

第154回ふじのくに防災学講座

2023年2月6日に発生したトルコ巨大地震の現地調査報告

2023 TÜRKİYE EARTHQUAKES: Observations and Lessons



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*Dedicated to the people who lost their lives and injured
by the 2023 Pazarcık and Ekinözü Earthquakes of Türkiye*

内容/CONTENT

- LOCATIONS AND MAIN CHARACTERISTICS — 位置と主な特徴
- TECTONICS — テクトニクス
- GEOLOGY — 地質
- PRE- AND POST- SEISMICITY 前進・余震活動
- FOCAL MECHANISMS AND STRESS FIELD — 発生機構・応力場
- SURFACE DEFORMATION FROM GPS & DINSAR — GPS&DINSARによる地表面変位
- SURFACE FAULTING AND ASSOCIATED DAMAGE 地表面断層
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- TRANSPORTATION FACILITIES 運輸施設被害
- GEOTECHNICAL DAMAGES 地盤被害
- DAMS ダムの被害
- LIFELINES ライフライン被害
- INDUSTRIAL FACILITIES 産業施設被害
- DAMAGED AND COLLAPSED STRUCTURES 構造物の損傷・崩壊
- UNUSUAL OBSERVATIONS 異常現象観測

位置と主な特徴

LOCATIONS & MAIN CHARACTERISTICS OF THE DOUBLET EARTHQUAKES

The **Pazarcık earthquake** at 4:17 (TST) on February 6, 2023 Rupturing on the segments of East Anadolu Fault (EAF) and Dead-Sea Fault. The initial fault length (50+135+105=) 270 km and reach to a total length of 400-450 km.
Ekinözü earthquake occurred on E-W trending Çardak faults with a total length of 120km. As of 15 February 2023, Number of casualties is 50783 (Türkiye)+8476 (Syria). 10 provinces with a total population of 15 million people were affected.

Affected provinces

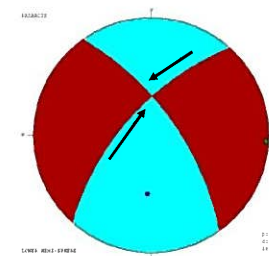


PAZARCİK EARTHQUAKE/地震

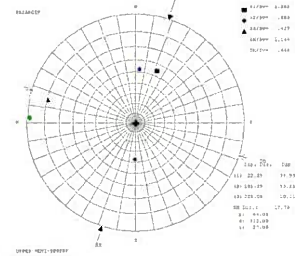
| Institute | Mw | LAT | LON | Depth (km) | Fault Plane | | | Auxiliary Plane | | |
|-----------|-----|------|------|------------|-------------|-----|------|-----------------|-----|------|
| | | | | | Strike | Dip | Rake | Strike | Dip | Rake |
| QCMT | 7.8 | 37.6 | 37.5 | 15 | 54 | 70 | 11 | 320 | 80 | 160 |
| USGS | 7.9 | 37.4 | 37.8 | 33 | 234 | 79 | 14 | 142 | 76 | 169 |
| KOERI | 7.7 | 37.1 | 37.1 | 10 | 222 | 64 | -27 | 324 | 65 | -152 |
| ERD | 7.8 | 37.2 | 37.1 | 18 | 233 | 74 | 18 | 140 | 77 | 168 |
| IPGP | 8.0 | 37.2 | 37.0 | 13 | 230 | 81 | -18 | 323 | 72 | -171 |



Rupture involved segments of Dead-Sea Fault Zone and East Anadolu Fault Zone



Focal Mechanism

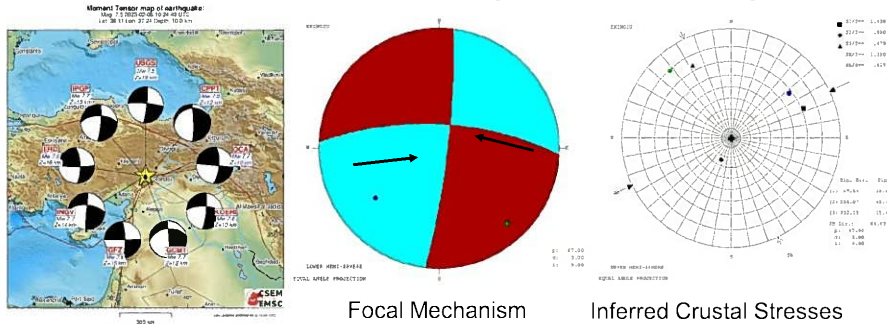


Inferred Crustal Stresses

THE EKİNÖZÜ EARTHQUAKE /地震

| Institute | Mw | LAT | LON | Depth (km) | Fault Plane | | | Auxiliary Plane | | |
|-----------|-----|------|------|------------|-------------|-----|------|-----------------|-----|------|
| | | | | | Strike | Dip | Rake | Strike | Dip | Rake |
| QCMT | 7.7 | 38.1 | 37.2 | 12 | 261 | 42 | -8 | 358 | 84 | -132 |
| USGS | 7.6 | 38.0 | 37.2 | 19 | 276 | 82 | -6 | 6 | 85 | -172 |
| KOERI | 7.6 | 38.0 | 37.3 | 10 | 273 | 67 | -9 | 6 | 81 | -157 |
| ERD | 7.6 | 38.0 | 37.2 | 16 | 174 | 90 | 13 | 358 | 73 | 174 |
| IPGP | 7.7 | 38.0 | 37.2 | 13 | 270 | 60 | -9 | 5 | 82 | -150 |

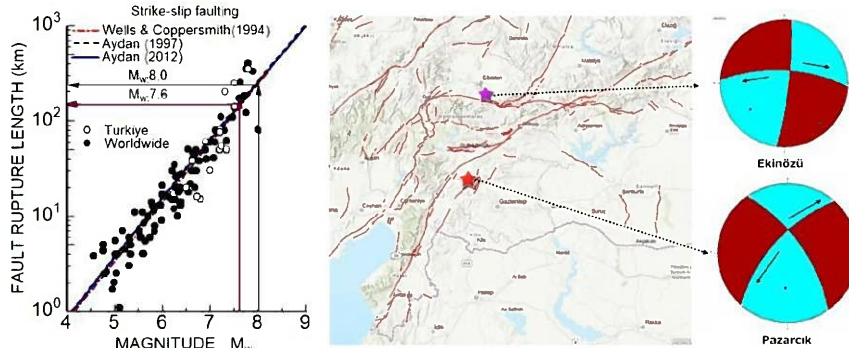
Rupture involved Çardak segment of Çardak and Sürgü Fault Zone



Focal Mechanism Inferred Crustal Stresses
Maximum horizontal stress is rotated by 45 degrees

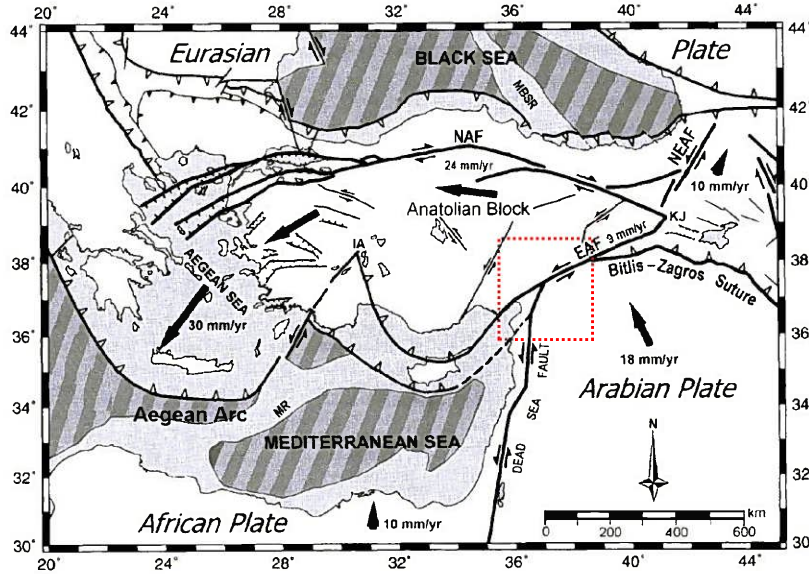
Estimation of the Earthquake Parameters

| Length | Mw | AMAX (gals) | VMAX (kines) | DMAX (cm) | Tr (s) |
|--------|-----|-------------|--------------|-----------|--------|
| 147 | 7.6 | 1020,3 | 72.9 | 506 | 35.6 |
| 195 | 7.8 | 1217.6 | 87.0 | 721 | 45.8 |
| 222 | 7.9 | 1320.7 | 94.3 | 848.4 | 51.4 |
| 255 | 8.0 | 1440.6 | 102.3 | 1009.5 | 58.2 |



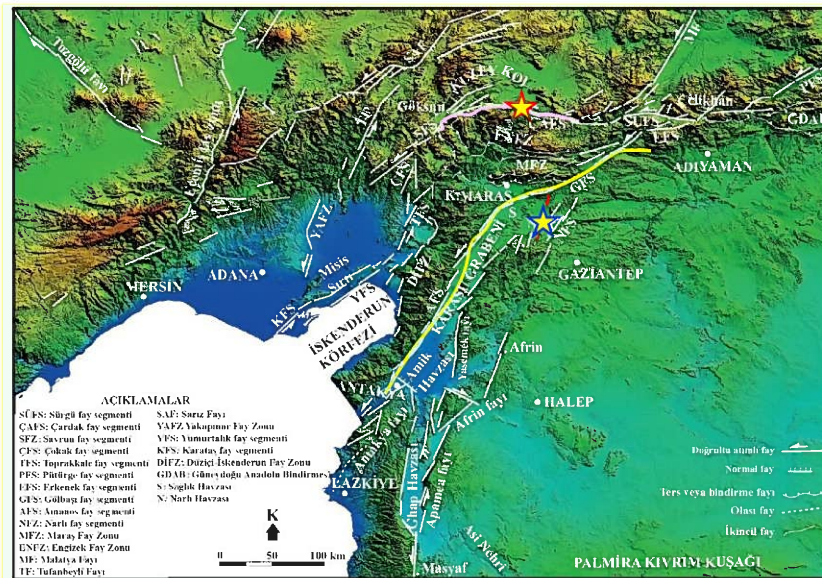
Total Magnitude is about 7.9 for a fault rupture of 270 km long and 20 km wide with an average offset of 4m.

テクトニクス・GLOBAL TECTONICS (Ulusay and Aydan (2005))



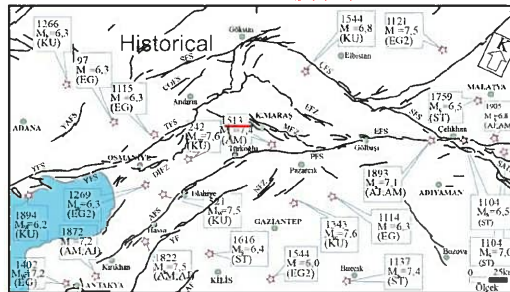
Relative slip between Arabian and African plates cause the westward movement of Anadolu plate

地域的テクトニクス・REGIONAL TECTONICS



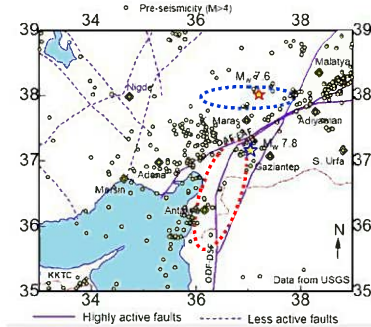
Red line: Narlı Fault (DSFZ); Yellow line:Amanos&Pazarcık Fault; Pink line:Çardak

地震活動・SEISMICITY

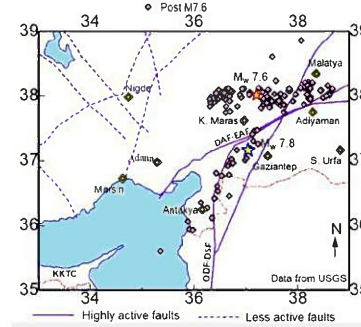


526 Antakya (Antioch) M>7
 1513 Kahramanmaraş M=7.4
 Earthquakes occurred in seismic-gaps · 空白域

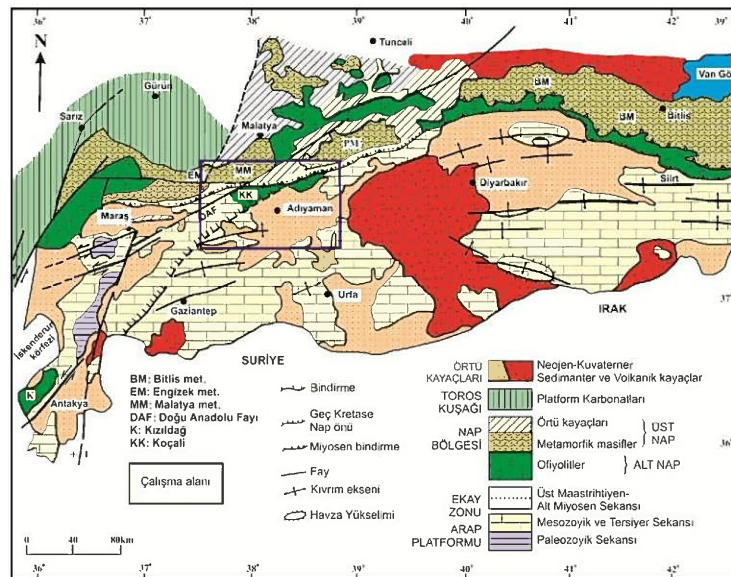
Pre-Seismicity



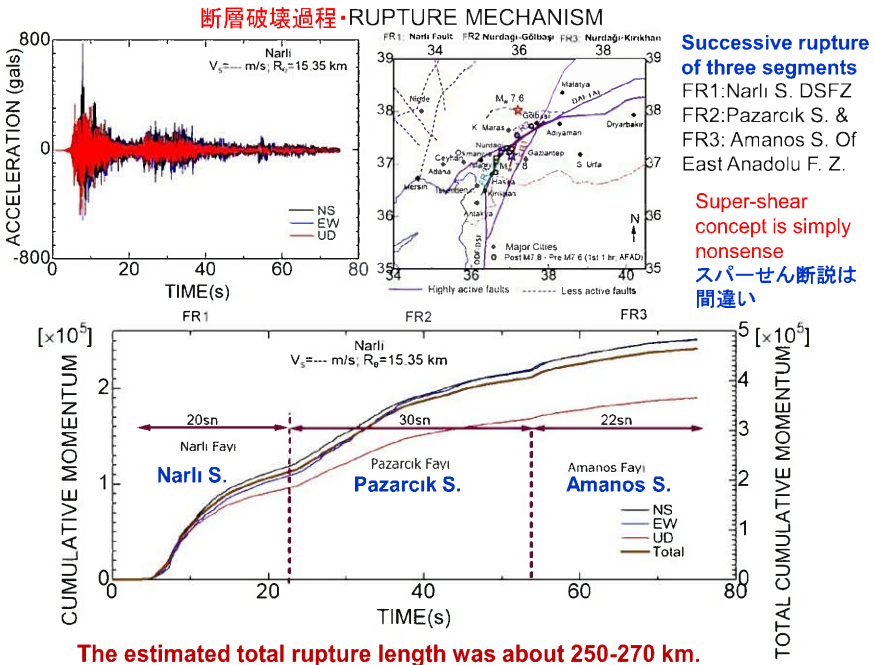
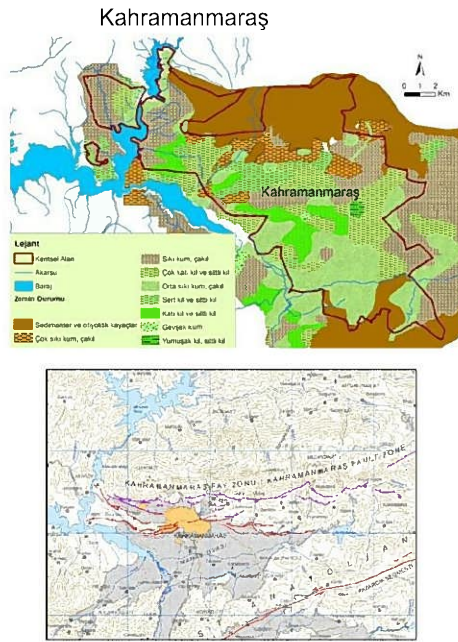
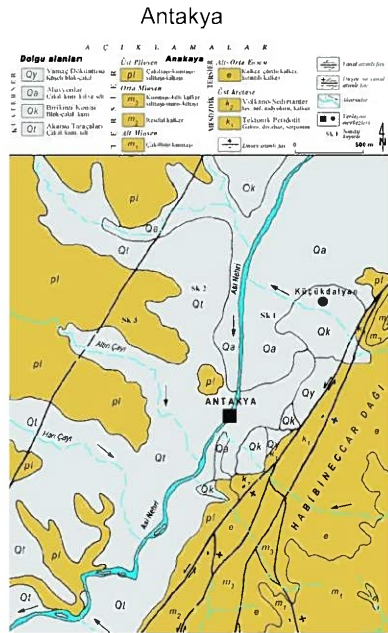
Post-Seismicity



地質・Regional Geology of the affected Region



Damaged cities are located over alluvial deposits.



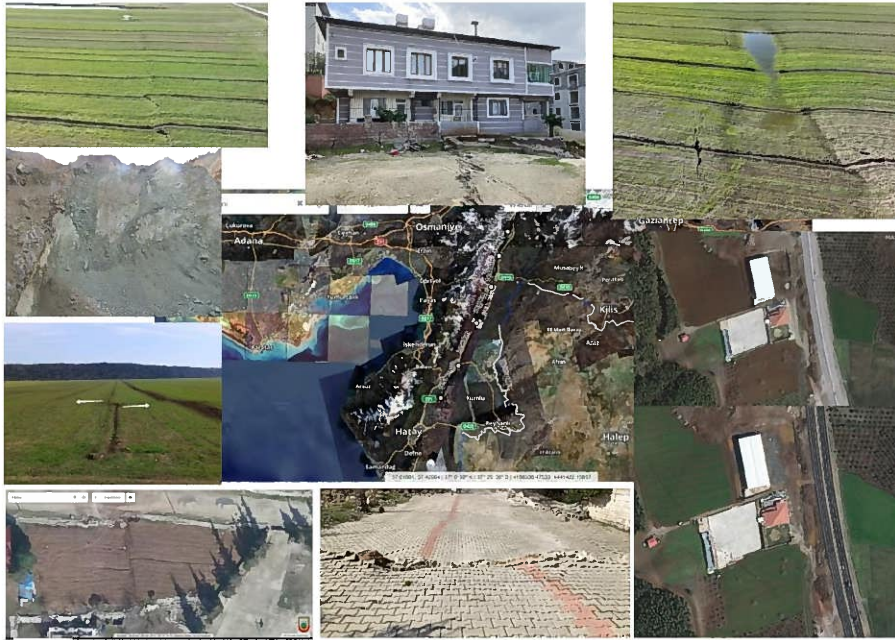
FR1 – NARLI SEGMENT - DSFZ



FR2– PAZARCIK SEGMENT - EAF



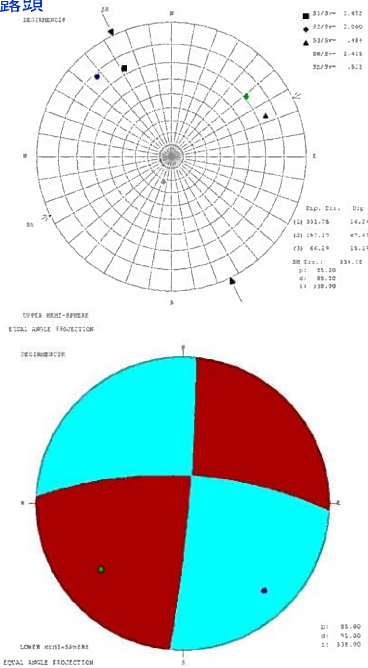
FR3- SEGMENT - EAF



Degirmencikにおける断層露頭



Striation and gouge

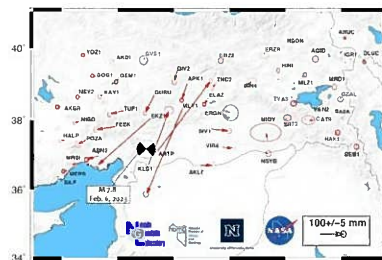


EKİNÖZÜ EARTHQUAKE – ÇARDAK SEGMENT

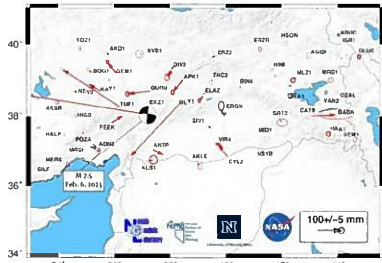


断層変位・SURFACE DEFORMATION FROM GPS and DINSAR

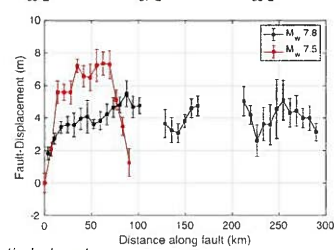
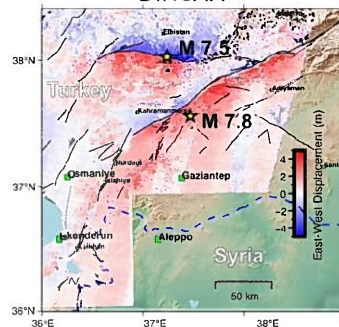
THE PAZARCİK EARTHQUAKE



THE EKİNÖZÜ EARTHQUAKE¹

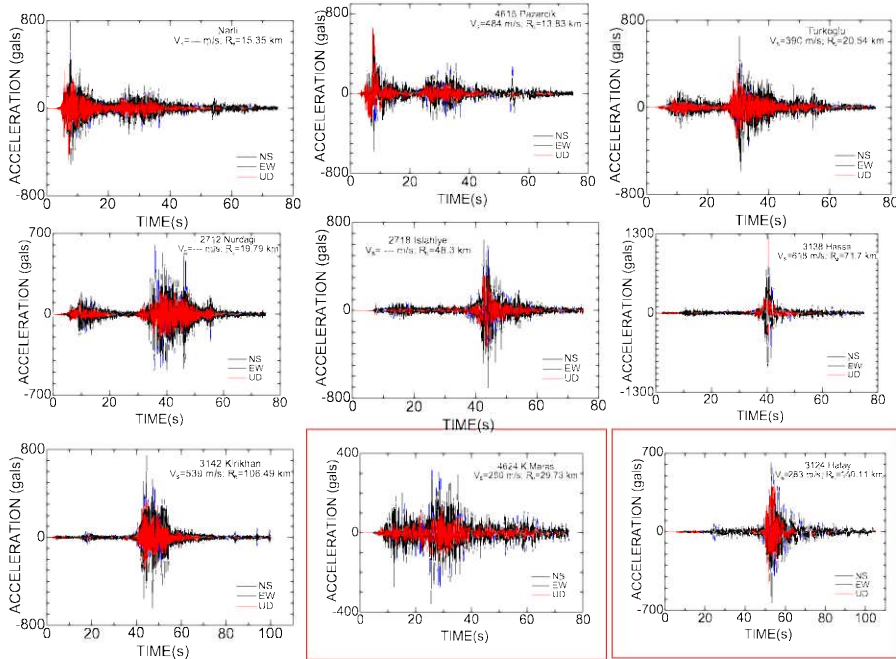
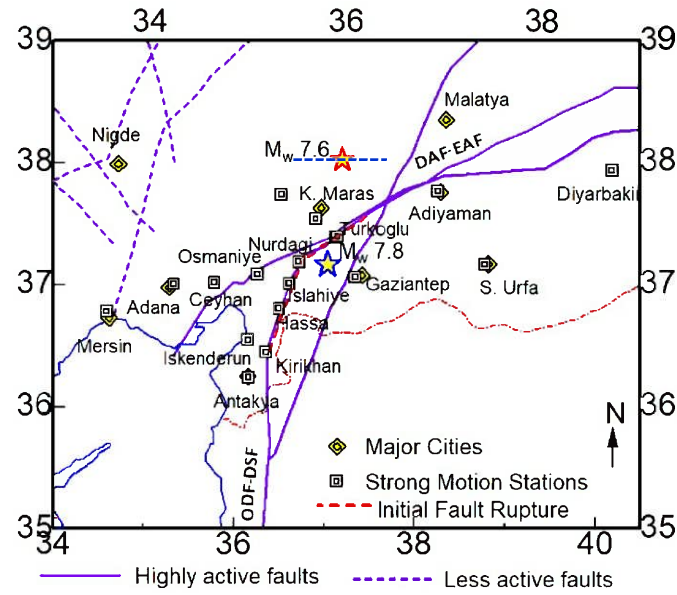


DINSAR

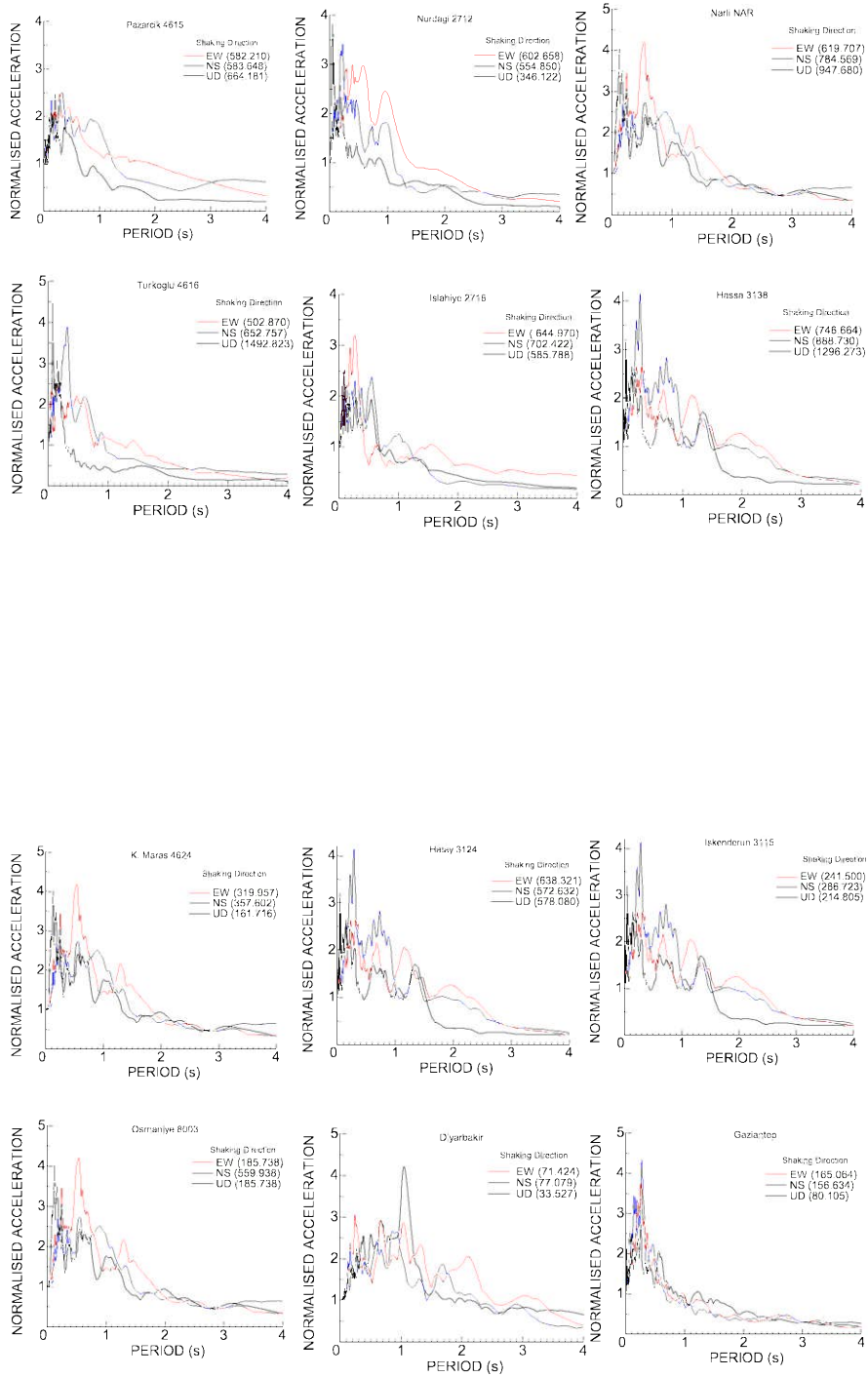


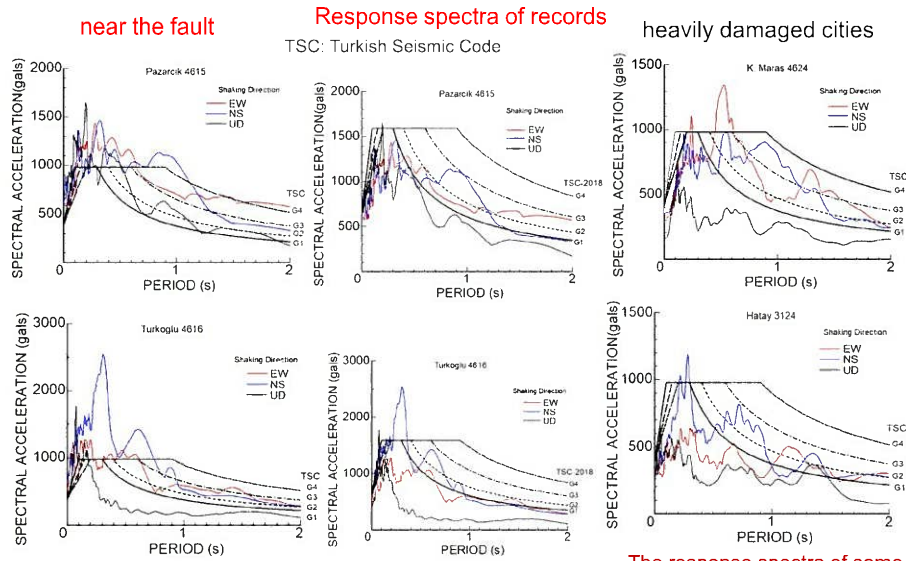
(From Nevada Geodetic Laboratory
[/NVGeodeticLab/status/1625241970460491777/photo/1](http://NVGeodeticLab/status/1625241970460491777/photo/1))

強震記録とその特徴・STRONG MOTION RECORDS



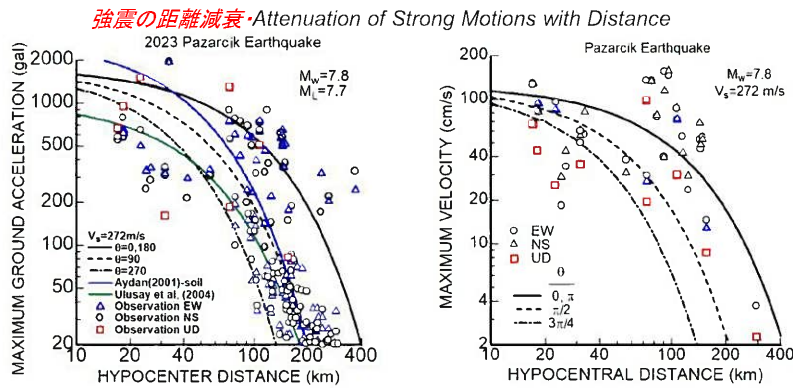
加速度応答スペクトル・Response Spectra of the selected stations



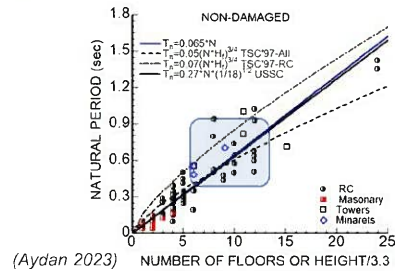
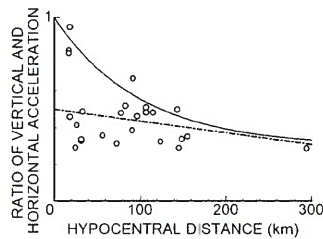


The response spectra of some selected stations along the fault rupture zone were greatly exceeded the seismic design spectra of Türkiye and its 2018 revised version.

The response spectra of some selected stations in the heavily damaged cities were within the seismic design spectra of Türkiye.



Attenuation relations need some further modifications



建物の被害・Building Damage



Kahramanmaraş



Antakya (Hatay)



Buildings toppled in opposite direction against ground movement (Newton's law of action-reaction)

Adiyaman



Elbistan



(damaged by Ekinözü Earthquake)

建物の損傷および破壊要因 ・ Causes of Damage and Collapse

Not obeying the Turkish Seismic Code

Poor workmanship

Construction negligence and lack of moral

Resonance

Soft Story

Pounding of adjacent structures



The causes remain to be the same since 1992 Erzincan earthquake

歴史的構造物 ・ HISTORICAL STRUCTURES



Gaziantep Castle

Malatya Ulucami

Kahramanmaraş Castle

Diyarbakır Castle

Collapsing minaret



Adıyaman Karakuş Tumulus



Antakya Church

運輸施設被害 ・ TRANSPORTATION FACILITIES

空港・Airports



The circle indicates the airports in the epicentral area

Gaziantep Airport is shown at the time of Pazarcık earthquake occurred. Note the small pieces of debris falling from the **suspended ceilings**. Similar situations occurred at Kahramanmaraş and Malatya Airports.

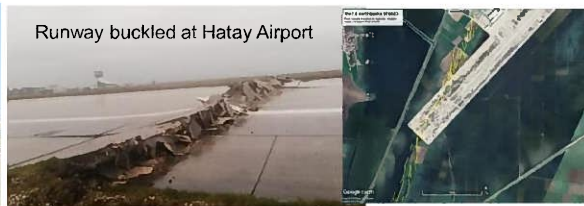
The runway of Hatay airport buckled



Hatay Airport ・ 空港



Ground settled around the terminal building at Hatay Airport



Runway buckled at Hatay Airport

Under reparation



Test flight on February 11, 2023



Runway was repaired on February 11, 2023

First flight was done on February 12, 2023

鉄道・Railways



Locations of the damaged railway lines (from TCDD)

Damage was mainly caused by deformation of rails wherever they are crossed by earthquake faults.

In addition, trains and wagons were derailed or toppled.

Rockfalls and slope failures also caused obstructions.



Buckling of rails due to faulting and ground deformation, toppling of trains

Göksu Abdülhamit-Han Bridge

Completed in 1929



Istanbul-Bağdat Railway Line



Heavy splitting cracks of piers near foundations

Railway Bridge near Kuyumcular (Varto Mezrası)



Roadways

Roadways and railways should not be elevated and they should be constructed on the existing ground surface in active fault zones.



TAG Expressway

Bridges Nurdağı-Gaziantep Highway

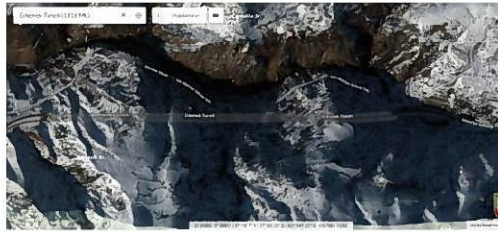


Overpass Bridge collapsed due to permanent ground movements



Bridge collapse due to pier settlement due to ground failure (Antakya)

トンネル被害 ・ Tunnel Damages



Location of Erkenek tunnel
Old Erkenek Tunnel is 330m long and unsupported
New Erkenek Tunnels are 1816 m long



Traces and Rockfalls above the portals of new Erkenek tunnels

New Erkenek Tunnels

Spalling of concrete linings in New Erkenek Tunnels



Collapse of concrete lining occurred despite they were reinforced.

Portal and block falls in Old Erkenek Tunnels

Old Erkenek Tunnel excavated in limestone is 330m long and unsupported except portals



Masonry Bridges from Ottoman Period

Batıyaz Taş Köprü



Demirköprü Taş Köprü



They are structurally stable despite some dislocation of rock blocks.

断層近傍の橋脚 Viaducts nearby fault surface rupture



No damage despite close proximity fault ruptures

They are built as redundant structures with continuous steel girders

不静定構造物としての設計



Turgut Özal Viaduct



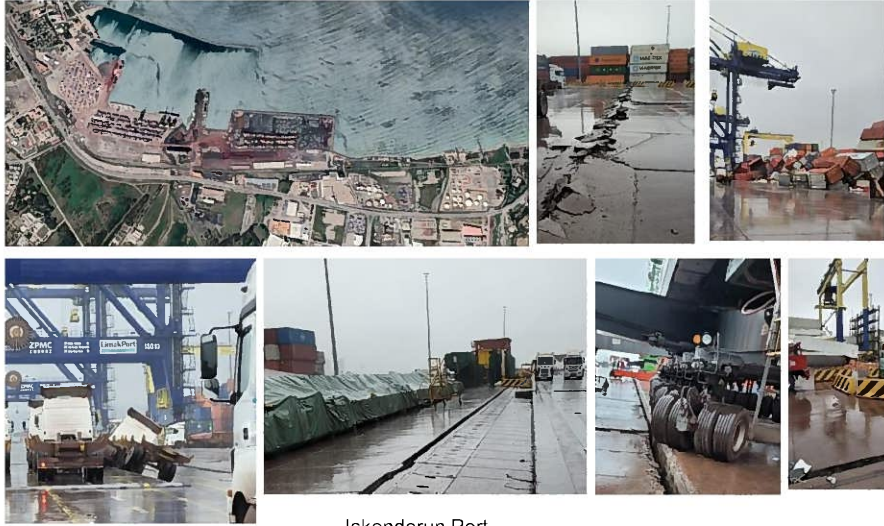
静止しているトラックの転倒 ・ Toppled stationary vehicles

Adiyaman-Malatya highway



Implying high ground motions

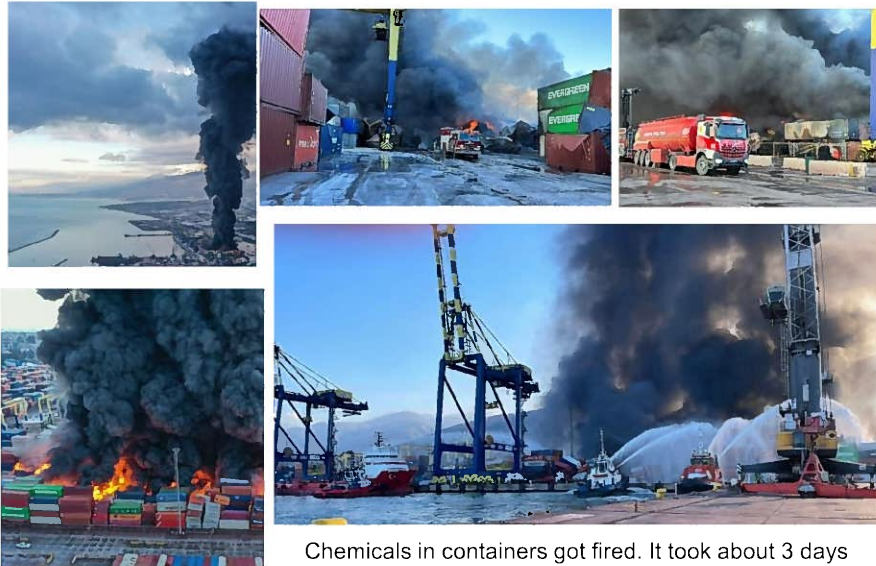
港の被害 ・ Ports



Iskenderun Port

Structural Damage is small: Small settlement, pounding, separation etc.

火災 ・ Fires at Iskenderun Port



Chemicals in containers got fired. It took about 3 days to extinguish fires.

ライフライン ・ LIFELINES



**Toppled Pylon
Gözpinar**



**Toppled Pylon
Gözpinar**



**Toppled Pylon
Tavla**



**Bended Pylon
Narlı**

Dislocated or toppled transformers



電信柱の座屈・ Bended buckled steel utility poles due to high strong motions



落石・地盤災害・断層による電信柱の被害 ・ Failure or Tilting of Steel Utility Poles



RC電信柱の被害 ・ Failure or Tilting of RC Utility Poles



Afşin-Elbistan Thermal Power Plant ・ 火力発電所



Minor damage. However, some replacements of old and slightly damaged components have been implemented.



Re-started on May 19 after overall check of the plant.

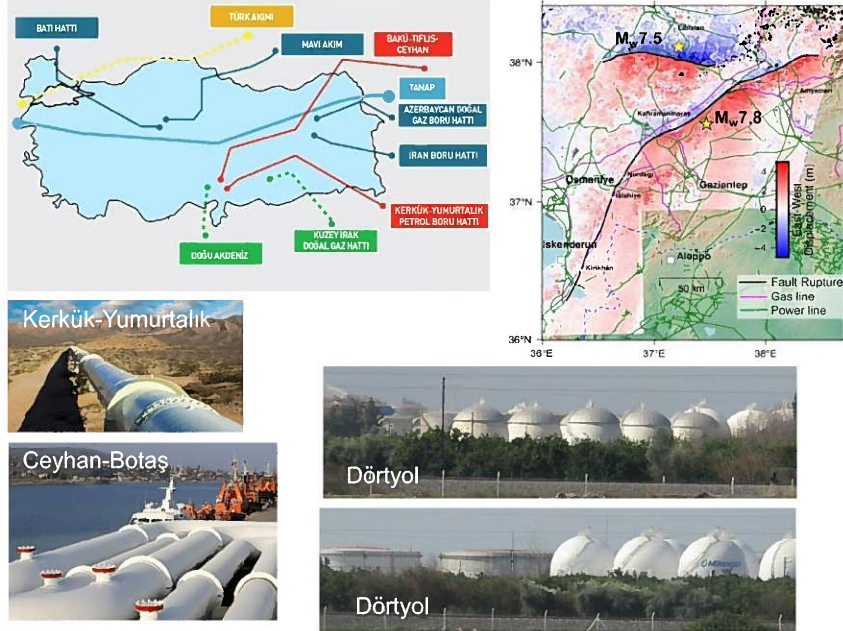
水道パイプの被害 ・ Water Pipe Damage and Repairs



水道パイプの被害 ・ Water Pipe Damage



石油・天然ガスパイプライン ・ PIPELINES OF PETROLEUM AND NATURAL GAS



天然ガスパイプラインの爆発 ・ Natural Gas Pipeline Fires



産業施設 ・ INDUSTRIAL FACILITIES



火災 ・ Fires

天井落盤 ・ Roof-Beam Collapses



ダム被害 ・ DAMS
Sultansuyu Dam

Kartalkaya Dam

Sürgü Dam

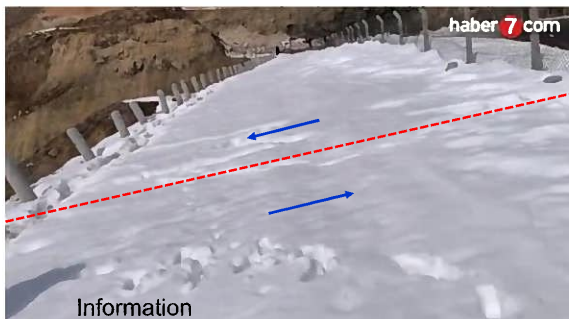
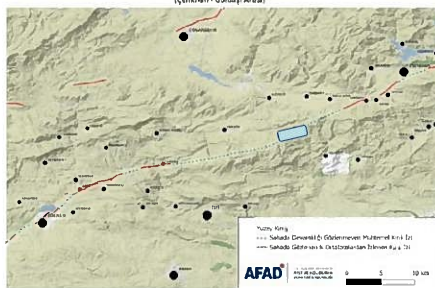


Atatürk Dam



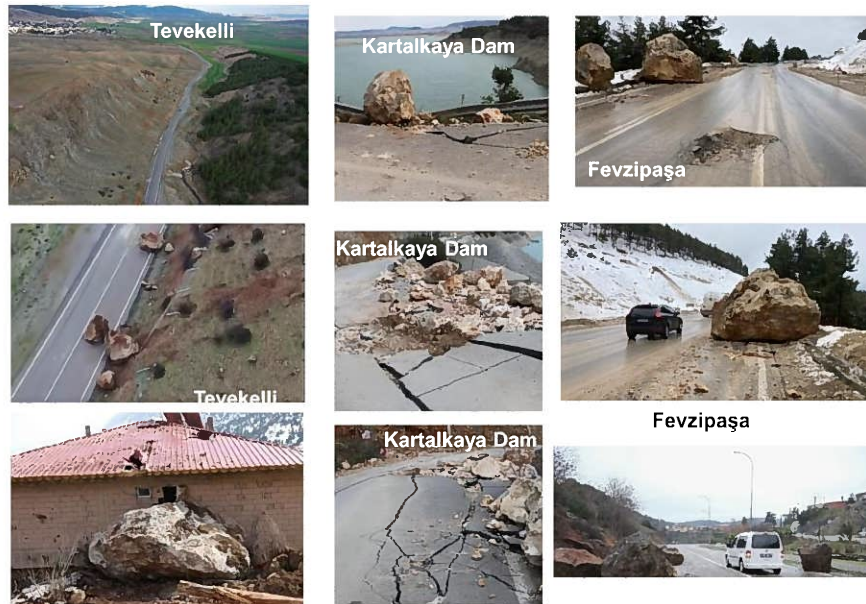
Longitudinal Separation cracks between clay core and rock/earth fill

ERKENEK DAM ・ 被害 Partial rupture of Erkenek segment (65km)



Information

地盤被害 ・ GEOTECHNICAL DAMAGES
 落石 ・ Rockfalls



地滑り ・ Slope Failures (Landslides)



地滑りダム ・ Landslide Dams



Islahiye



Tepehan



Amanos Kaledibi

陥没 ・ Sinkholes



Nurhak



Gaziantep Yavuzlar District

液状化 & 側方流動 ・ Liquefaction and Lateral Spreading

Antakya-Reyhanlı Highway



液状化による建物の被害 ・ EFFECT OF LIQUEFACTION ON BUILDINGS



Gölbasi



地表面断層の建物被害への影響・INTERACTION BETWEEN FAULTS AND BUILDINGS





The quality of construction and foundation type are not appropriate

Tevekelli



EFFECT OF FAULTING ON LIQUEFACTION RELATED SANDBOILS



Damage to Canals - Waterways



異常現象観測 ・ UNUSUAL OBSERVATIONS



犬が吠える Barking dogs just before the earthquake



Balıklığöl, Şanlı Urfa

発光現象 ・ Earthquake lights



Kahramanmaraş



Antakya

謝辞 ・ ACKNOWLEDGEMENTS

This reconnaissance is financially supported by International Consortium on Geo-Disaster Reduction (ICGdR)



ご清聴ありがとうございました
THANKS FOR YOUR KIND ATTENTION

ANY QUESTION?

