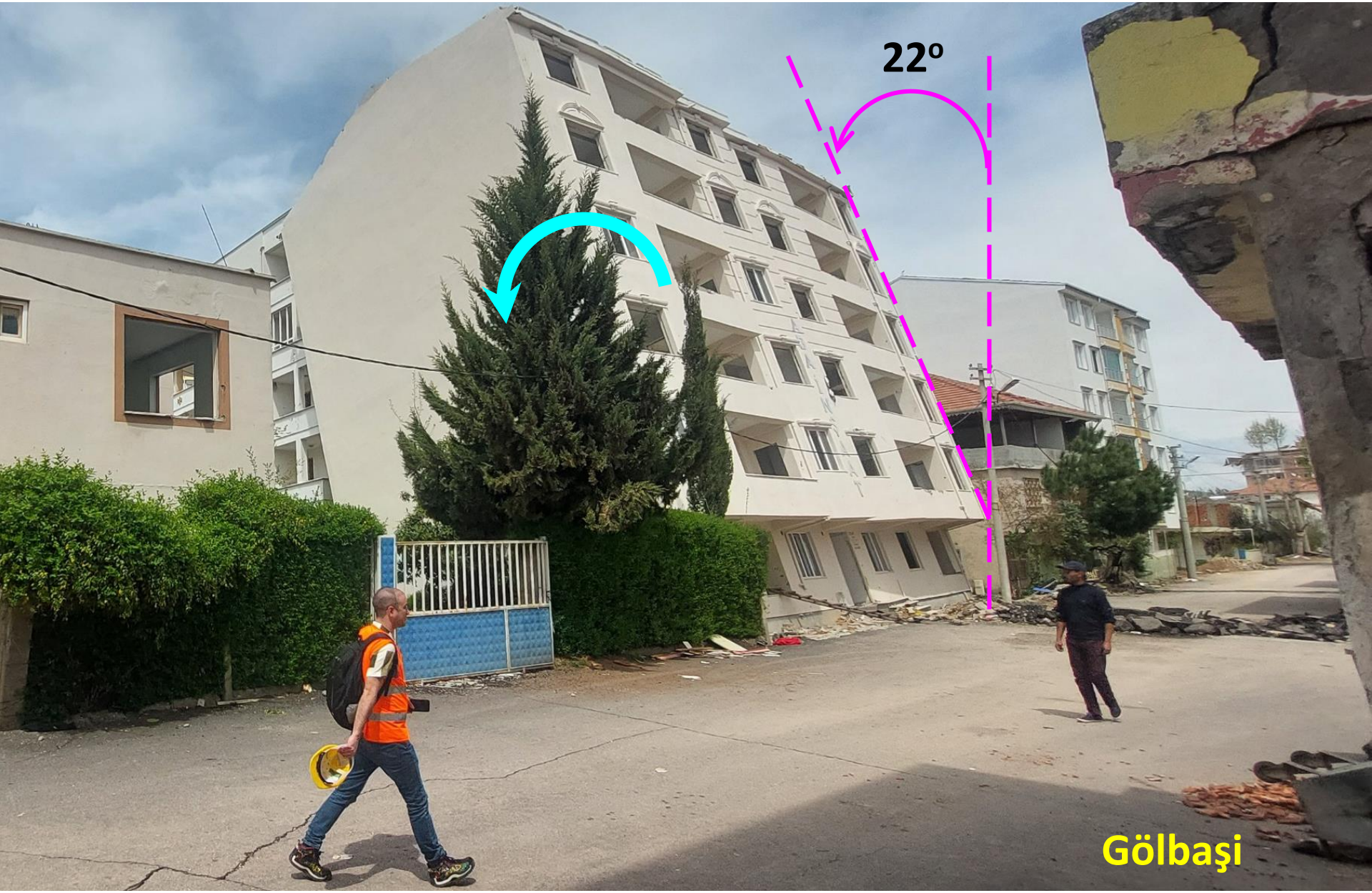
Rocking of whole buildings

Gölbaşi

YARIMAY İNŞ 16
DOĞAN APT.


$Q = m A_c$
h_c
mg
A_S
Δu
Δu
Δu
Δu
S
A_R

Gölbaşi


22º
Gölbaşi

Gölbaşi
What happened?? broken story ??

Gölbaşi

≈ 2+ m
Gölbaşi

This rocking type of structural response

is not unusual in Turkey

It happened before: in 1999 Izmit M7.4 earthquake in Adapazari

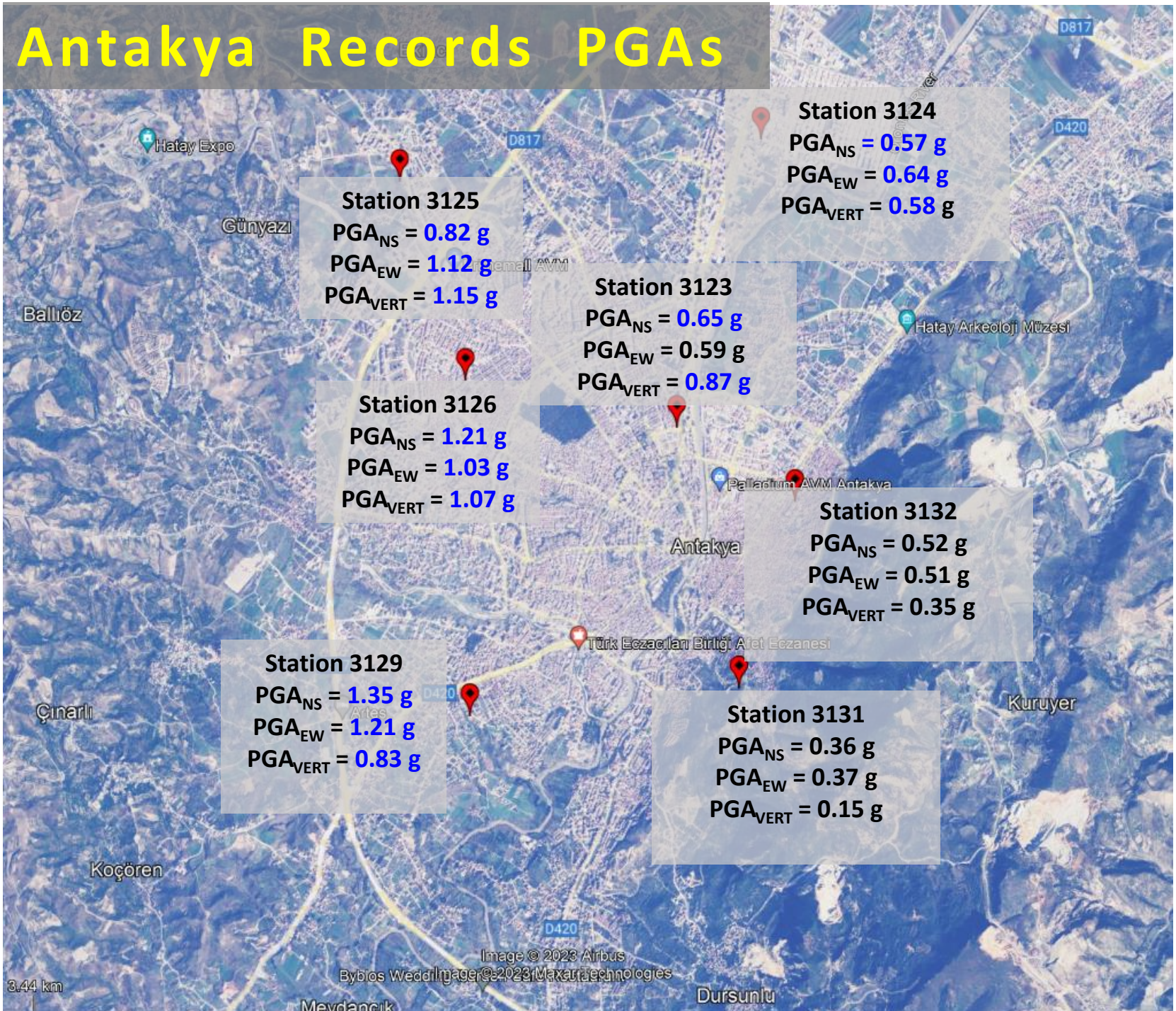
DAMAGE IN ANTAKYA

DAÑOS EN ANTAKYA

Photo: **REUTERS/Umit Bektas**

Antakya **[Photo: Ercin Erturk/Anadolu Agency via Getty Images]**

Antakya Records PGAs



The old center of Antakya is totally flattened

The “modern” part of Antakya is SEVERELY damaged

The “modern” part of Antakya is SEVERELY damaged

7-story RC building : lost the ground floor

7-story RC building : lost the ground floor

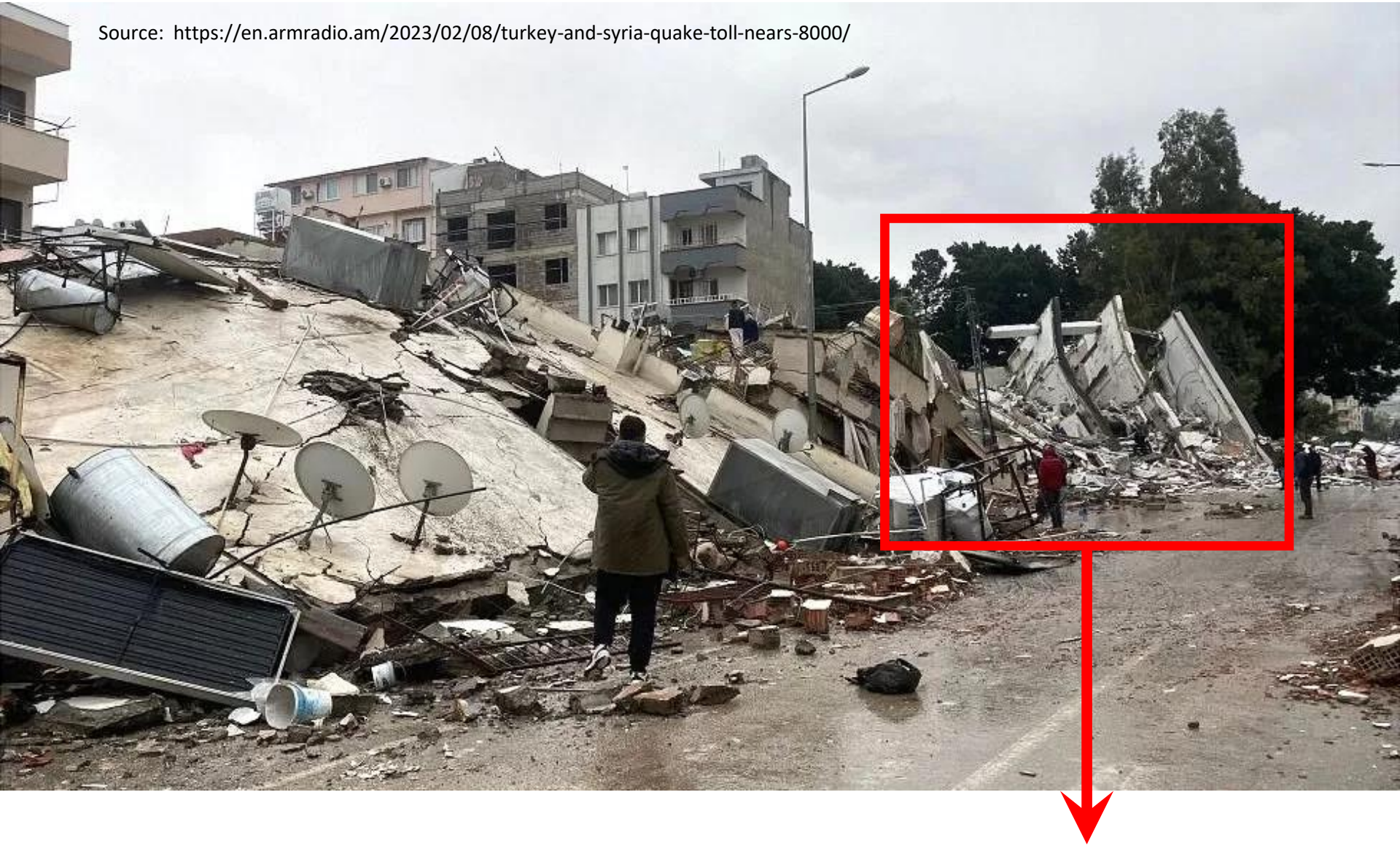
NO BEAMS, POOR JOINTS !

¡SIN VIGAS, JUNTAS POBRES!

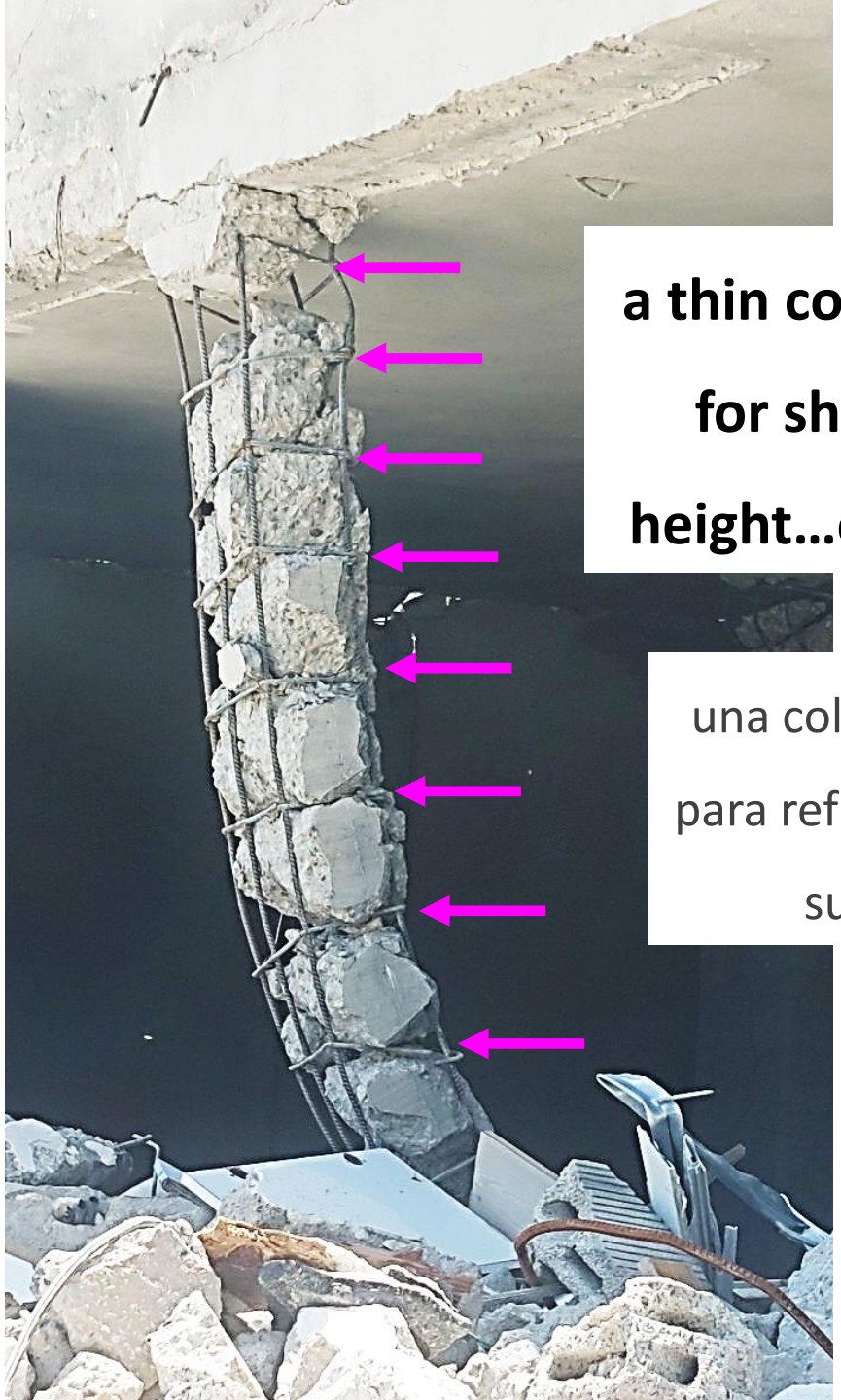
Source: The New York Times

A hotel recently constructed: lost the ground floor

Un hotel de reciente construcción: perdió la planta baja


Source: https://en.armradio.am/2023/02/08/turkey-and-syria-quake-toll-nears-8000/

Numerous building without any beam, with small size columns (inappropriate even for 1-story buildings in a region of moderate seismicity).



a thin column with only 10 stirrups for shear reinforcement in its height…of course totally collapsed

una columna delgada con **solo 10 estribos** para refuerzo de cortante en su altura... por supuesto totalmente colapsada

Reasons of extensive STRUCTURAL DAMAGE

NATURAL HAZARD : Extremely strong seismic shaking

- Sequence of 3 Eqs : M_W 7.8, 6.7, 7.5
- Extraordinary large spectral accelerations $S_A > 1$ g with over a wide period range
- PGVs very large, over 1.5 m/s !!

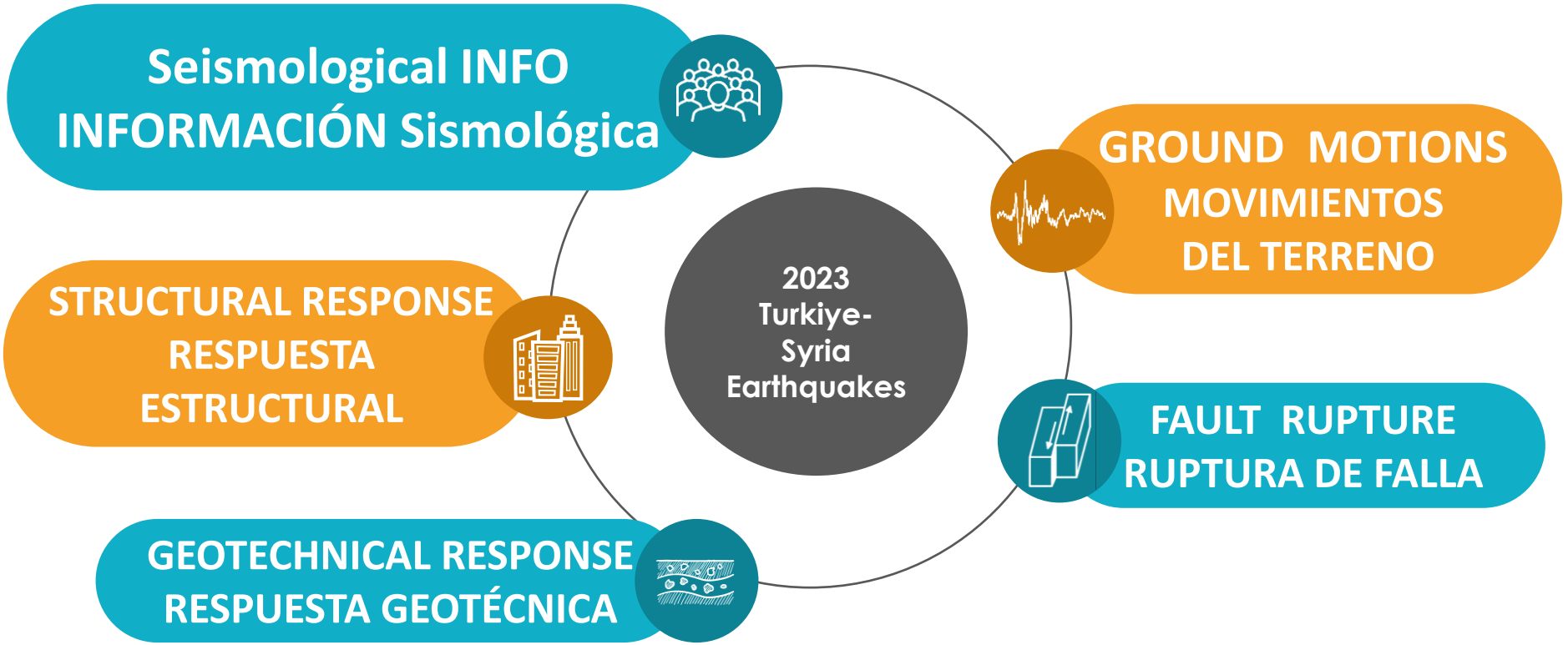
HUMAN factor : Engineering PRACTICE

- Structures NOT compliant with Turkish seismic codes
- INADEQUATE structural system for highly seismic regions

DEFFECTIVE STRUCTURAL SYSTEM WITH SEVERAL FATAL TECHNICAL FAULTS:

1. Very thin columns, but rather thick slabs
2. Very inadequate steel reinforcement (in size and number of longitudinal bars)
3. Transverse reinforcing bars of inadequate density and improperly tied
4. NO beams !! Slabs directly on columns, without continuity of Rebars, and no proper connection, NOT proper JOINTS
5. No frequent use of Shear Walls, even in > 10 story buildings

Glance over


Seismological INFO
INFORMACIÓN Sismológica
GROUND MOTIONS
MOVIMIENTOS
DEL TERRENO
2023
Turkiye-
Syria
Earthquakes
STRUCTURAL RESPONSE
RESPUESTA
ESTRUCTURAL
FAULT RUPTURE
RUPTURA DE FALLA
GEOTECHNICAL RESPONSE
RESPUESTA GEOTÉCNICA

Geotechnical DAMAGE

DAÑOS geotécnicos

Soil LIQUEFACTION

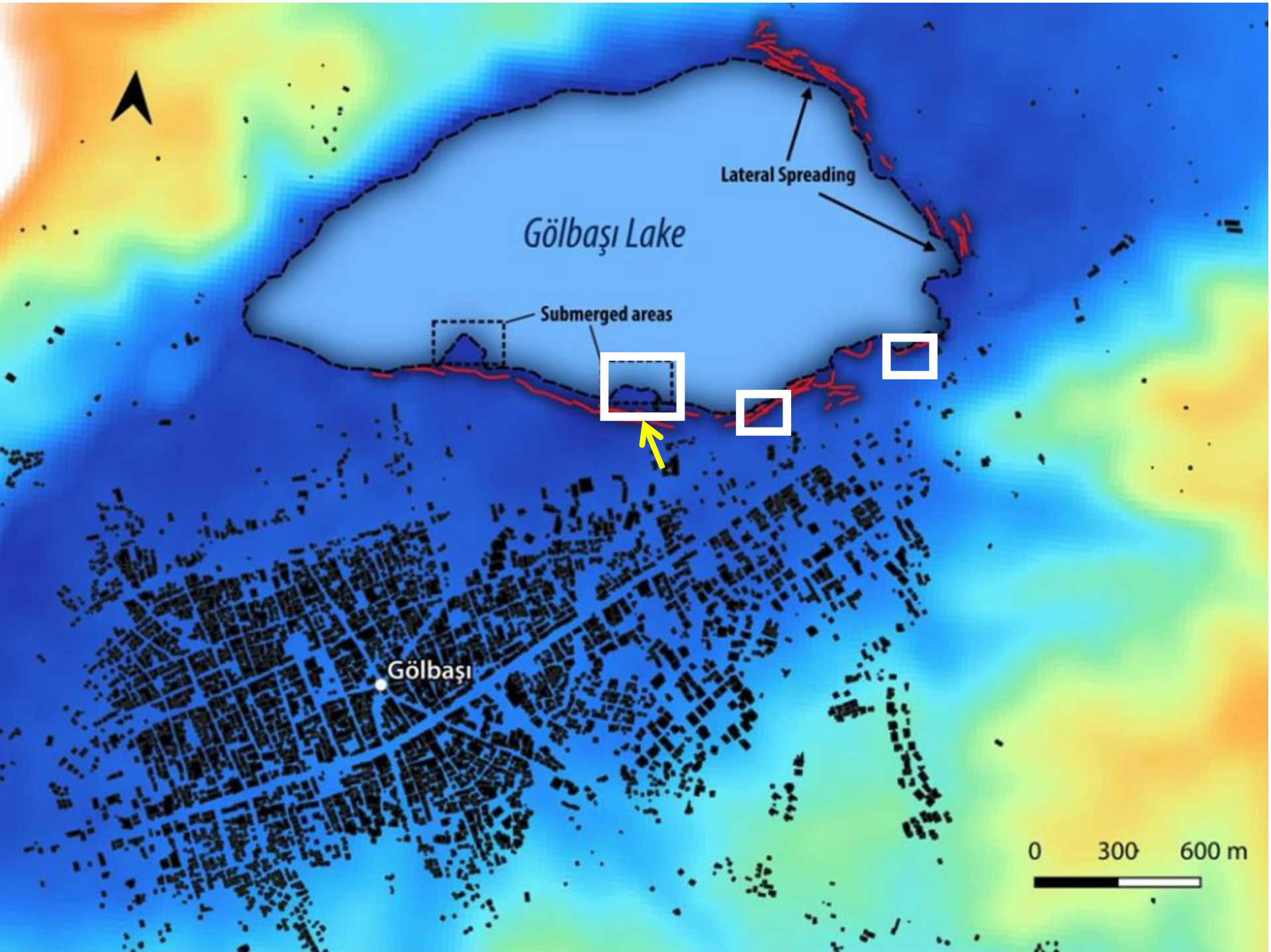
LIQUEFACCIÓN del suelo

Liquefaction : Sand boil outside Sekerova

Source: **Ozdemir Alpay**

DESTRUCTION of road embankment due to lateral spreading

DESTRUCCIÓN del terraplén de la carretera debido a la expansión lateral


Lateral Spreading
Gölbaşı Lake
Submerged areas
Gölbaşı
0
300
600 m

Total submergence of the building due to lateral spreading

Inmersión total del edificio debido a la expansión lateral

Soil movement direction
Dirección del movimiento del suelo

1.2 m

Geotechnical DAMAGE

DAÑOS geotécnicos

Seismic Subsidence

Subsidencia sísmica

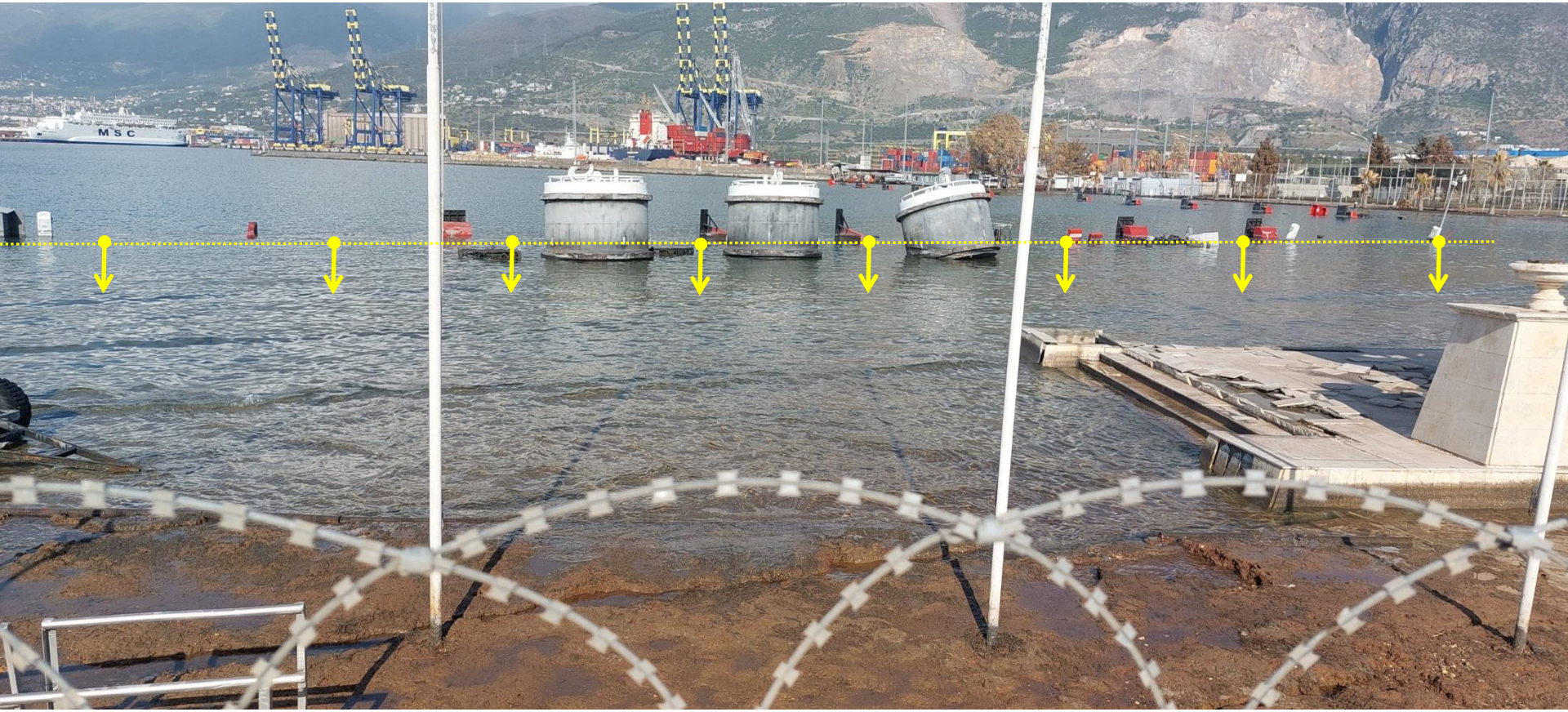
Subsidence in the coastal neighborhoods of Iskenderun

Subsidencia en los barrios costeros de Iskenderun

Asentamiento de suelo de 20 cm

Submergence of a military Port in Iskenderun

Inmersión de un puerto militar en Iskenderun



Gracias por su atención

Thank you for your attention