ASSOCIATION FRANÇAISE DU GÉNIE PARASISMIQUE
COMITÉ FRANÇAIS DE MÉCANIQUE DES ROCHES
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INTRODUCTION

Aspects expérimentaux

Glissements de terrains associés aux tremblements de terre en Iran

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Sommaire

- **Quelques éléments de géophysique**
- **Différents types d'ondes**
- **Stabilité d'une faille**
- **Essais de cisaillement cyclique**
- **Glissements de terrain en Iran**
- **Conclusions**

Quelques éléments de géophysique

Structure du globe terrestre

En résumé ...

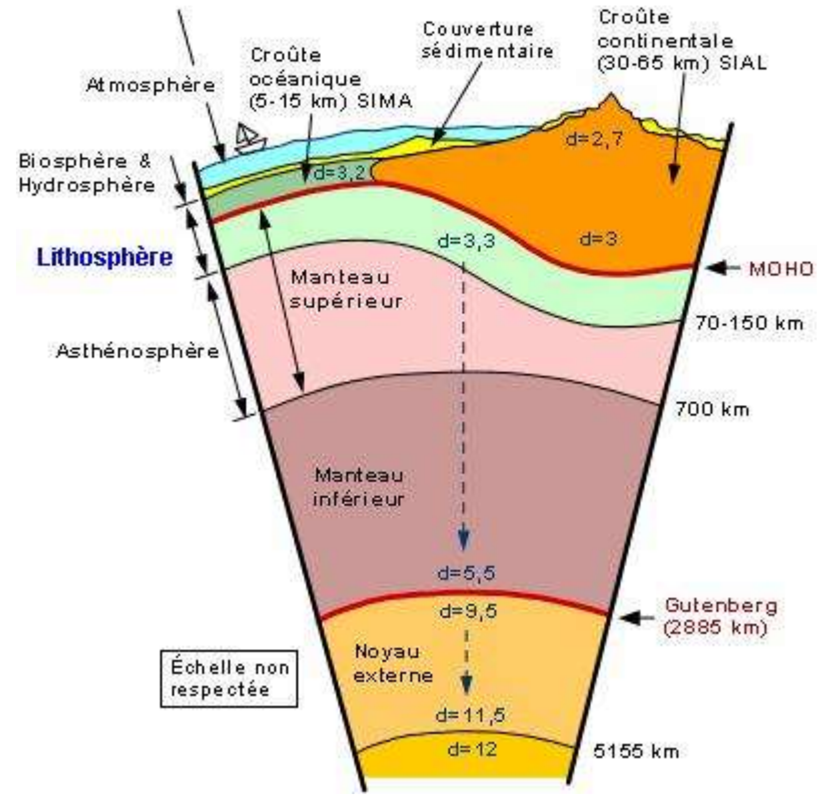
CROUTE
- CONTINENTALE (**SIAL**)
  - r. granitiques (d=2,7)
  - r. intermédiaires (d=3)
  - plaines continentales (30-35 km)
  - montagnes (50-65 km)
- OCÉANIQUE (**SIMA**) (5-15 km)
  - basaltes (d=3,2)

—— discontinuité de Mohorovicic (MOHO) ——

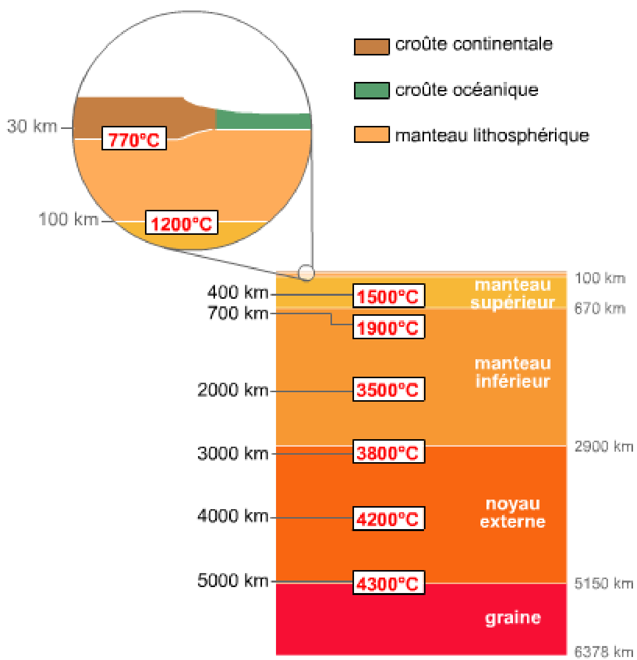
MANTEAU (péridotite)
- SUPÉRIEUR: se divise en deux couches
  - couche rigide dont la base se situe à 70 km, sous les océans à 150 km, sous les continents
  - couche plastique jusqu'à 700 km
- INFÉRIEUR
  - couche solide: de 700 à 2885 km

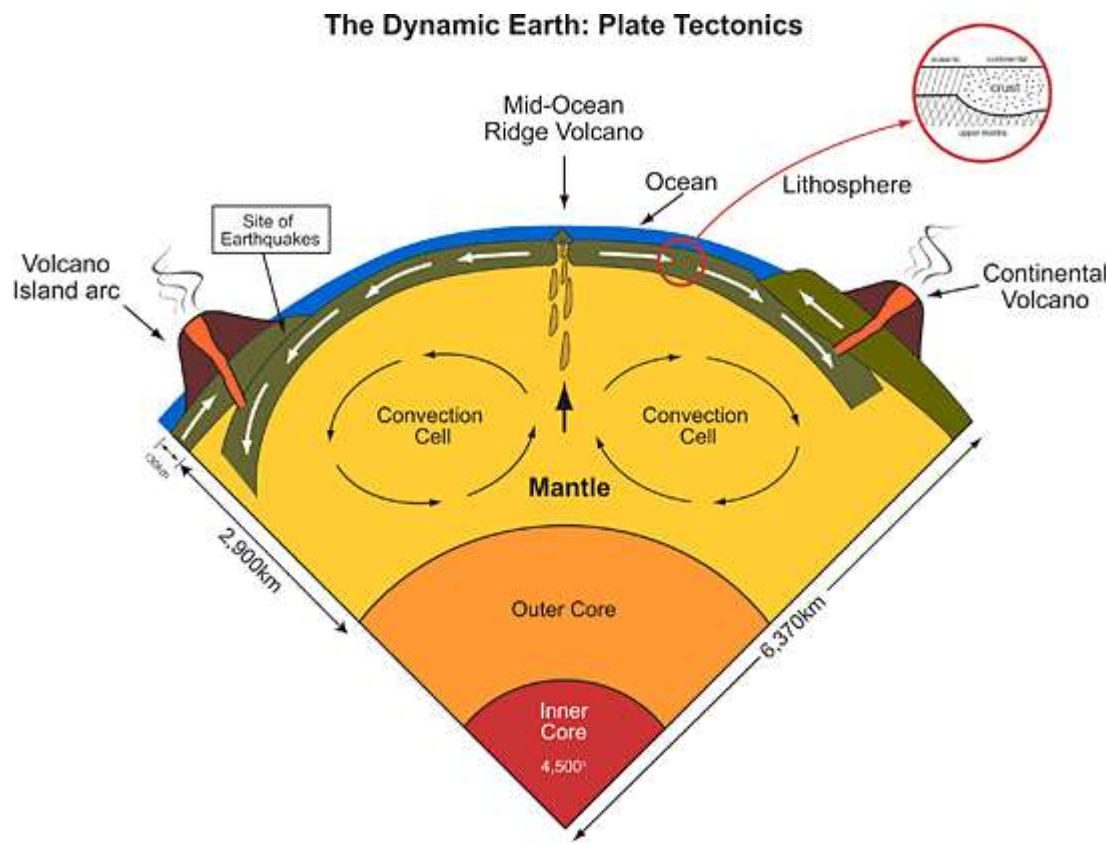
—— discontinuité de Gutenberg ——

NOYAU (fer et nickel)
- EXTERNE, liquide, de 2885 à 5155 km
- INTERNE, solide, de 5155 à 6371 km

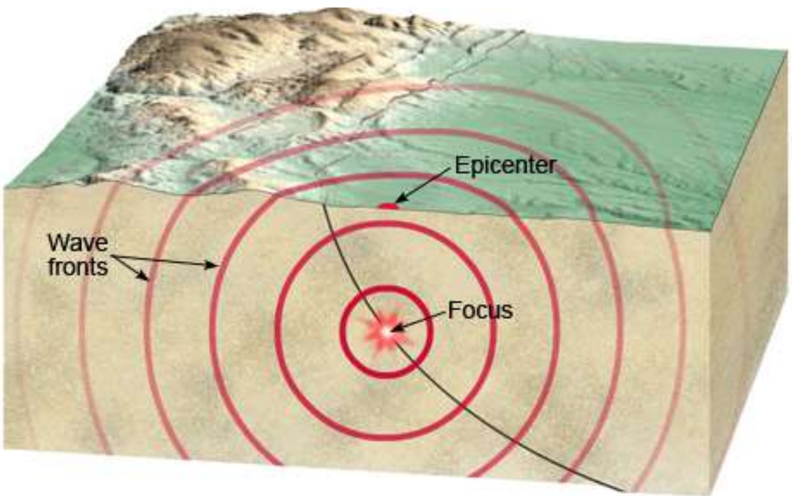


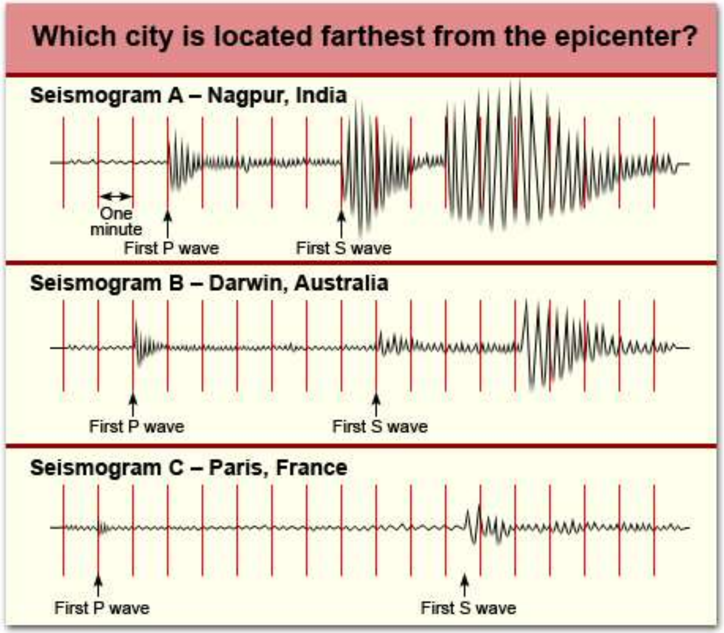
Géodynamique interne



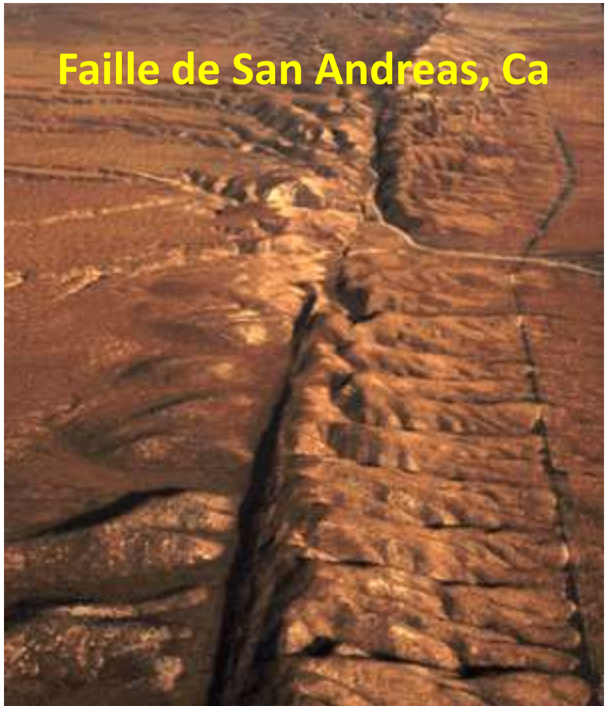


Sismicité et tremblements de terre

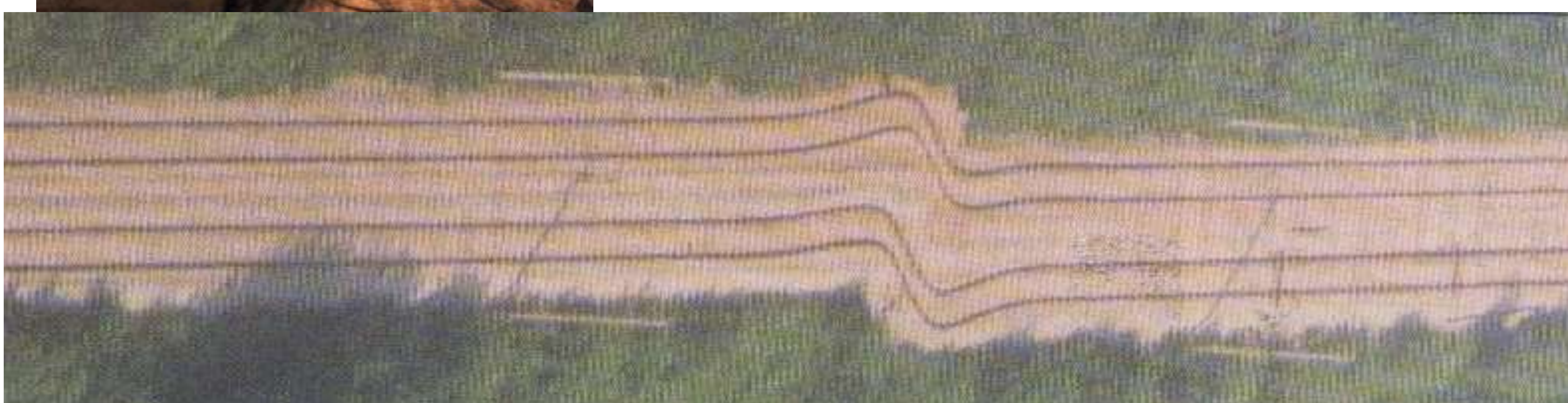




Failles majeures et séismes



Séisme en Turquie

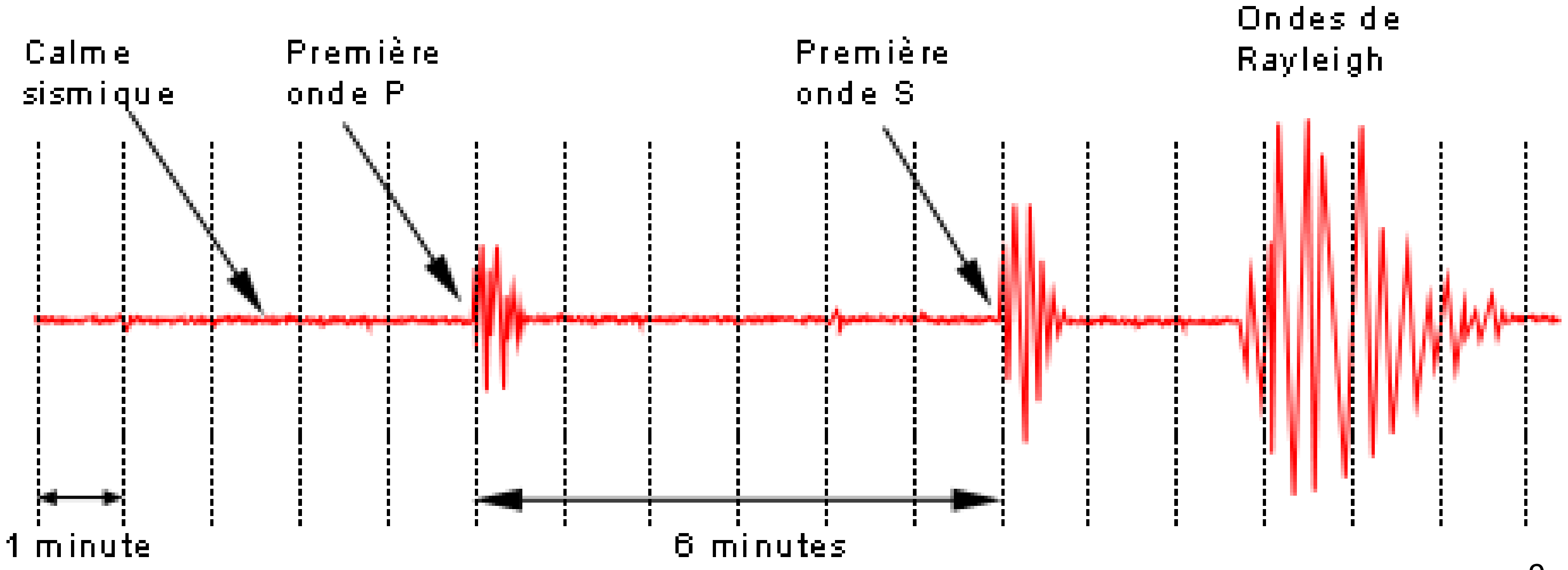


Différents types d’ondes

Différents types d’ondes

- **Onde de volume**
  - **Ondes primaires, P (onde longitudinale ou de compression)**
  - **Ondes secondes, S (onde transverse ou de cisaillement)**

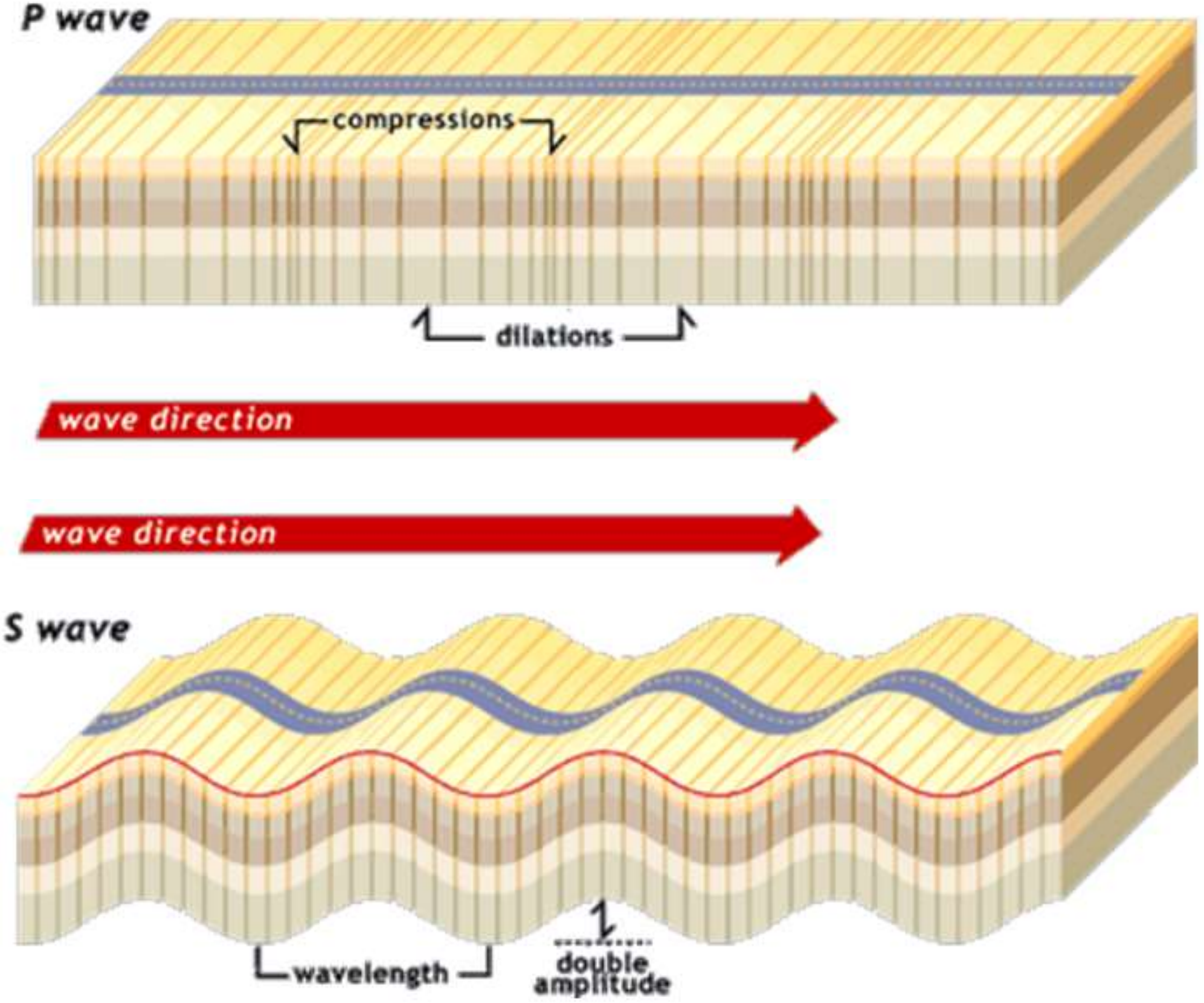
- **Ondes de surface**
  - **Ondes de Rayleigh**
  - **Ondes de Love**



Ondes de volume

Ondes P ou ondes primaires (ondes de compression ou ondes longitudinales)

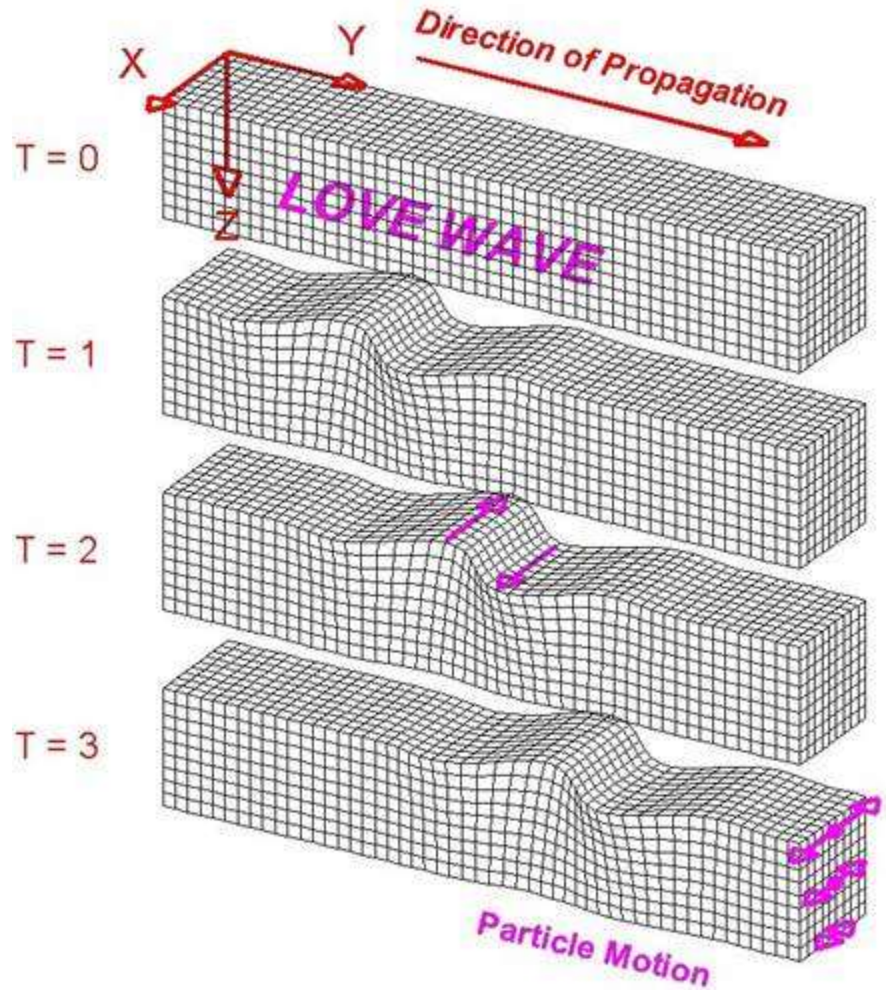
Ondes S ou ondes secondes (ondes de cisaillement ou ondes transverses)



Ondes de surface

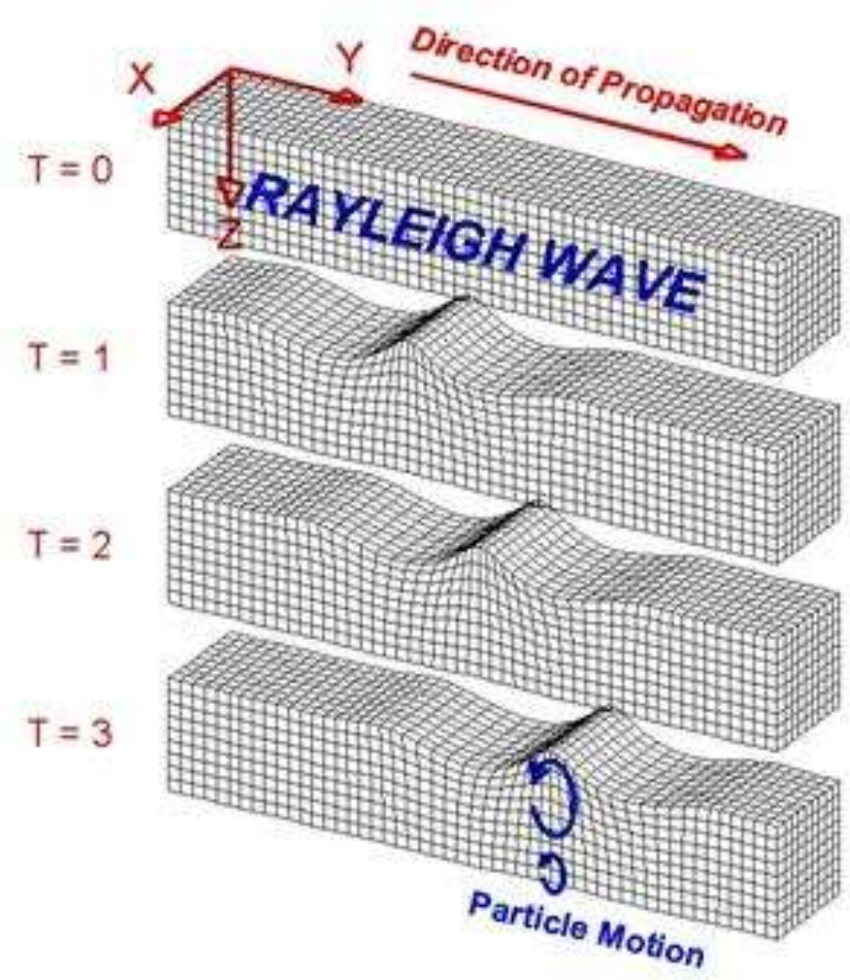
Ondes guidées par la surface de la Terre. Leur effet est comparable aux ridules formées à la surface d'un lac. Elles sont moins rapides que les ondes de volume mais leur amplitude est généralement plus forte.

- <u>Onde de Love</u> : le déplacement est essentiellement le même que celui des ondes S sans mouvement vertical.
- Les ondes de Love provoquent un ébranlement horizontal qui est la cause de nombreux dégâts aux fondations des édifices. Les ondes de Love se propagent à environ 4 km/s, elles sont plus rapides que les ondes de Rayleigh.

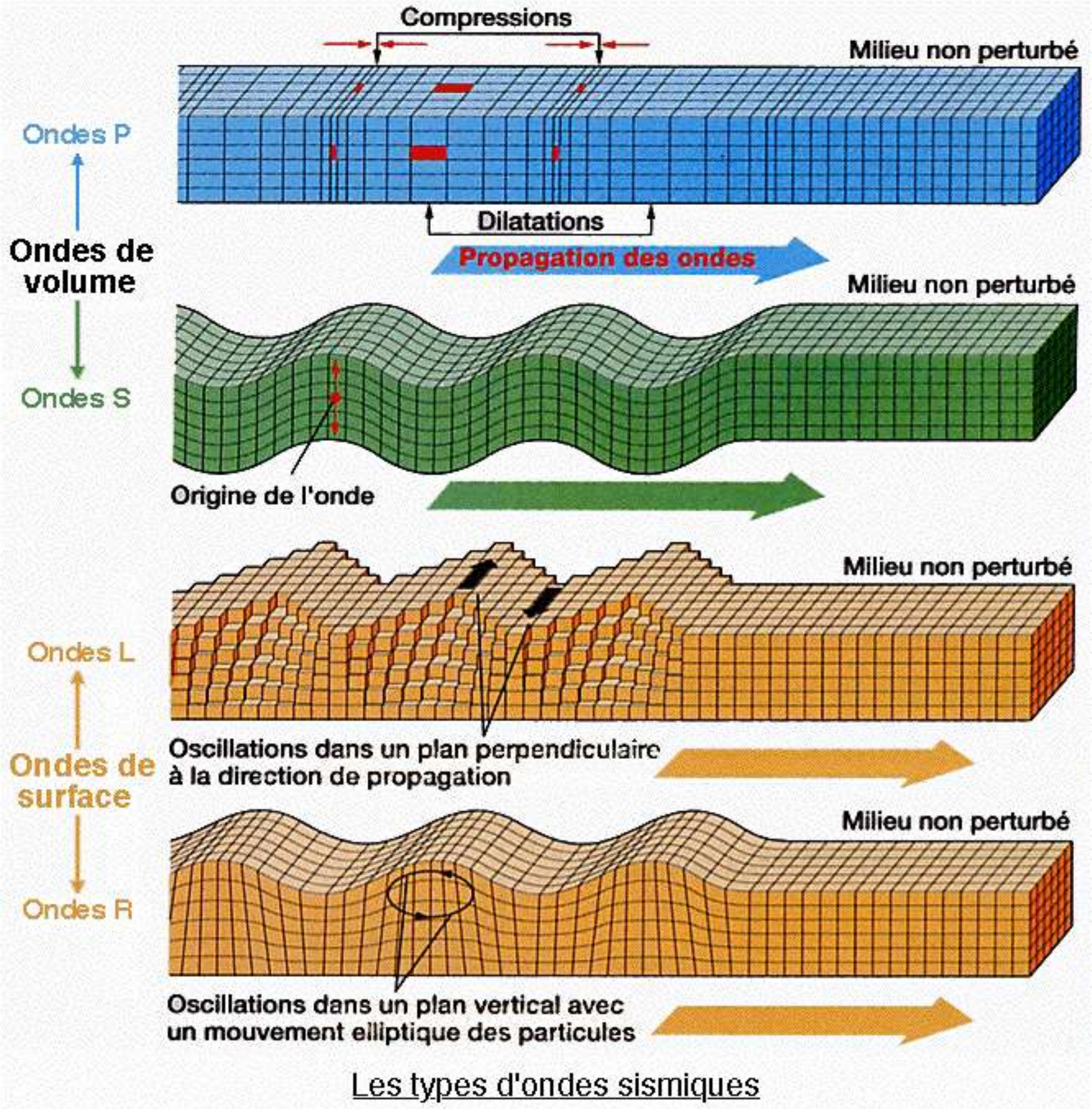


Ondes de surface

- **Onde de Rayleigh** : le déplacement est complexe, assez semblable à celui d'une poussière portée par une vague, un mouvement à la fois horizontal et vertical, elliptique, en fait.

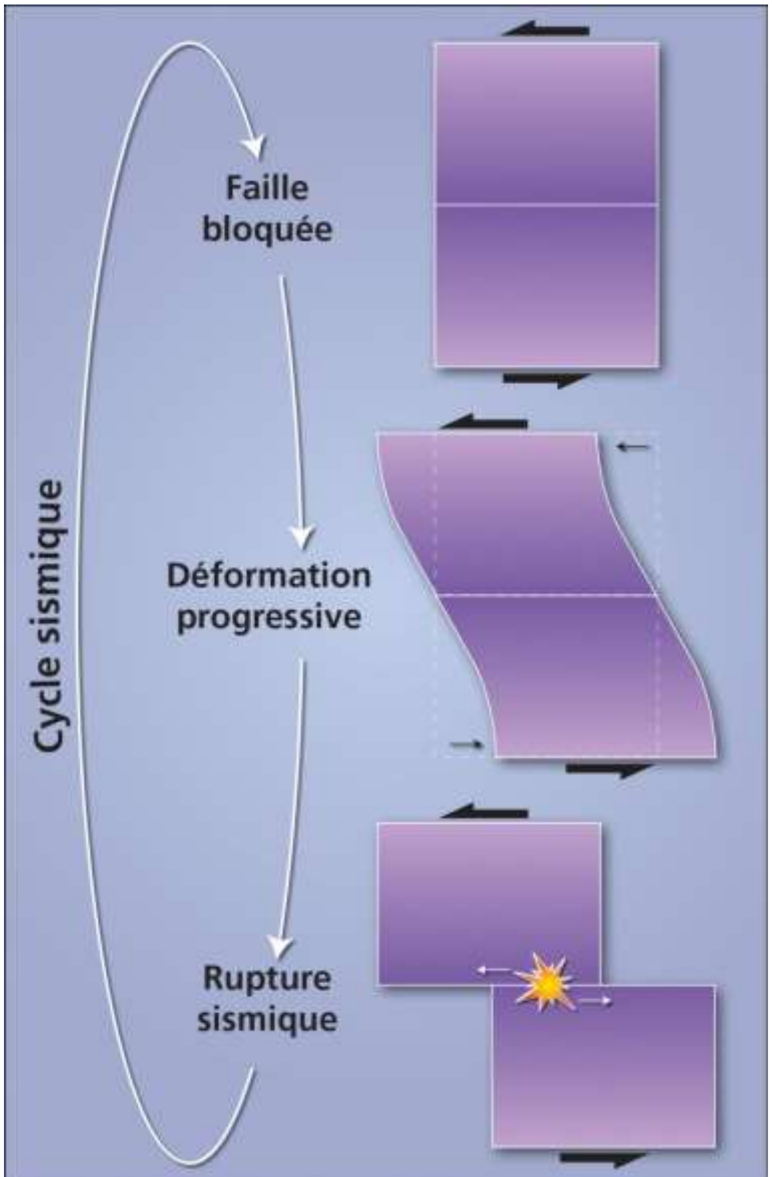


Ondes de volume et ondes de surface



Stabilité d’une faille

Origine d'un séisme

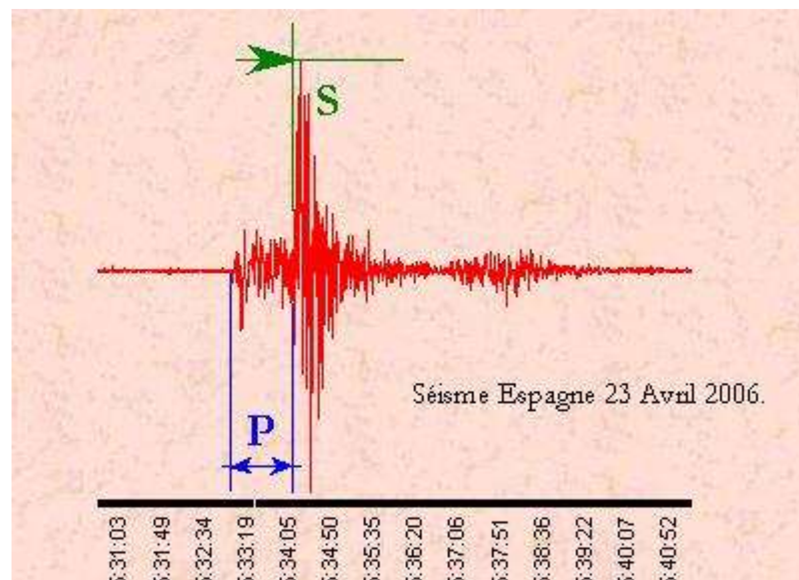


Séisme: Rupture brutale de l'écorce terrestre; libération soudaine d'énergie élastique emmagasinée: ondes

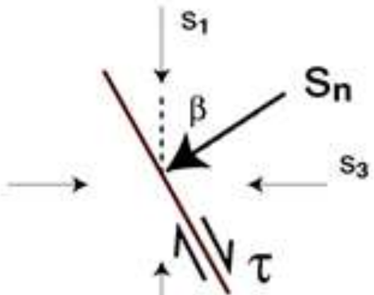
Loi de Gutenberg-Richter

$$Log\,N = a + b\,M$$

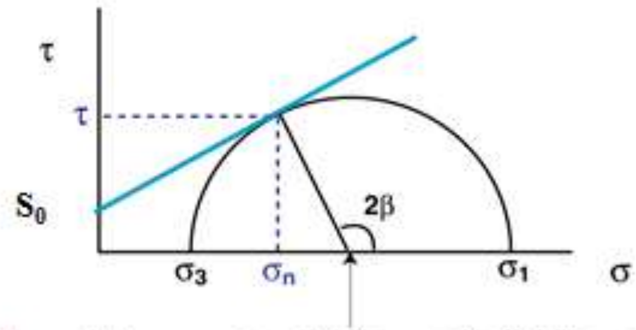
M, magnitude
N, nb d'évènements



Conditions de stabilité d'une faille



$$\sigma_{ij} = \delta_{ij} - \delta_{ij} P_p$$



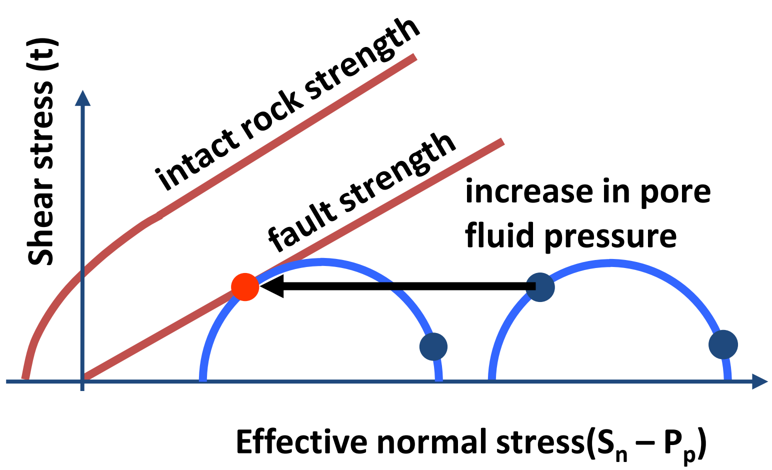
Normal stress: $\sigma_n = 0.5 (\sigma_1 + \sigma_3) + 0.5 (\sigma_1 - \sigma_3) \cos 2\beta$

Shear stress: $\tau = 0.5 (\sigma_1 - \sigma_3) \sin 2\beta$

$S_o \sim 0$

$$\frac{\sigma_1}{\sigma_3} = \frac{S_1 - P_p}{S_3 - P_p} = [(\mu^2 + 1)^{1/2} + \mu]^2$$

$$\tau = S_0 + \mu\sigma_n$$



Friction defines both limiting stress magnitudes and orientation of faults likely to slip

● Critically stressed fault ● Non-critically stressed fault

Conditions de stabilité d'une faille

$$\frac{\sigma 1}{\sigma 3} = \frac{S1 - Pp}{S3 - Pp} = \left[\sqrt{\mu^2 + 1} + \mu\right]^2 \qquad \left[\sqrt{\mu^2 + 1} + \mu\right]^2 = 3.1 \text{ for } \mu = 0.6$$

Normal:

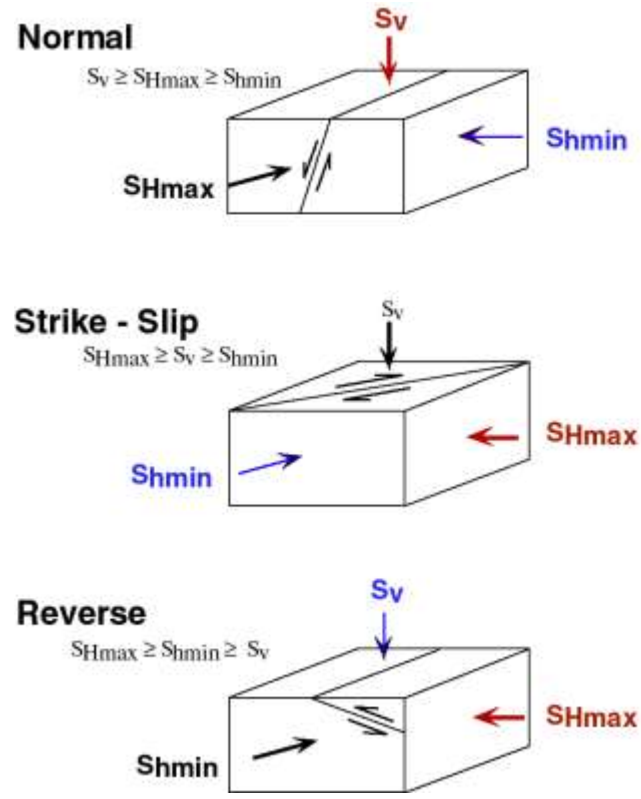
$$\frac{Sv - Pp}{Sh\min - Pp} = \left[\sqrt{\mu^2 + 1} + \mu\right]^2$$

Décrochement:

$$\frac{SH\max - Pp}{Sh\min - Pp} = \left[\sqrt{\mu^2 + 1} + \mu\right]^2$$

Inverse:

$$\frac{SH\max - Pp}{Sv - Pp} = \left[\sqrt{\mu^2 + 1} + \mu\right]^2$$



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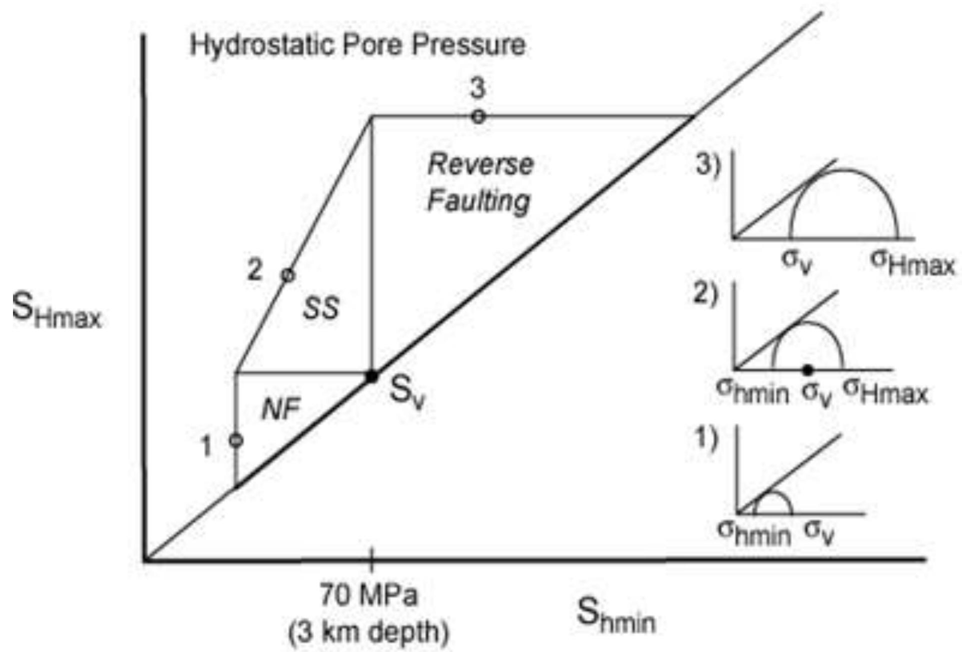

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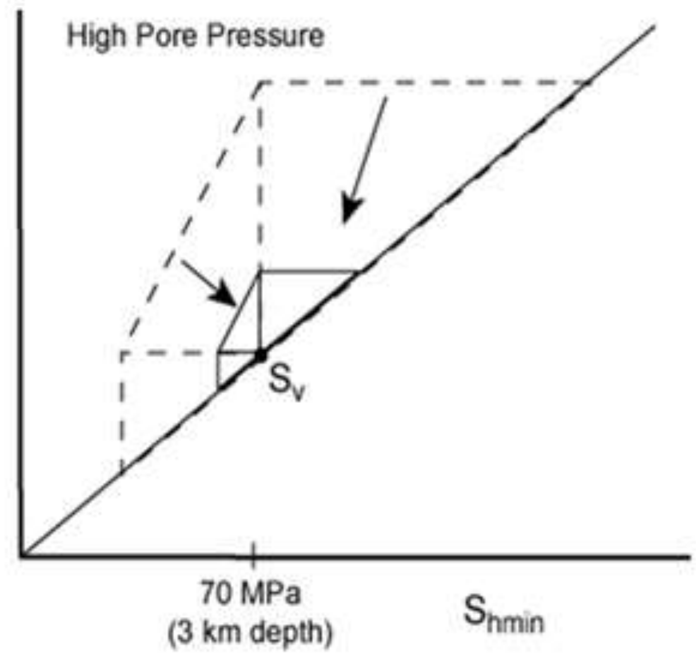
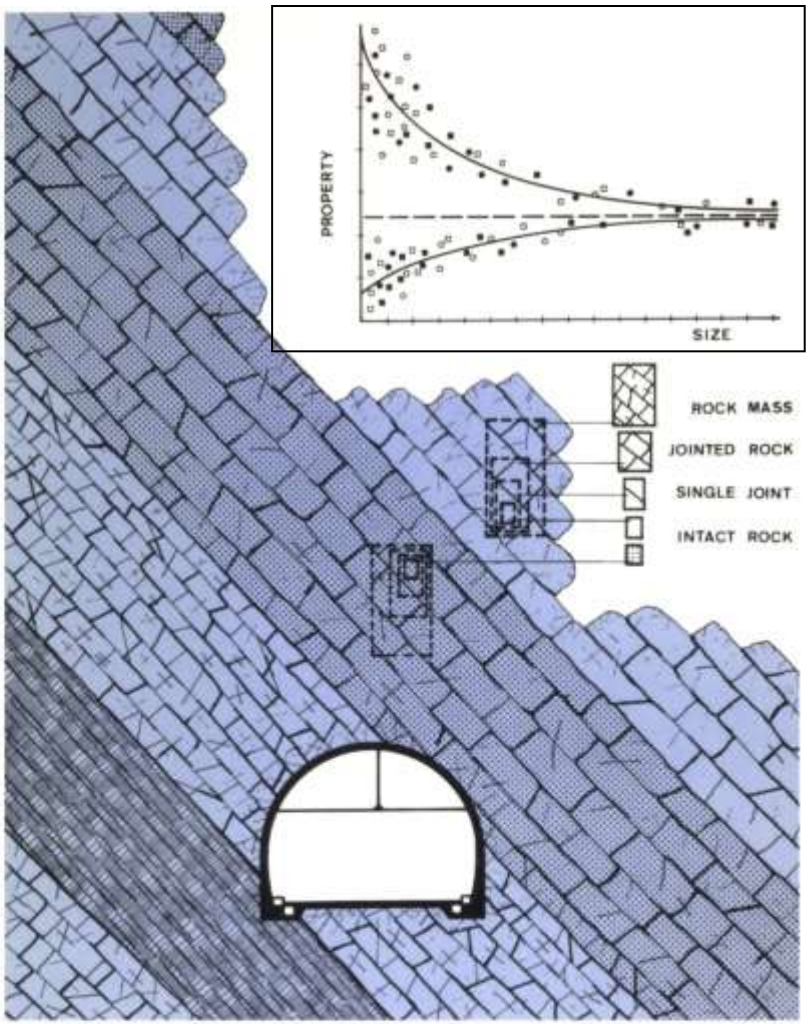


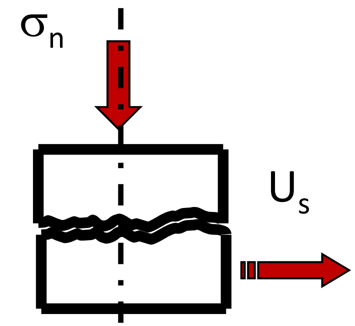
Essais de cisaillement cyclique

Complexité des structures géologiques



D'après Pinho da Cunha (1992)

- Hétérogénéités
- Discontinuités
- Anisotropie
- Effet d'échelle (Micro-Macro)
- Incertitudes sur les propriétés



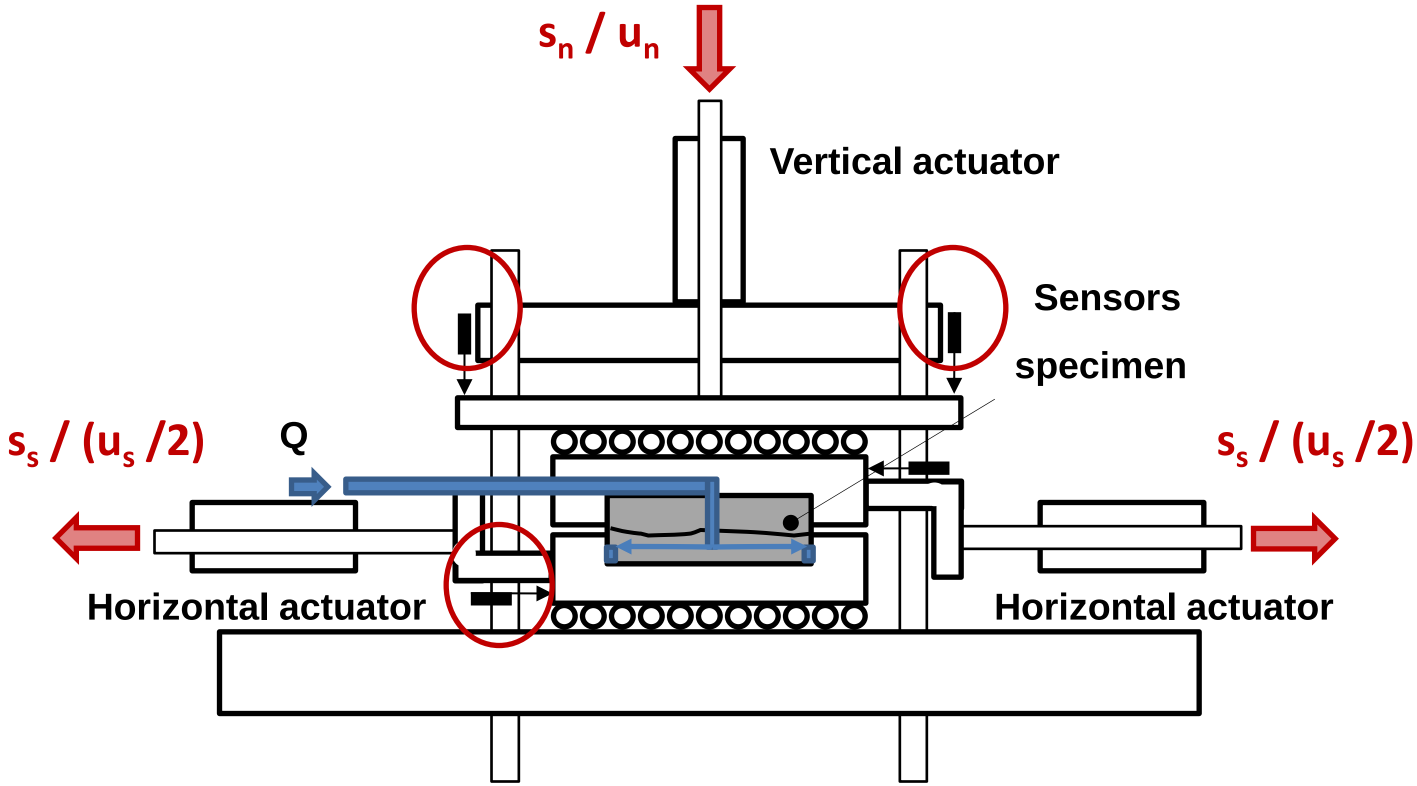
Modélisation = Idéalisation (i.e. simplification)

↓

Hiérarchie des phénomenes

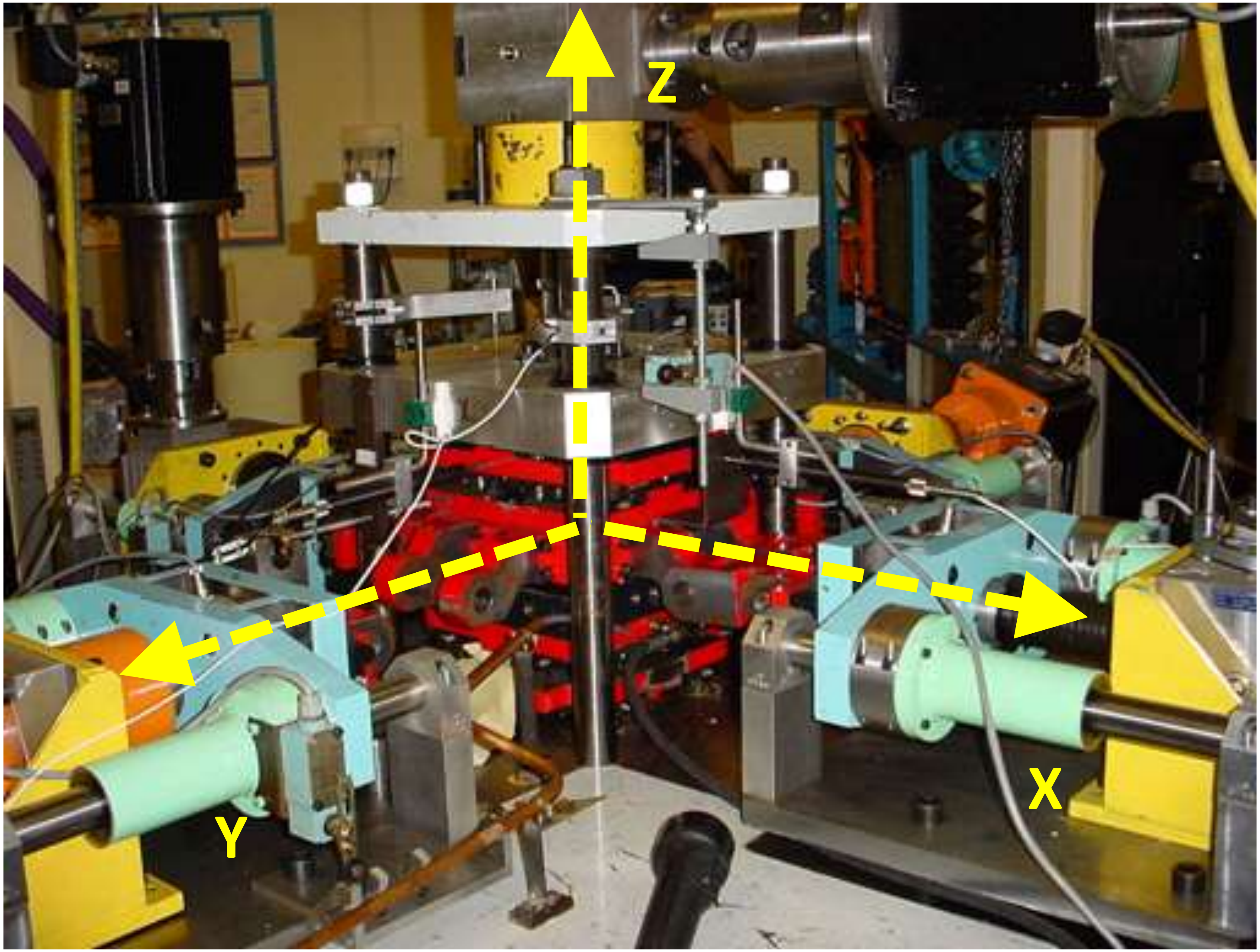
Essais de cisaillement 3D

- Stress and displacement servo-controlled in the 3 directions
- Fluid injection : Control Pressure Volume

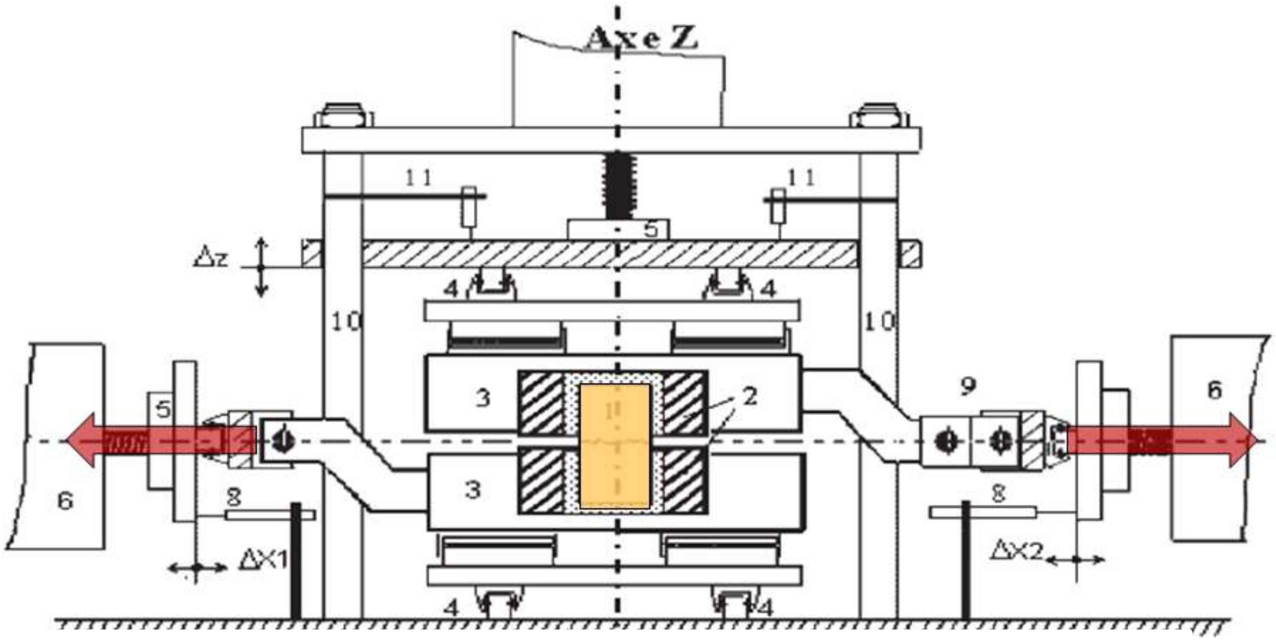


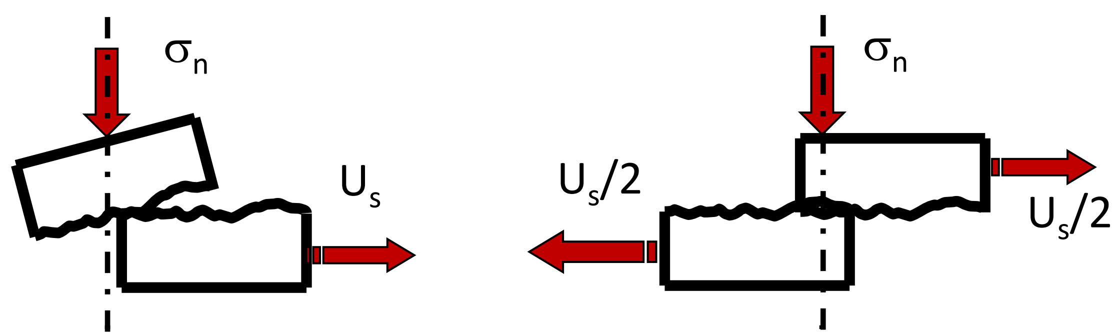
Boulon M. (1995), A 3D direct shear device for testing the mechanical behaviour and the hydraulic conductivity of rock joints. Second Int. Conf. on Mechanics of Jointed and Faulted Rock MJFR-2, Vienne, Balkema ed. Rotterdam, Pays Bas, pp 407-413.

BCR 3D : Servo-Controlled Direct Shear Equipment



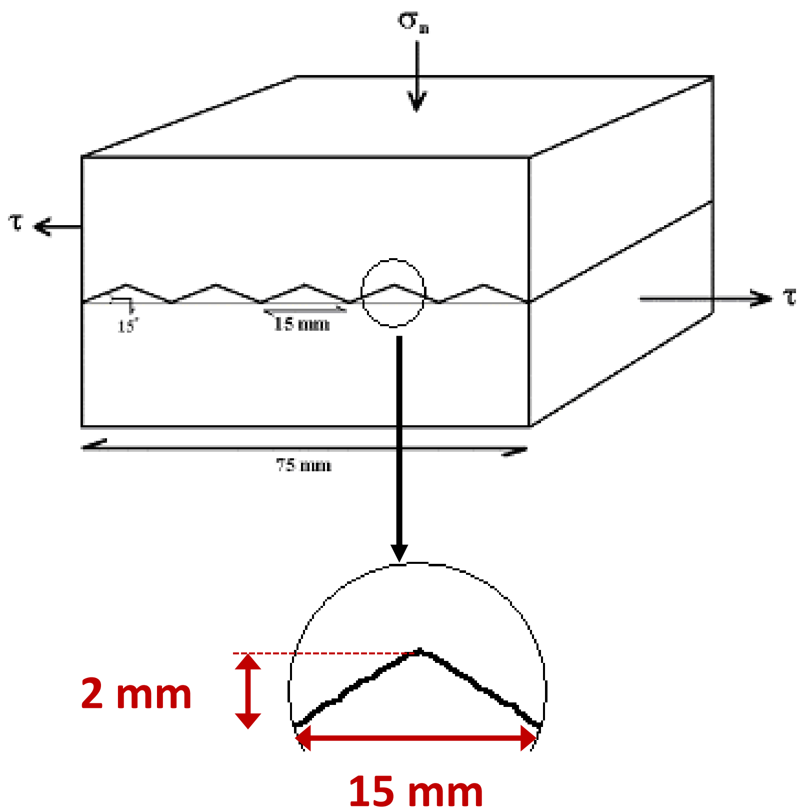
BCR 3D : Servo-Controlled Direct Shear Equipment





Conventional shear box : rotation **BCR3D shear box : no rotation**

Shear test on artificial saw tooth joints



Dilation angle = 15°

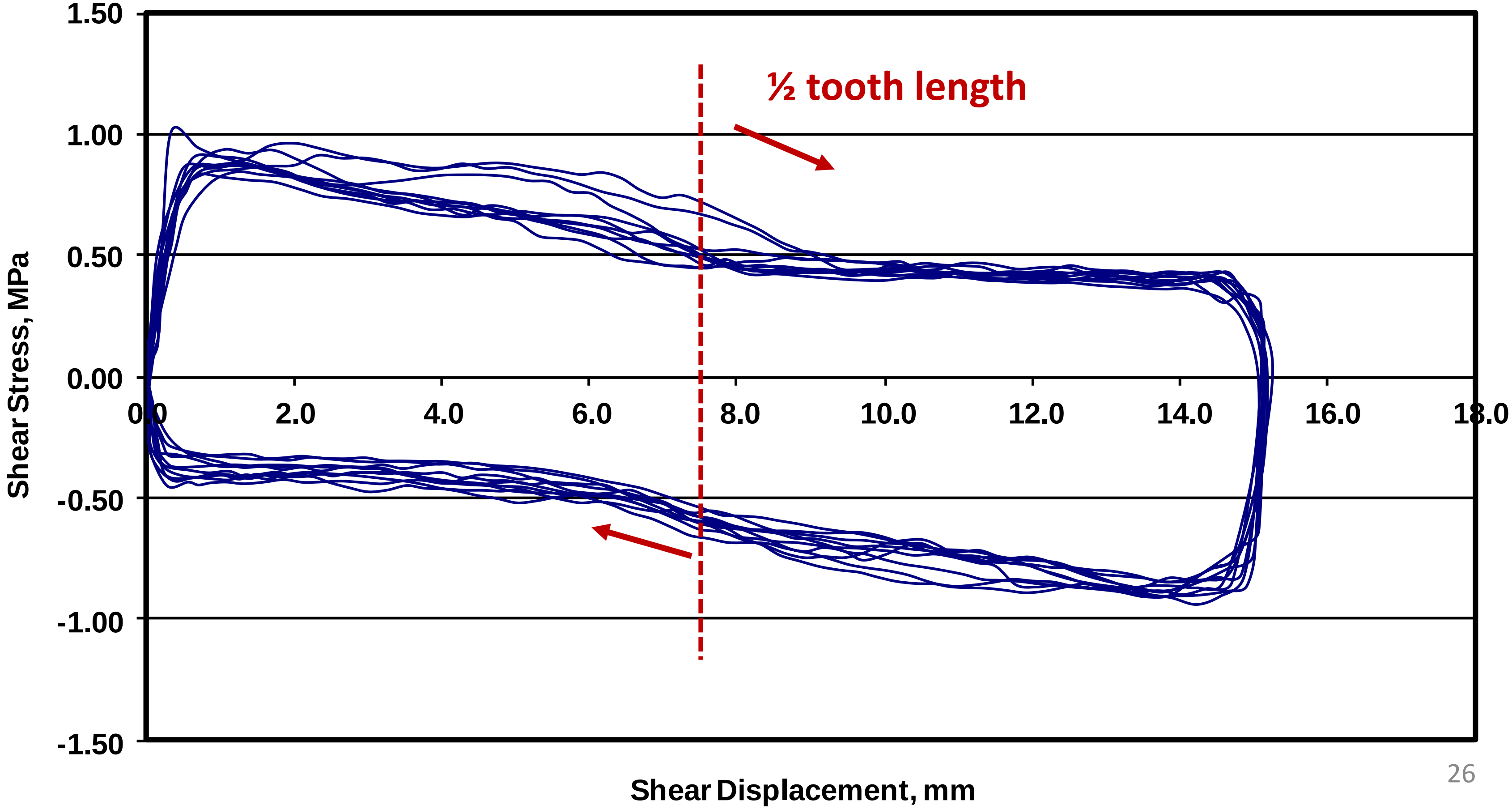
M. K Jafari , K Amini Hosseini, F. Pellet, M. Boulon, O. Buzzi (2003), Evaluation of Shear Strength of Rock Joints Subjected to Cyclic Loading, Soil Dynamics and Earthquake Engineering, vol 23, no 7, pp 619-630.

Shear stress- shear displacement curve for 10 cyclic displacements

Constant Normal Load test

σ_n = 1.2 MPa

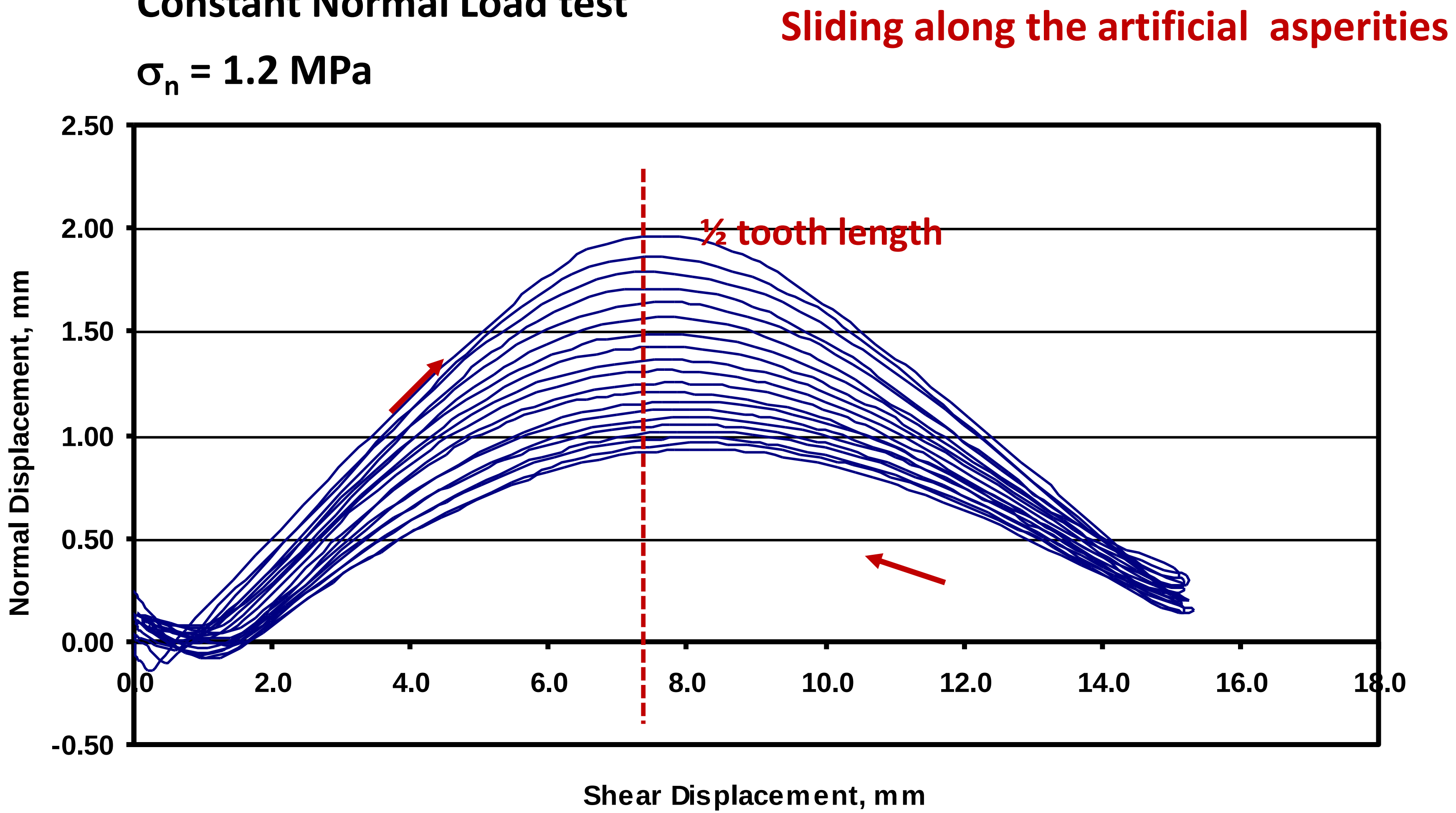
Sliding along the artificial asperities



Asperities degradation due to 10 cyclic displacements

Constant Normal Load test

σ_n = 1.2 MPa

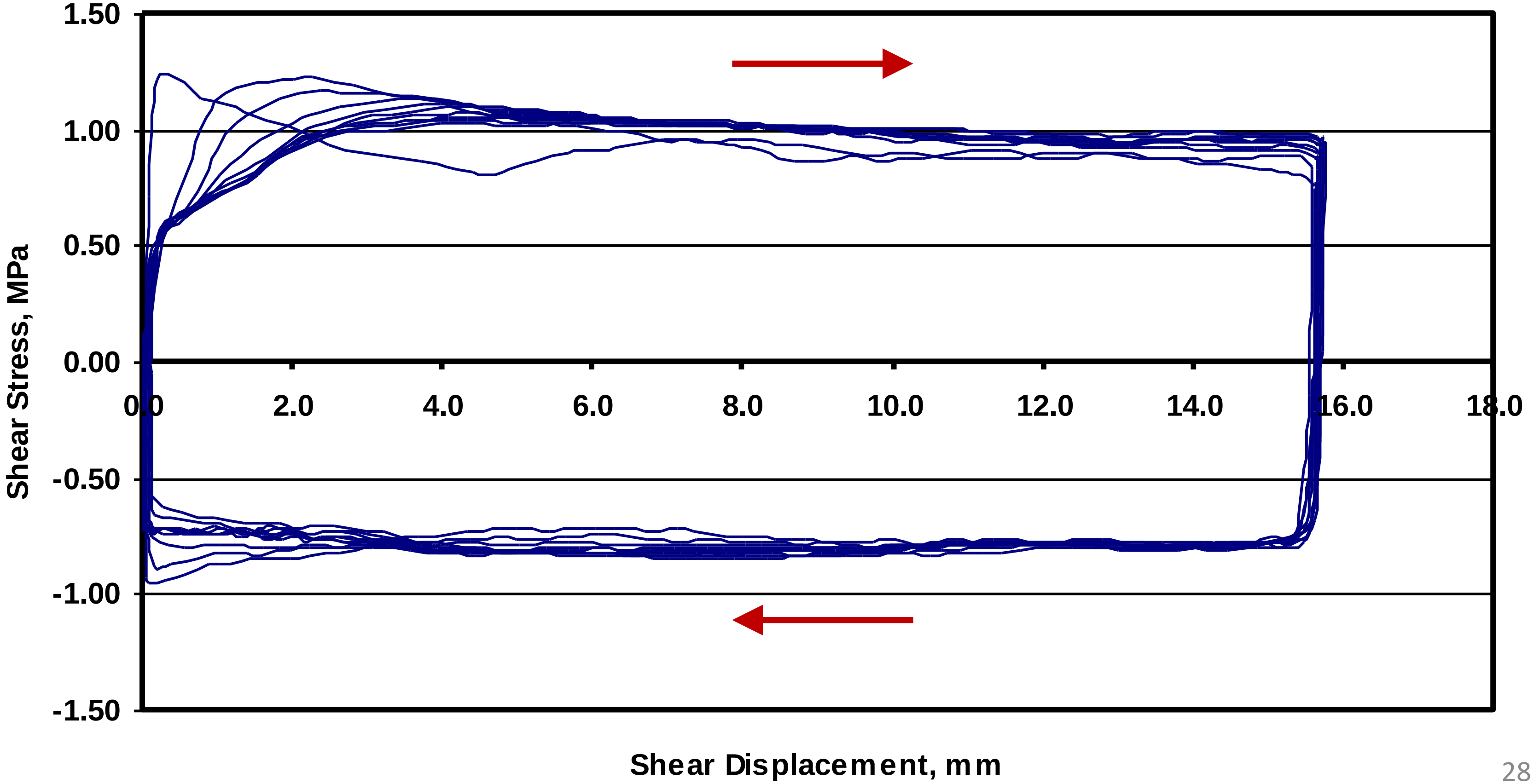


M.K. Jafari, F. Pellet, M. Boulon, K. Amini Hosseini (2004), Experimental study of mechanical behavior of rock joints under cyclic loading, Rock Mechanics and Rock Engineering, vol 37, no 1, pp 3-23.

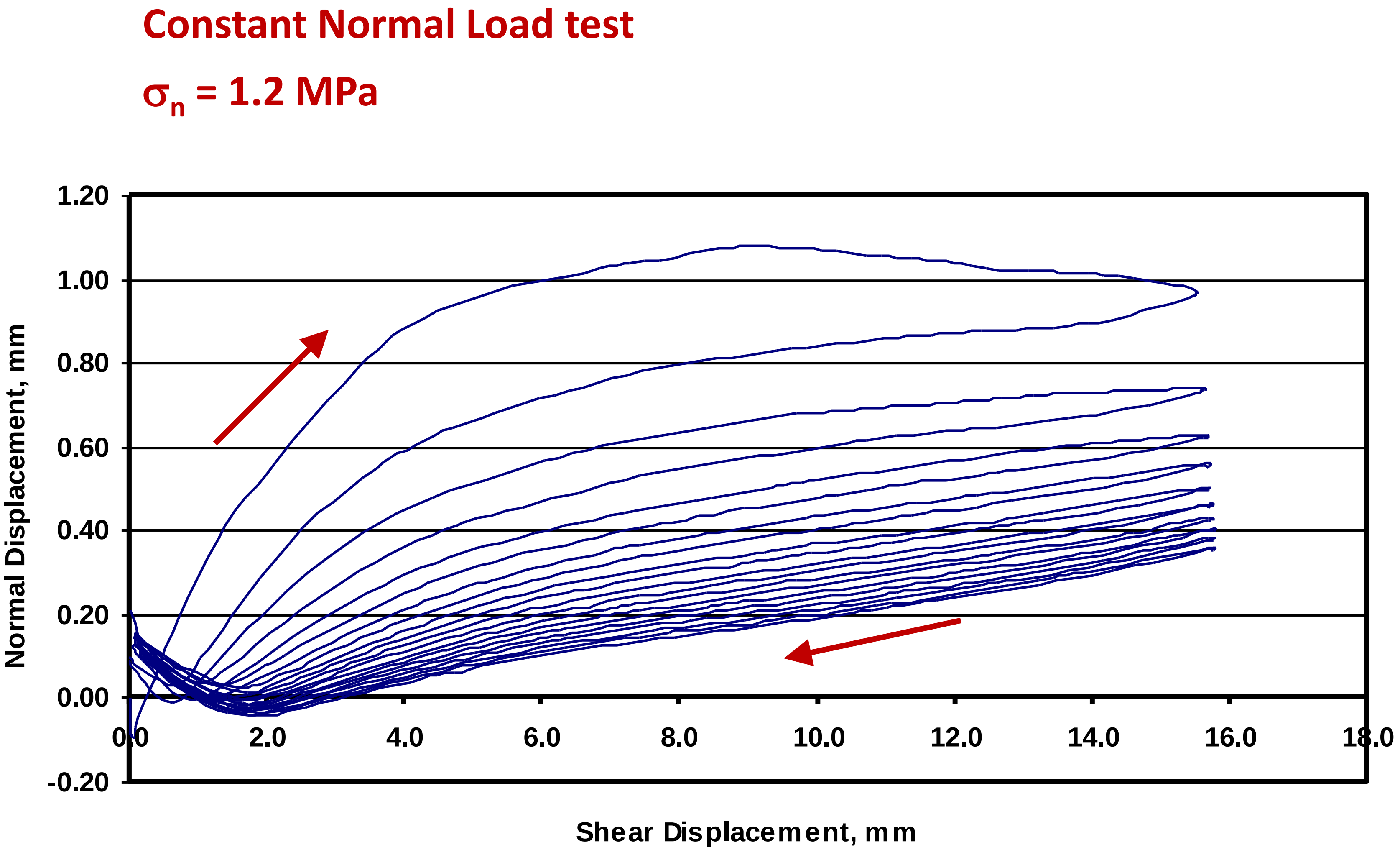
Shear stress- shear displacement curve for 10 cyclic displacements on replica of natural joint

Constant Normal Load test

σ_n = 1.2 MPa

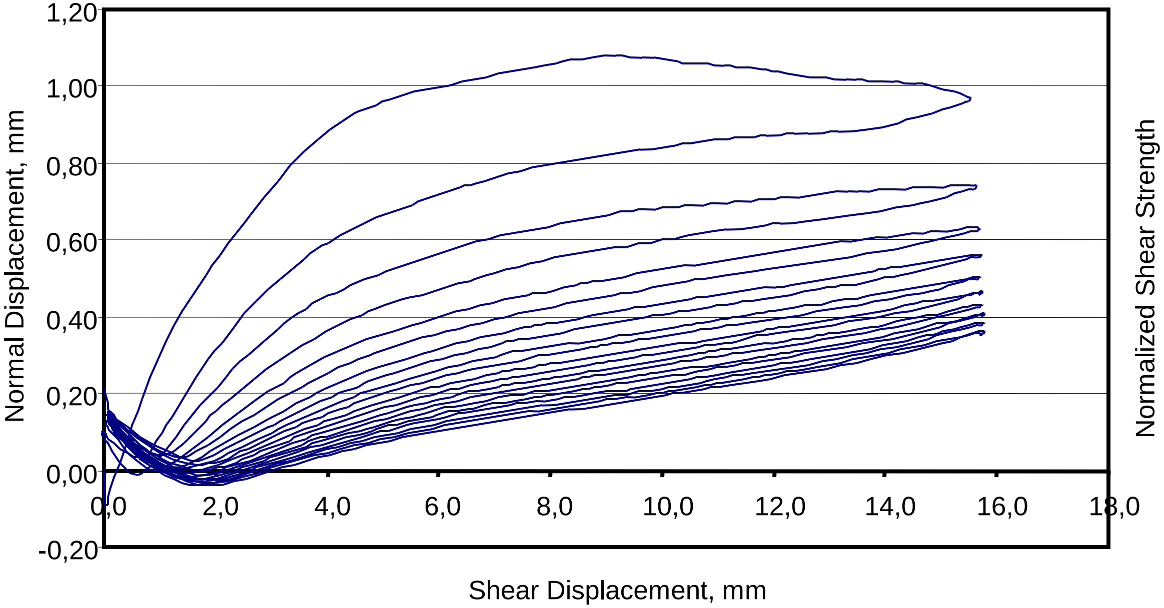


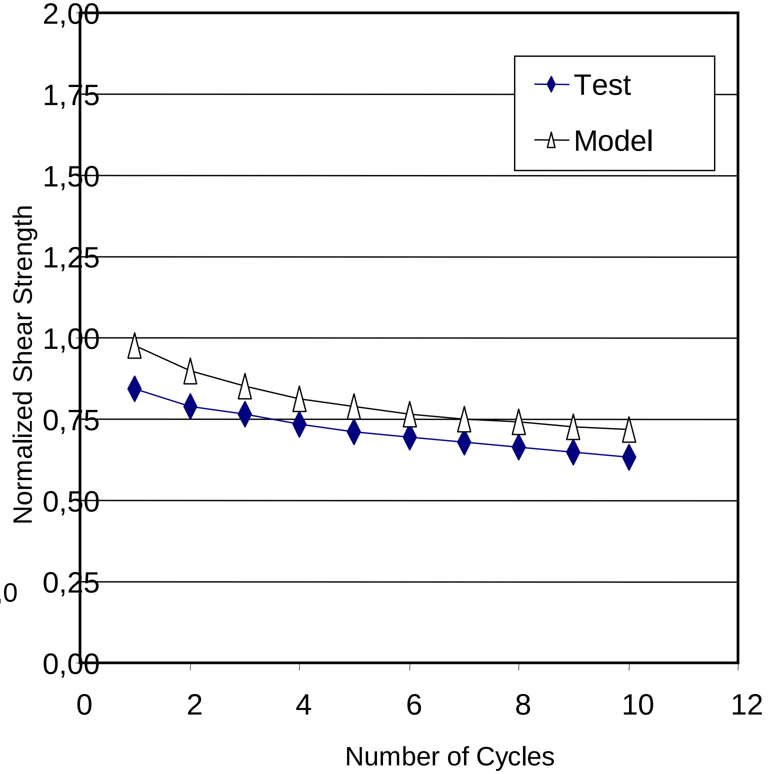
Asperities degradation due to 10 cyclic displacements on replica of natural joint



Damage to Rock Discontinuities Under Cyclic Loadings

Degradation of Rock Joint Strengths under Small Repetitive Earthquakes





Coll. IIEES - Tehran

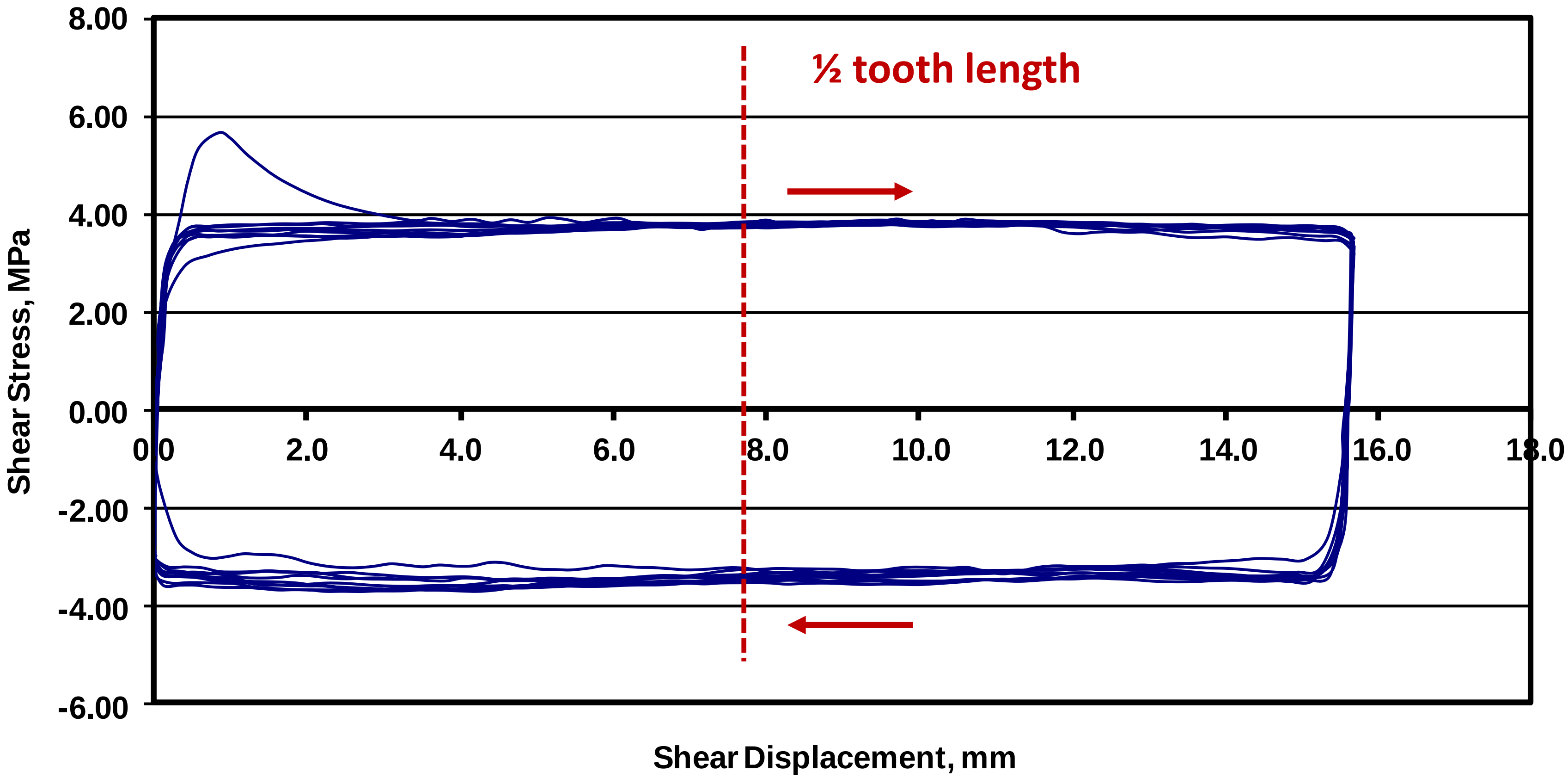
Experimental Study of Mechanical Behaviour of Rock Joint under Cyclic Loading, Rock Mechanics and Rock Engineering, Vol 37, n°1 (2004)

Shear Stress- Shear Displacement curve for 10 cyclic displacement

Constant Normal Load test

Artificial asperities are sheared

σ_n = 6.5 MPa

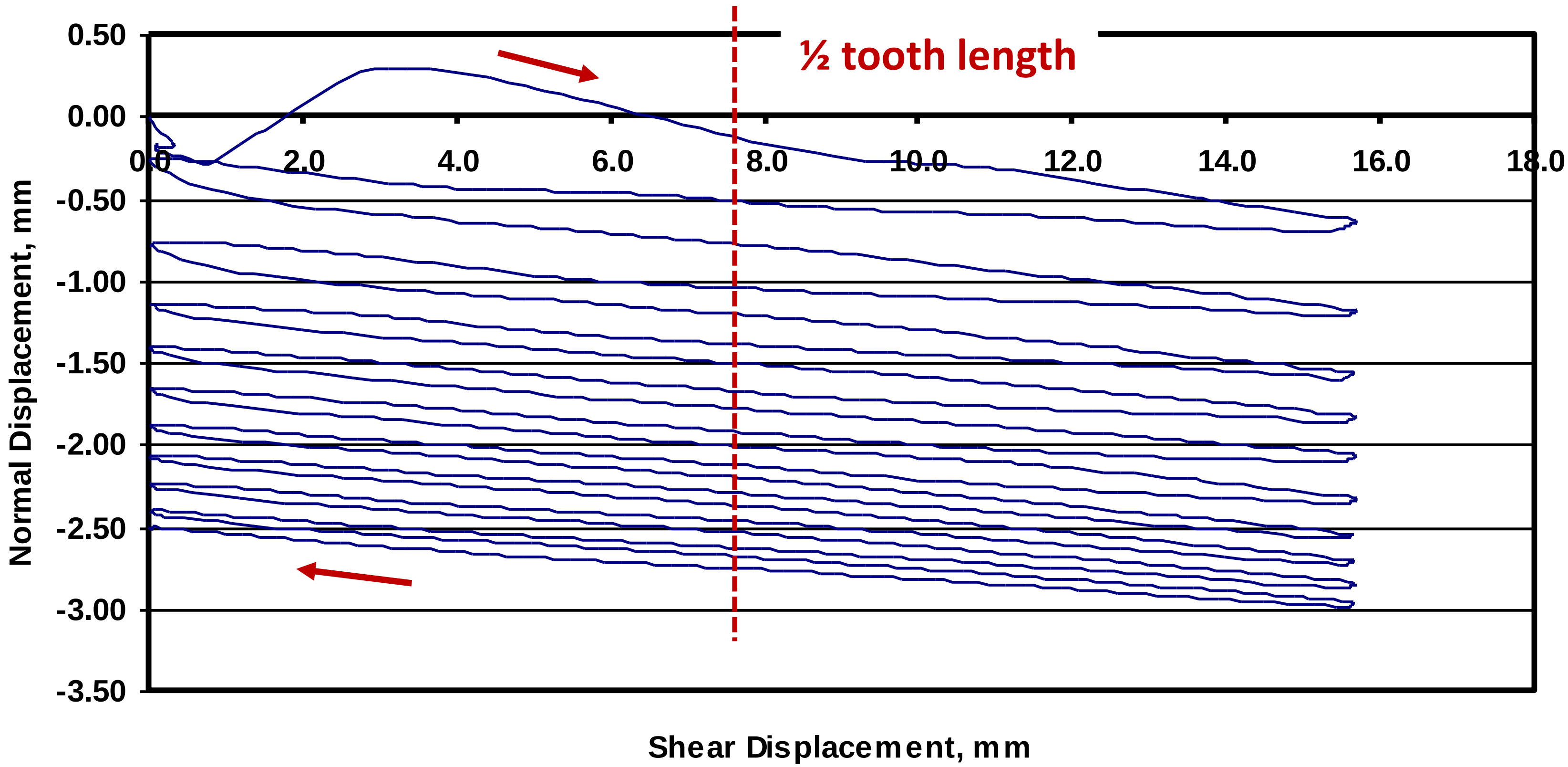


Asperities degradation due to 10 cyclic displacements

Constant Normal Load test

Artificial asperities are sheared

σ_n = 6.5 MPa

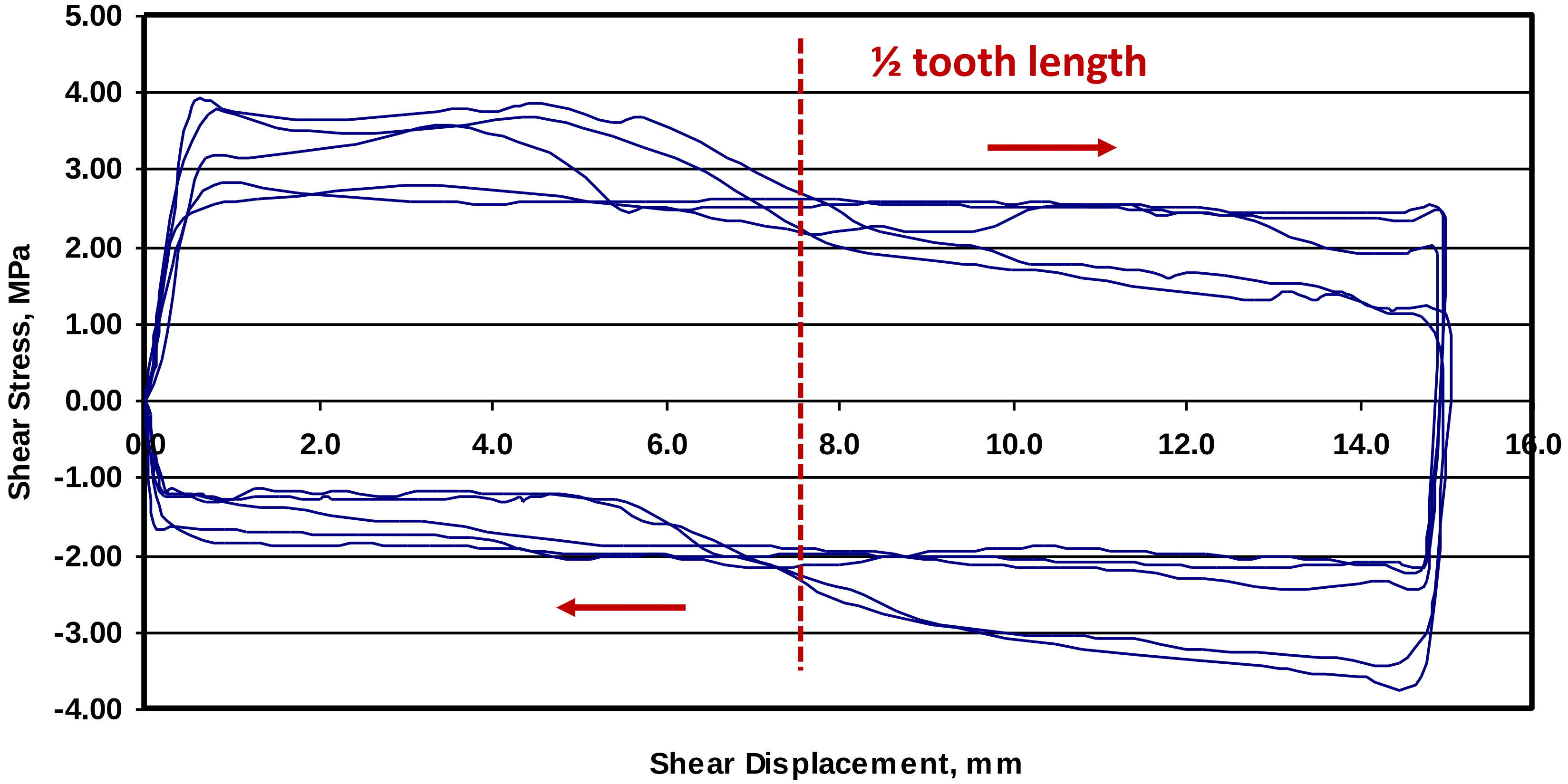


Shear stress- shear displacement curve for 5 cyclic displacements

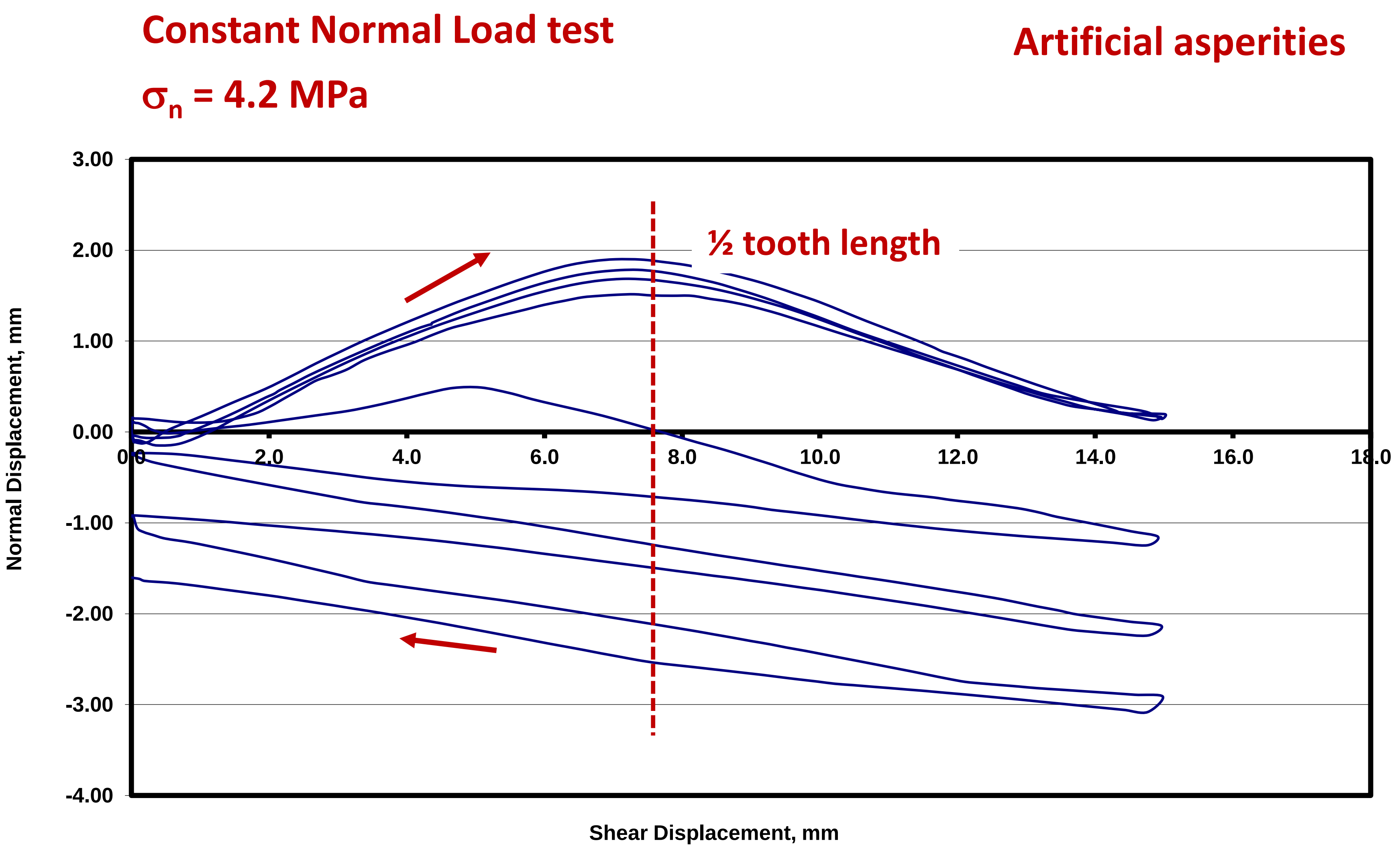
Constant Normal Load test

Artificial asperities

σ_n = 4.2 MPa



Asperities degradation due to 5 cyclic displacement



Equation for shear strength degradation

$$\frac{\tau}{\sigma_n} = \frac{b\,NC^p\,i_n^{\,q} + c}{1 + b\,NC^p\,D_n^{\,q}}$$

σ_n = 1.2 MPa

b = –0.33 ; c = 1.44 ; p = 0.12 ; q = 0.3

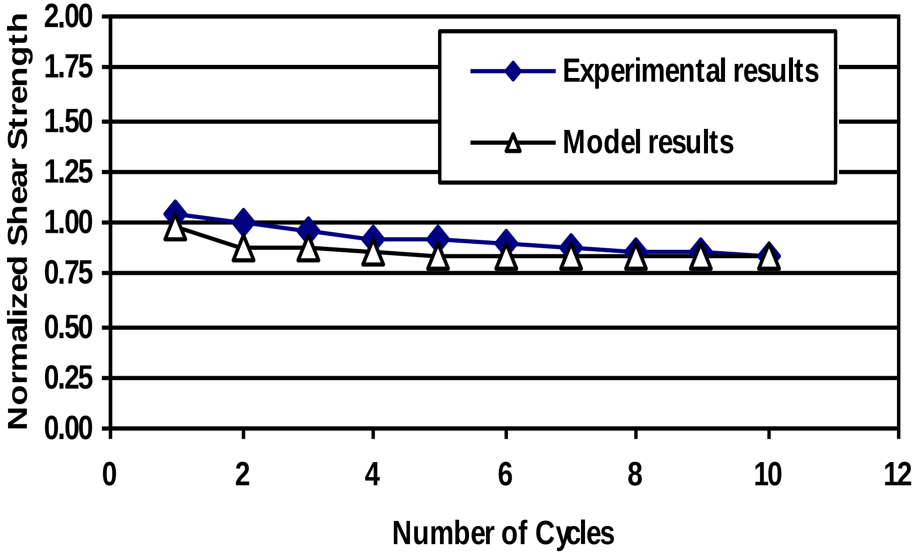
τ : Shear strength

σ_n : Normal stress

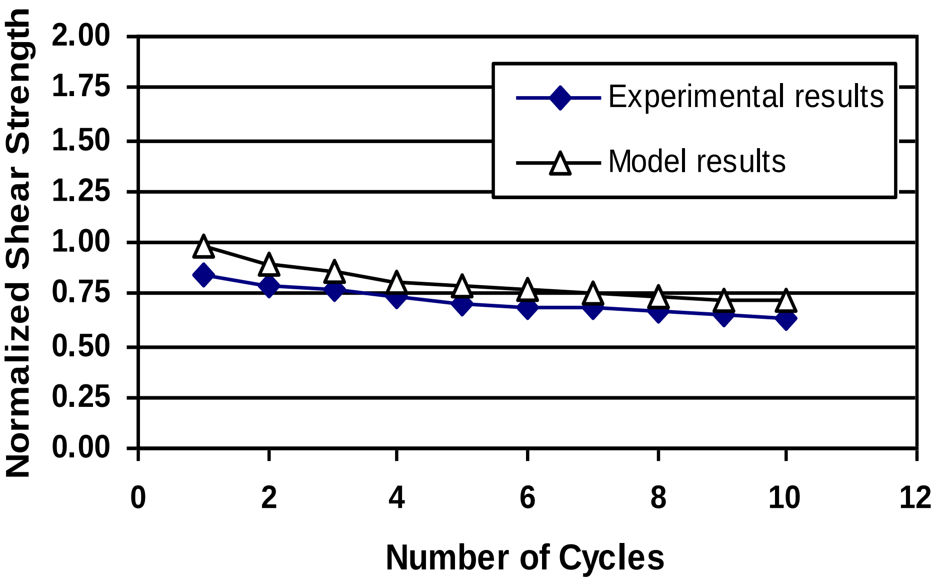
NC : Number of displacement cycles

i_n : Normalized dilation angle (normalized by the maximum angle measured before the test)

D_n : Normalized degradation (normalized by maximum value of asperities amplitude).



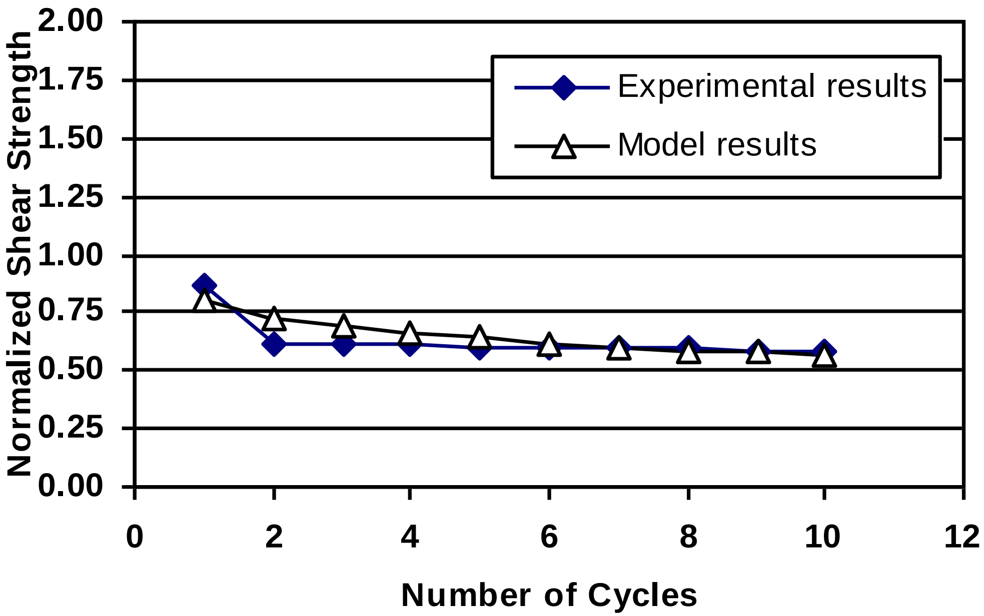
Natural joint



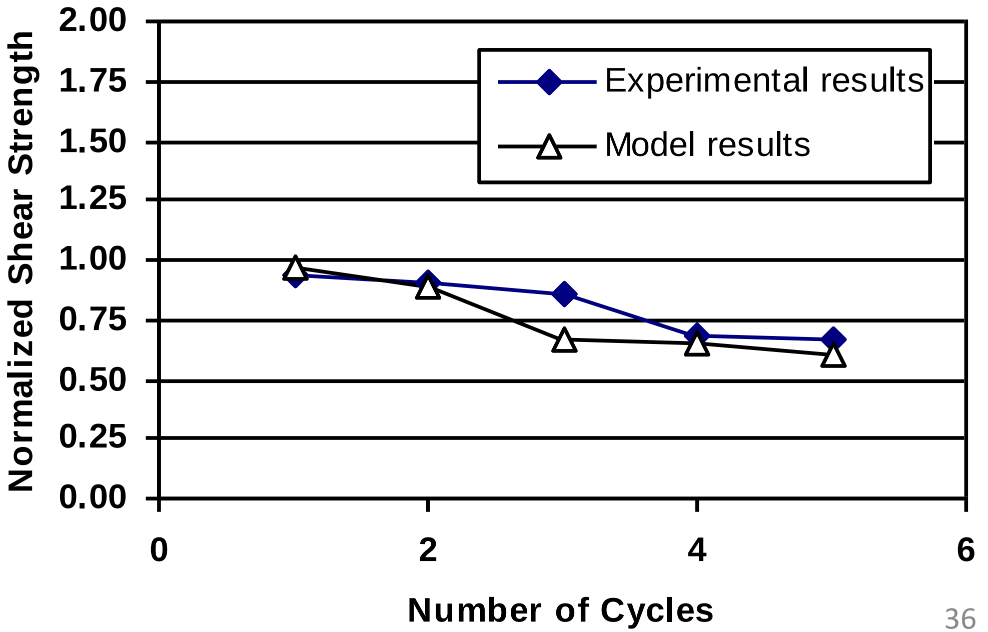
Saw tooth joint

Measured versus evaluated shear strength by the mathematical model

Normal Stress = 6.5 MPa



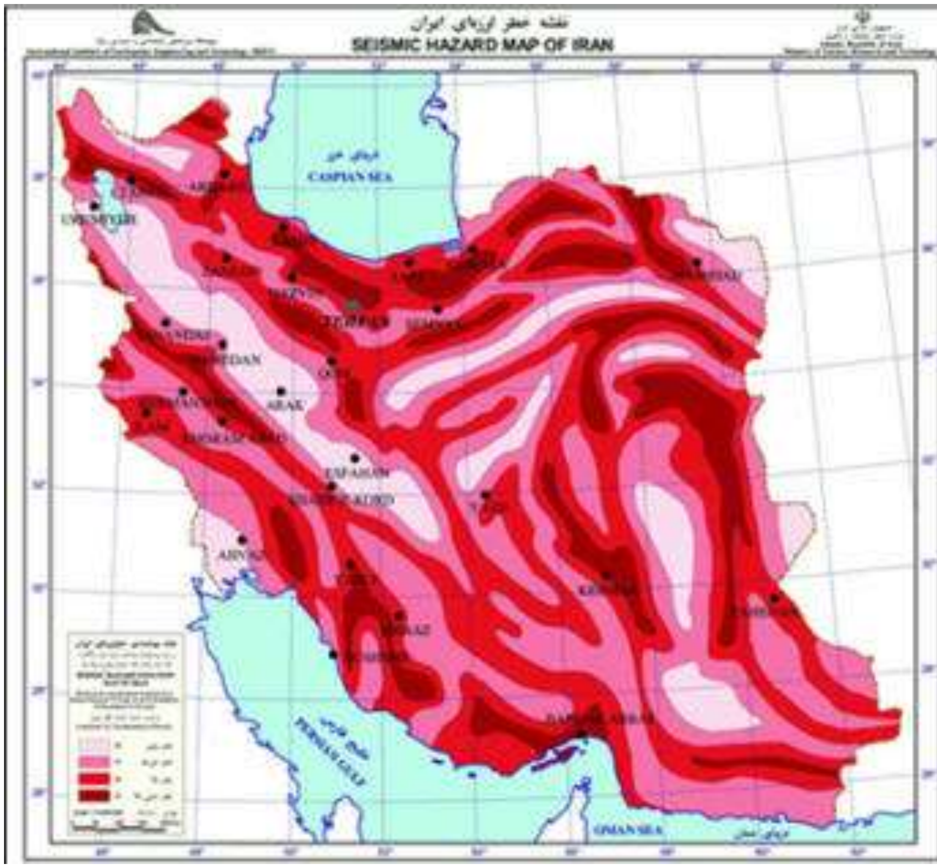
Normal Stress = 4.2 MPa

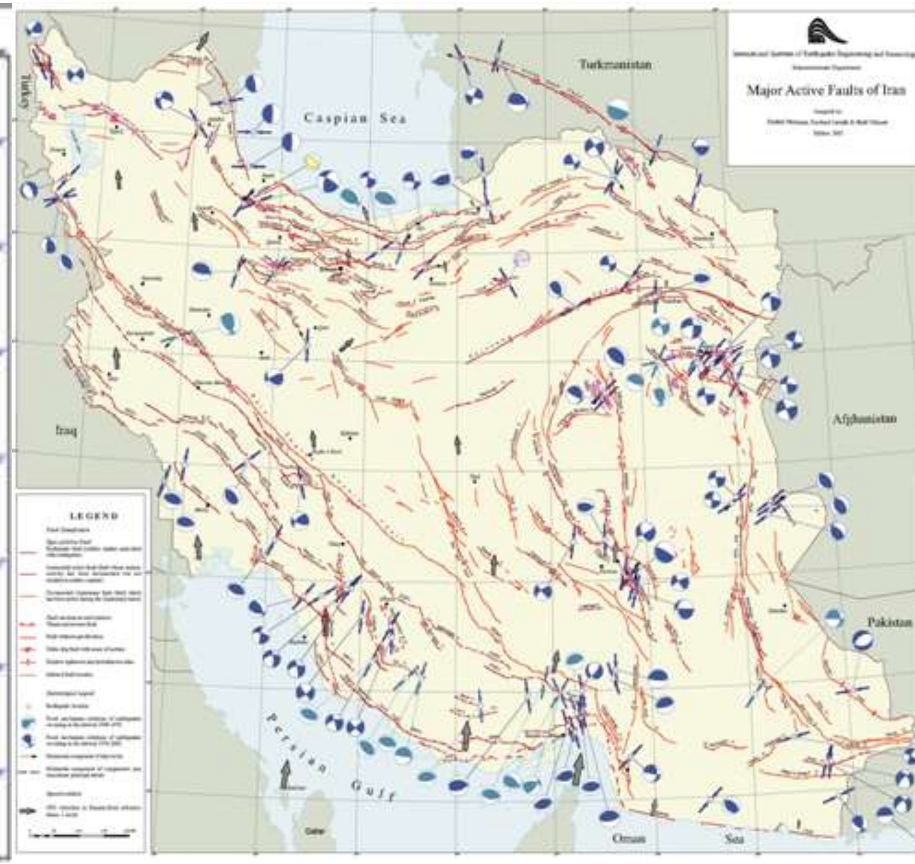


Saw-Tooth samples

Glissements de terrain en Iran

Tectonic context and seismic hazards of Iran





History of destructive earthquakes

Year	Location	Mag.	Year	Location	Mag.
743	Ray	7.2	1608	Taleghan	7.6
763	Khorasan	7.6	1721	Tabriz	7.7
815	Sistan	7.0	1780	Tabriz	7.7
855	Ray	7.1	1830	Damavand	7.1
856	Ghomes	7.9	1871	Ghochan	7.2
943	Atrak	7.6	1909	Silakhor	7.4
958	Ray	7.7	1929	KopehDagh	7.3
1042	Tabriz	7.6	1930	Salmas	7.2
1177	Bouin Zahra	7.2	1945	Makran	8.0
1209	Neishabor	7.6	1962	Bouin Zahra	7.2
1270	Neishabor	7.1	1968	Dashte Bayaz	7.4
1336	Khaf	7.6	1978	Tabas	7.3
1389	Neishabor	7.6	1981	Golbaf	7.1
1405	Neishabor	7.6	1990	Manjil	7.7
1483	Makran	7.7	1997	Ardakool	7.3

Bam (2003), Silakhor (2006), Varzaghan (2012)

Other earthquakes associated with slope instabilities in North of Iran along Alborz Mountain Ranges

Location	Year	Epicenter	Type	Magnitude	Main Effects
Ray	958	51.10-36.10	Landslide	7.7	A village was buried by mud and rock
Frame-Chardangeh	1127	53.54-36.35	Landslide	6.8	Dislocation of a village
Gorgan	1470	54.60-37.10	Landslide	5.5	A village was buried by mud and rock
Damavand	1830	52.28-35.73	Rock Fall	7.1	Blockage of main and peripheral roads
Talarood	1935	53.06-35.94	Landslide & rock-fall	5.8	42 killed by landslides
Bandpey Mazandaran	1957	52.74-36.07	Landslide & rock-fall	6.8	Blockage of local roads

Earthquakes and geo-hazards

- Ground Motion Amplification
- Lands subsidence
- Soil Liquefaction
- **Landslides and rock slope instabilities**

Rock slope instabilities in some recent earthquakes

Manjil-Roudbar Earthquake, June 1990 (Mw: 7.3)

- Fatalak village with over 100 population was completely buried under landslides.
- Some other villages in the area were damaged by slope instabilities.
- Rock-falls blocked several main and rural roads that caused some delays in providing emergency response services .


Rock slope instabilities in some recent earthquakes

Firooz Abad-Kojour Earthquake, May 2004 (Mw: 6.2)

- About 80% of casualties (32 of 41) was due to landslides and rock-falls
- Most of the local roads were blocked after earthquake due to slope instabilities

Rock slope instabilities in some recent earthquakes

Bam Earthquake, Dec. 2003 (Mw: 6.5)

- Some buildings and channels were damaged by slope instabilities

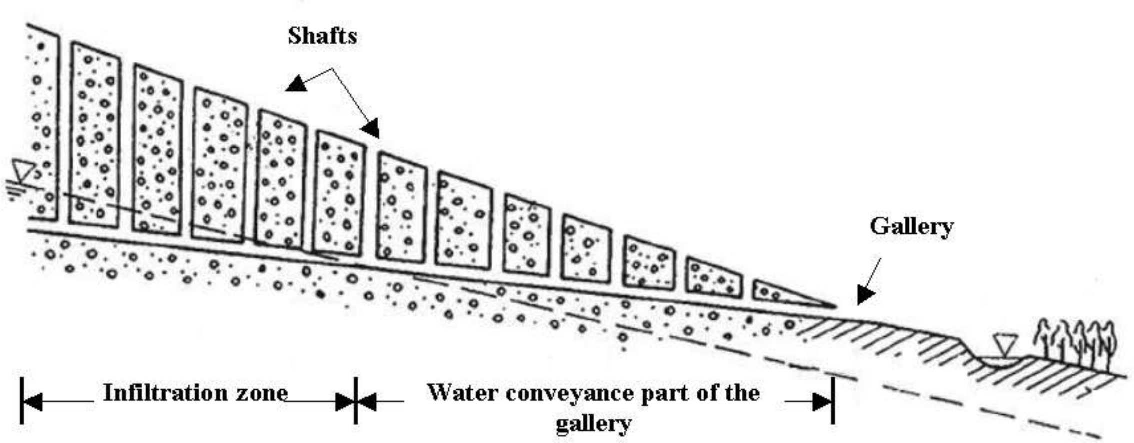
Arg-e-BamCitadel (before and after the earthquake)

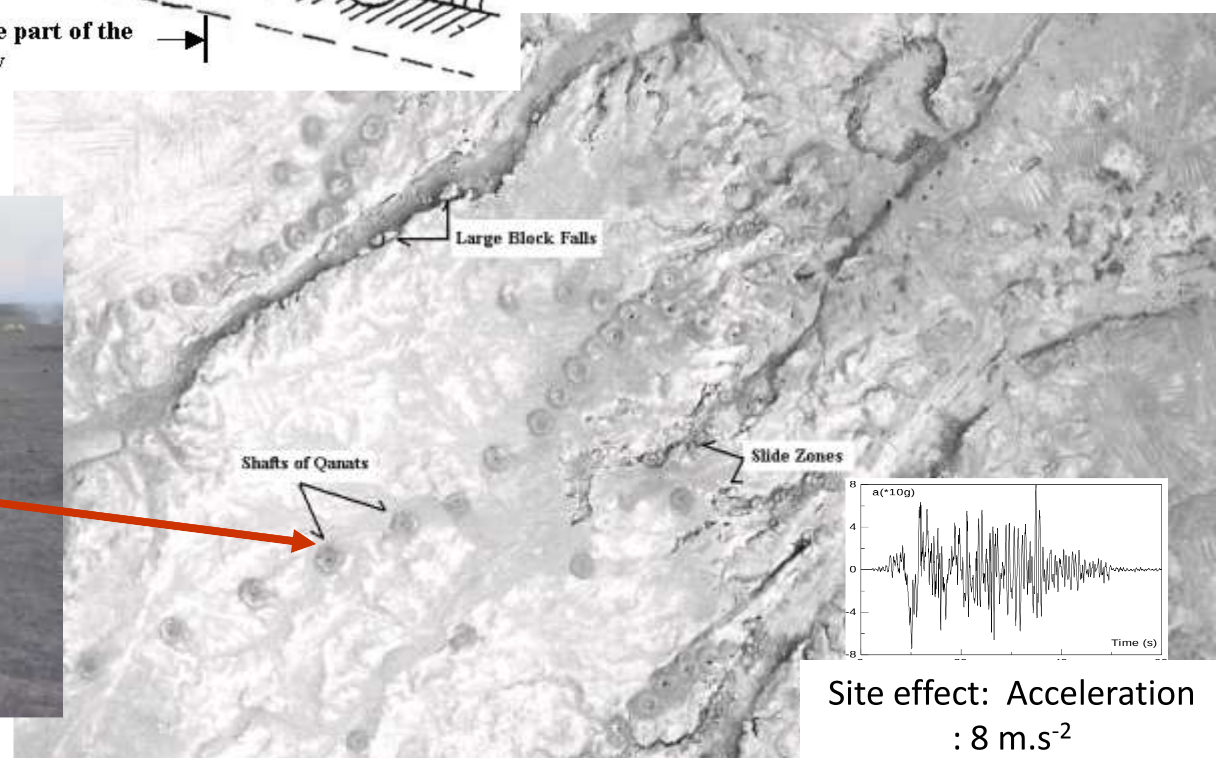
F. Pellet, et al (2005), Geotechnical performance of Quanats during the 2003 Bam, Iran, earthquake, Earthquake Spectra, EERI, vol 21, nº S1, pp137-164.

Rock slope instabilities in some recent earthquakes

Bam Earthquake, Dec. 2003 (Mw: 6.5)

- channels were damaged by slope instabilities





Site effect: Acceleration : 8 m.s^{-2}

Legal and institutional basis for reducing the impacts of geo-hazards associated with earthquakes in Iran

Institution	Main responsibilities
Working group of Earthquake and Landslide (Ministry of Road and Housing)	Preparing databases, providing training programs, research on causes and prevention measures, preparing micro-zonation maps
Disaster Management Organization (Ministry of Interior)	Managing all activities in natural hazards risk mitigation and management
Professional group on landslide (Ministry of Agriculture)	Research on landslide causes and hazard micro-zonation
Research centers and universities	Identifying geo-hazards prone areas and investigation on the best ways for risk reduction
Private companies	Implementing measures for ground stabilization and preparing micro-zonation maps

Evaluation and preparation of geo-hazard risk mitigation and management plans

A. Knowledge and information

1. Public awareness about geo-hazards and the importance of living in safe places;
2. Knowledge and information of local and national authorities and managers about the risk of geo-hazards and necessity of risk reduction planning;
3. Professional knowledge and skill of researchers and experts on geo-hazards risk mitigation measures.

B. Institutional capacities

4. Applicable laws and regulations for managing construction in hazard zones, compensation for losses by insurance or other fiscal measures;
5. Efficient institutional arrangements and structures for conducting risk management activities at local and national levels;
6. Adequate financial resources and mandates for controlling construction in geo-hazards prone areas.

Evaluation and preparation of geo-hazard risk mitigation and management plans

C. Risk assessment and mapping

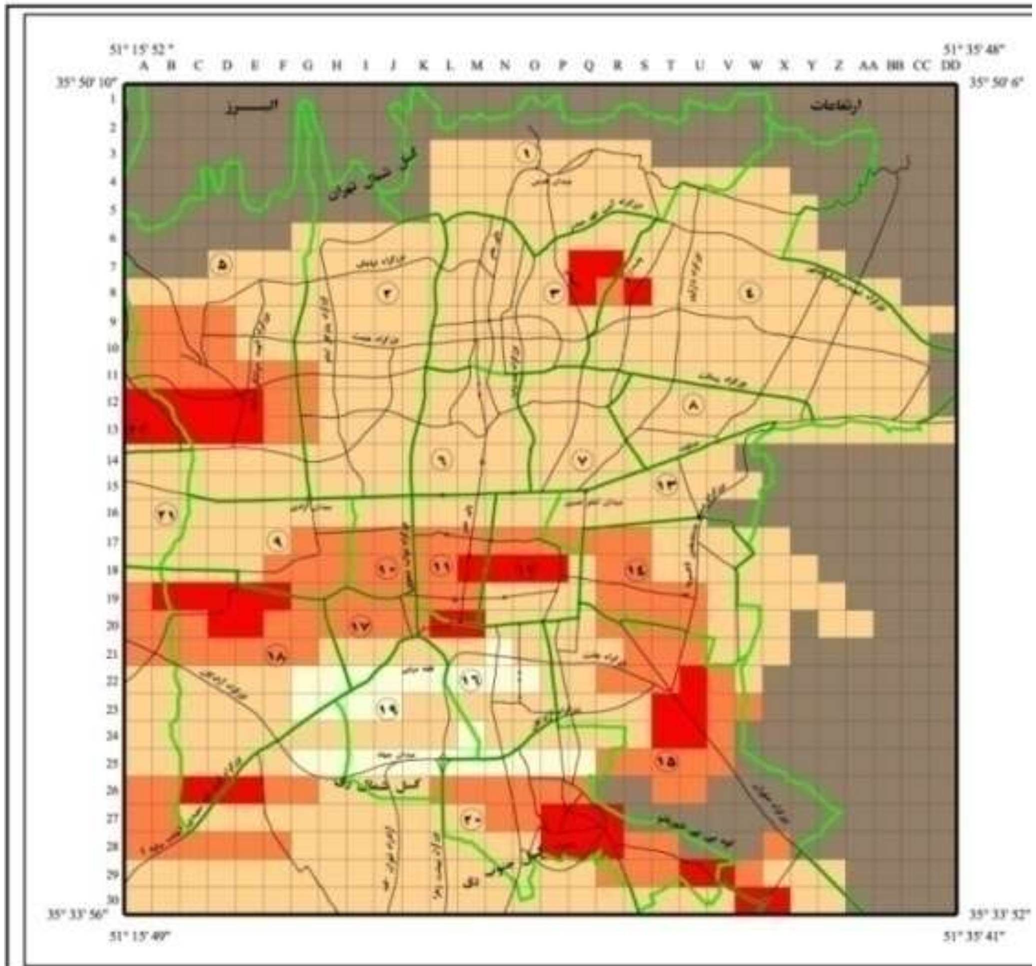
7. Available information and databases on geo-hazards
8. Technical capacity to provide necessary information for risk assessment
9. Prepared **micro-zonation maps** at the local and national levels

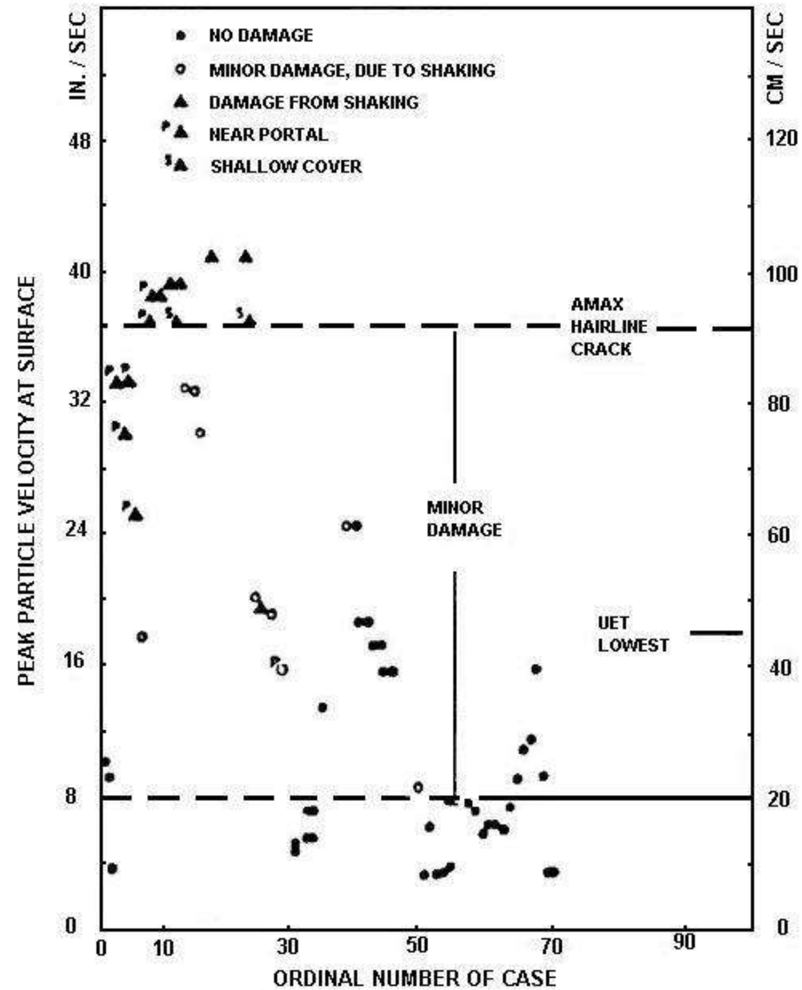
D. Risk reductions and countermeasures

10. Capacities for risk reduction (ground stabilization and improvement, safe construction in hazardous sites, etc.)
11. Available monitoring and early warning systems for controlling unstable areas and information dissemination
12. Level of application of advanced technologies for reducing the potential impact of instabilities (such as automatic shut down systems for gas and water networks, etc.)

Micro-zonation maps of Tehran

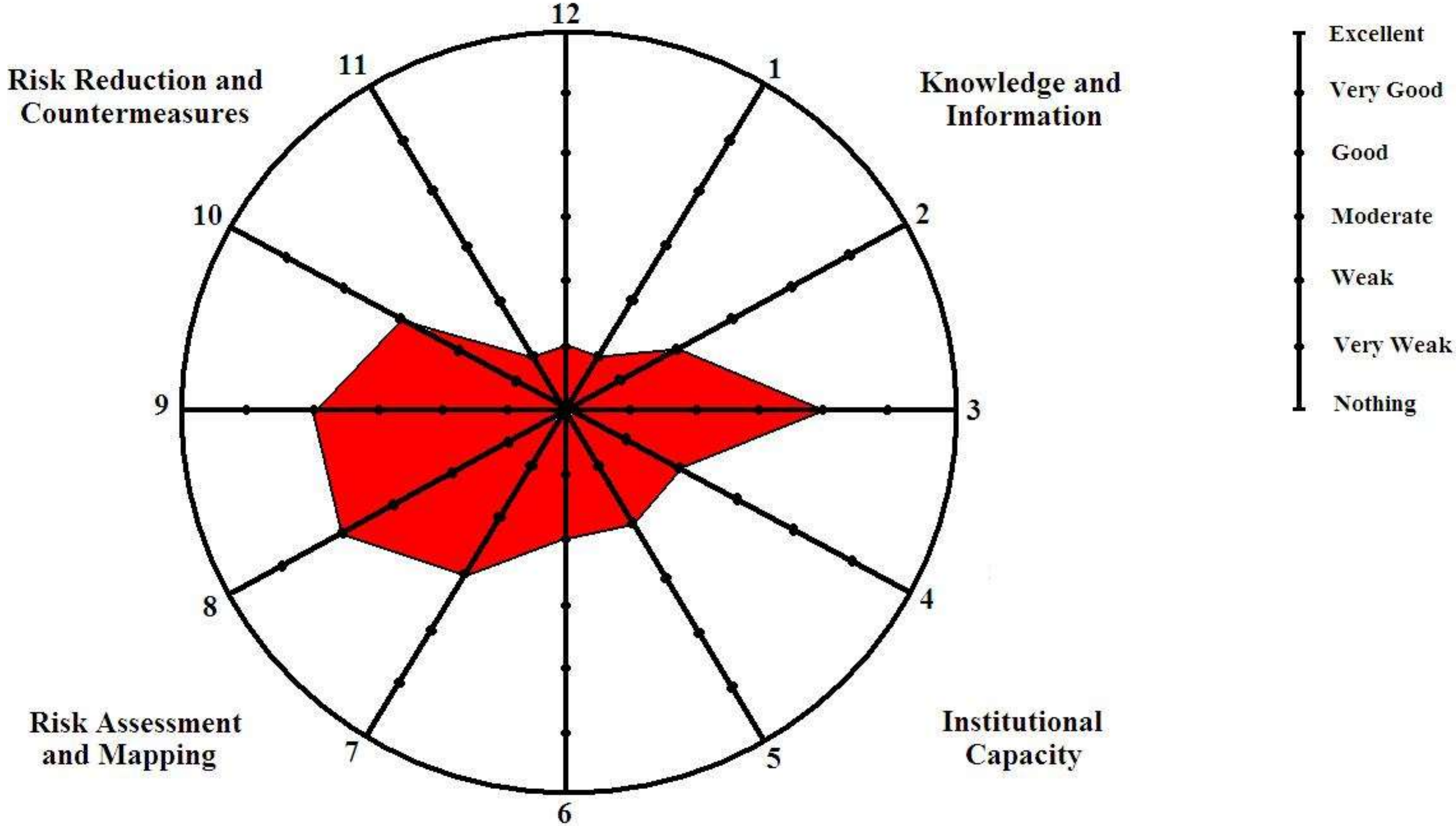
Peak Ground Acceleration (PGA): earthquake in Tehran based on probabilistic analysis.



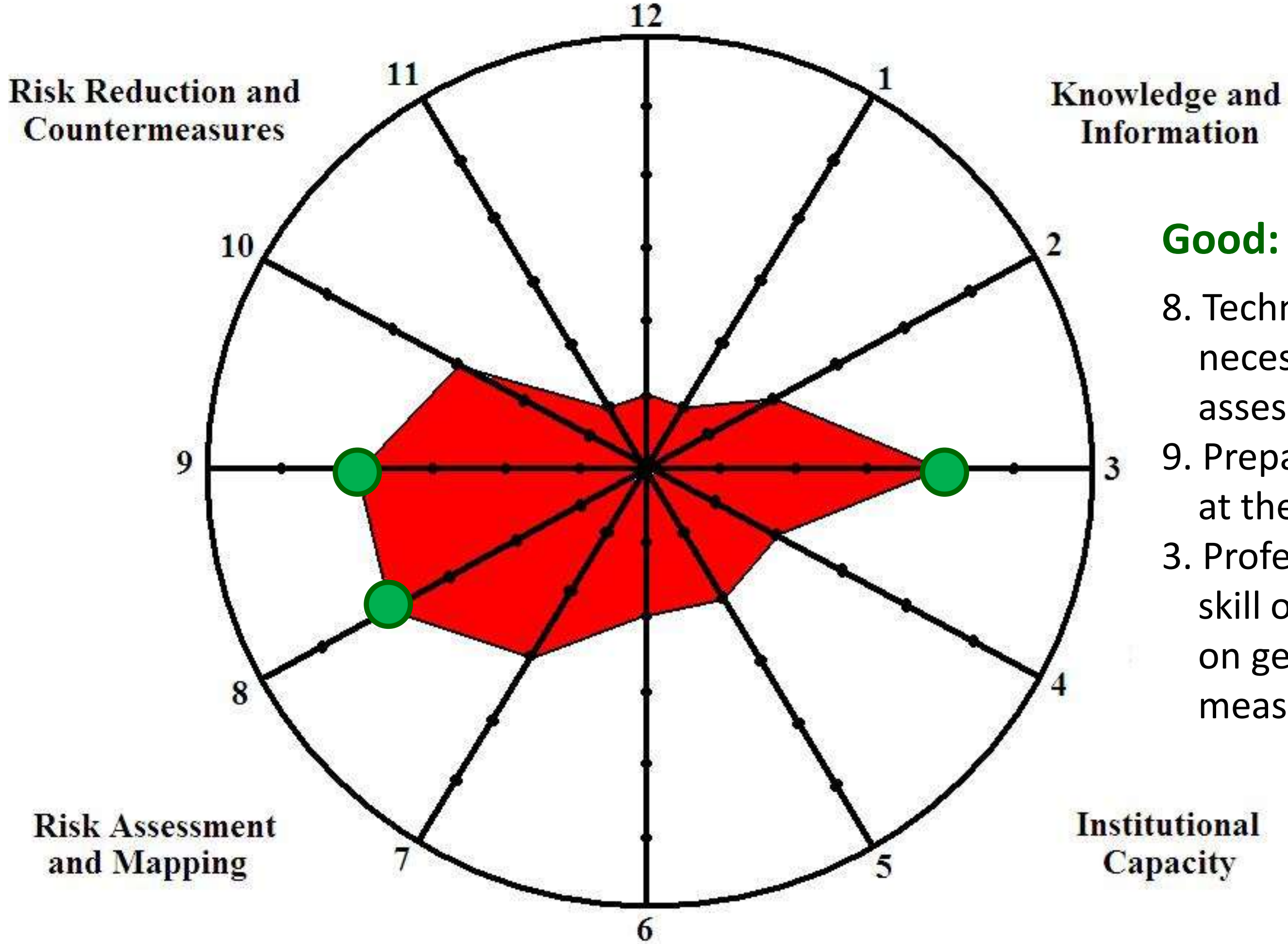


The dark red shows higher PGA and then potential higher ground shaking that may result in higher destruction.

Evaluation of existing situation in Iran based on the developed elements



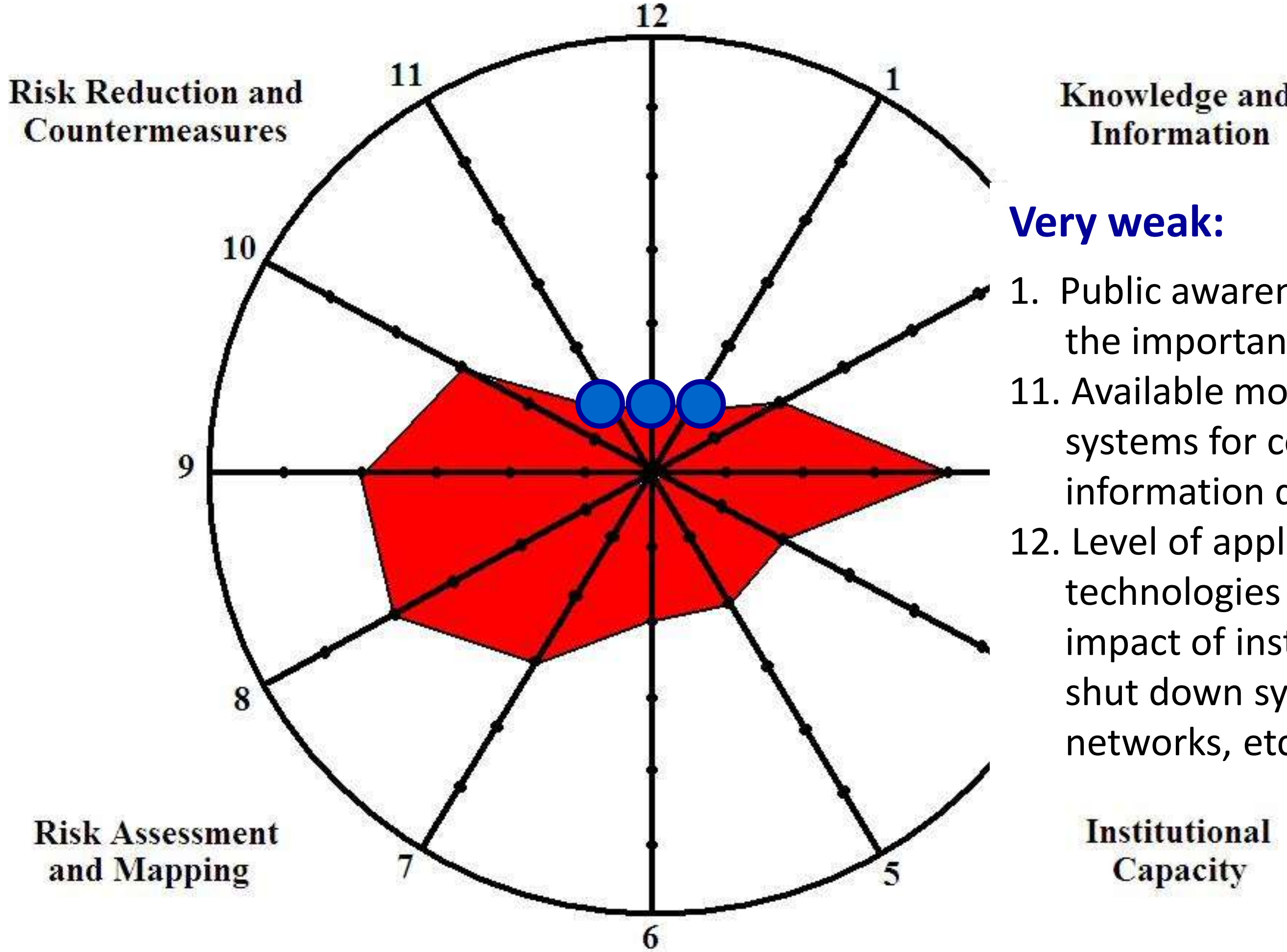
Evaluation of existing situation in Iran based on the developed elements



Good:

8. Technical capacity to provide necessary information for risk assessment
9. Prepared micro-zonation maps at the local and national levels
3. Professional knowledge and skill of researchers and experts on geo-hazards risk mitigation measures.

Evaluation of existing situation in Iran based on the developed elements



Very weak:

1. Public awareness about geo-hazards and the importance of living in safe places;
11. Available monitoring and early warning systems for controlling unstable areas and information dissemination
12. Level of application of advanced technologies for reducing the potential impact of instabilities (such as automatic shut down systems for gas and water networks, etc.)

Conclusions and recommendations

- In order to improve the existing conditions, it is necessary to determine priorities for strengthening each parameter by defining **short, mid and long term programs**.
- Institutional capacities should be enhanced in short term plans by enforcing regulations, allocating budgets and **strengthening institutional capacity.**
- Among the indicated parameters, those related to **risk assessment and risk mapping** as well as promoting knowledge and information should be carried out in short to mid-term programs prior to planning for remediation activities.

For success in making such plans, it is necessary to centralize the coordination of all activities of relevant organizations involved in geo-hazard risk reduction and prevention

Conclusions and recommendations

As an example, for reducing the impacts of landslides associated with earthquakes:

1. It is necessary to evaluate the risk of **slope instabilities** and impact of earthquakes on them;
2. Such information should be integrated with urban and rural development plans;
3. Simplified versions of such maps should be prepared and distributed among people and local authorities along with information to promote their knowledge on potential hazards
4. In the places exposed to such instabilities, based on cost-benefit analyses; the appropriate measures for risk reduction should be determined and applied.

All of these procedures should be implemented in the context of integrated risk reduction plans and should be managed and supervised by local and national disaster management authorities in order to be successful.

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Merci de votre attention!