The XVII European Conference on
Soil Mechanics and Geotechnical Engineering
Reykjavik Iceland
1 - 6 September 2019

# Dynamic properties of earth-core Italian dams from in-situ and laboratory tests

Reykjavik, September 1st, 2019

**Prof. Giuseppe Lanzo**
Dept. of Structural and Geotechnical Engineering
*giuseppe.lanzo@uniroma1.it*

SAPIENZA
UNIVERSITÀ DI ROMA

# Seismic assessment of existing dams in Italy

- ✓ More than 500 dams (≅ 170 embk dams) are located in the Italian territory, majority of which constructed between 1950-1970;
- ✓ most dams are placed in zones with a degree of seismic hazard that was generally underestimated at the time of their construction as compared with the new national seismic hazard map;
- ✓ seismic design was based on the "classical" pseudo-static approach;
- ✓ a new standard for dam design and evaluation was issued in 2014 (pseudo-static approach no ore allowed; dynamic deformation analysis requested)

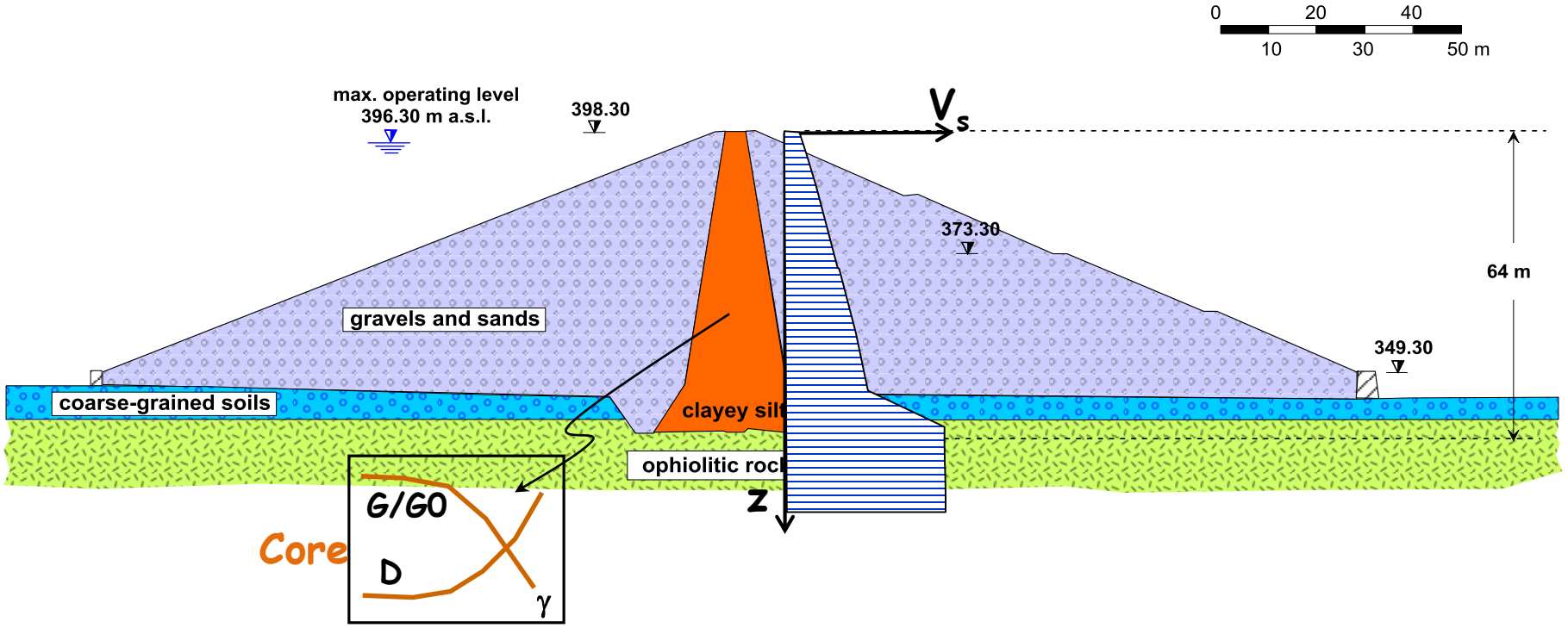
**Safety of large dams needs to be reassessed**

# Dynamic analyses for seismic assessment

Dynamic analyses requires proper characterization of material dam behavior.

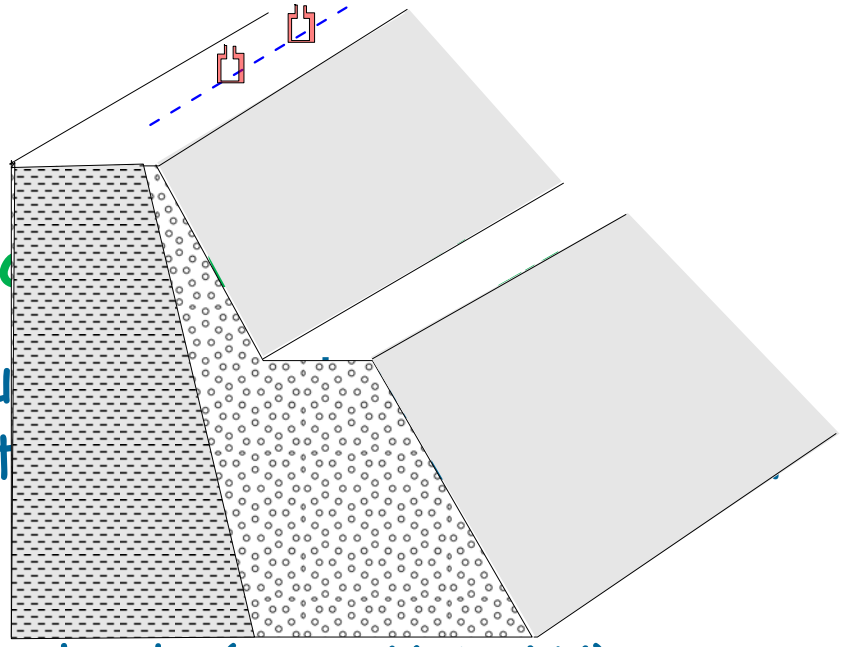
## Fundamental input parameters for **core material**:

- ✓ Vs ($G_0$) profile
- ✓ modulus reduction ($G/G_0$-$\gamma$) and damping (D-$\gamma$) curves



# Dynamic properties of core materials

**Very limited data** :



$V_s$ ($G_0$) profile through geophysi

- ✓ **invasive** (DH, CH, SCPT, su
  methods are generally prohibit
  leakage);

- ✓ **non-invasive** surface seismic methods (e.g., MASW)

  applicability of these techniques is restricted by unfavourable testing conditions

**Nonlinear stiffness and damping curves**

- ✓ laboratory testing on undisturbed samples seldom available

# $V_s$ ($G_0$) profile in the core of the dams

## Empirical correlations used for core material

**Mostly used**

$G_0 = f(e, \sigma'_m, OCR, \text{soil type})$

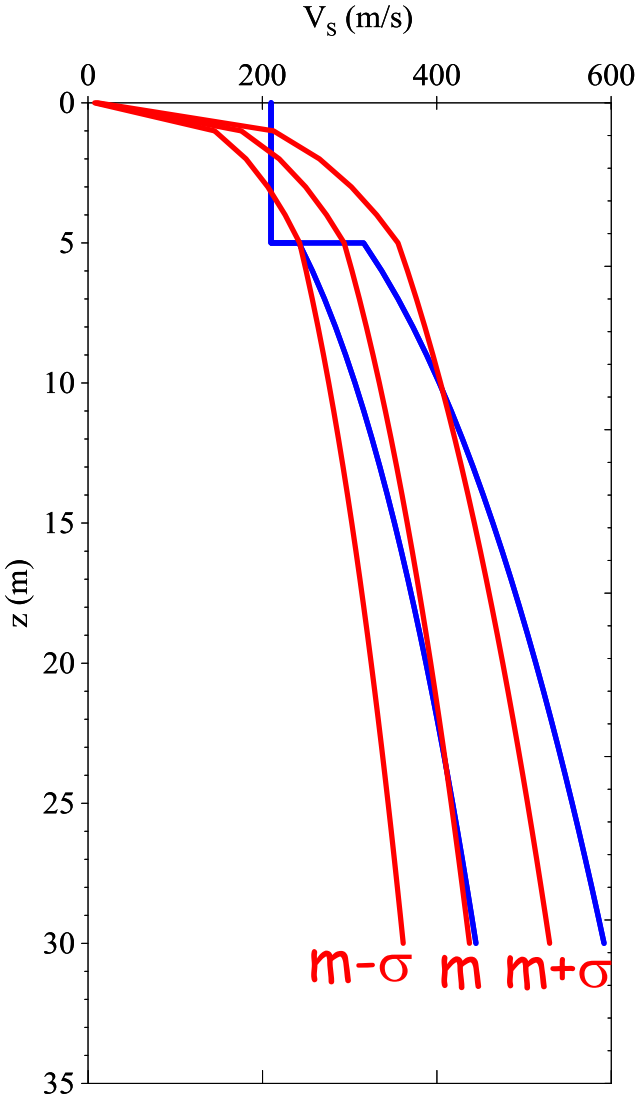
**Japan & Korea**

Sawada & Takahashi (1975)

**Based on Korean data**

Park & Kishida (2018)

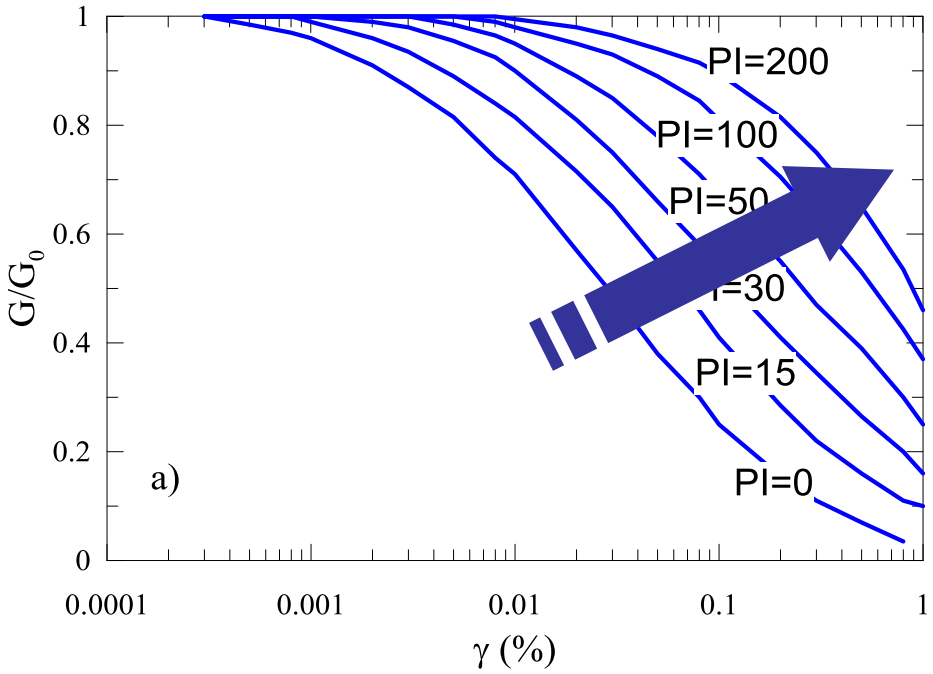
Vs measurements (DH tests) in the core of 21 ECR dams

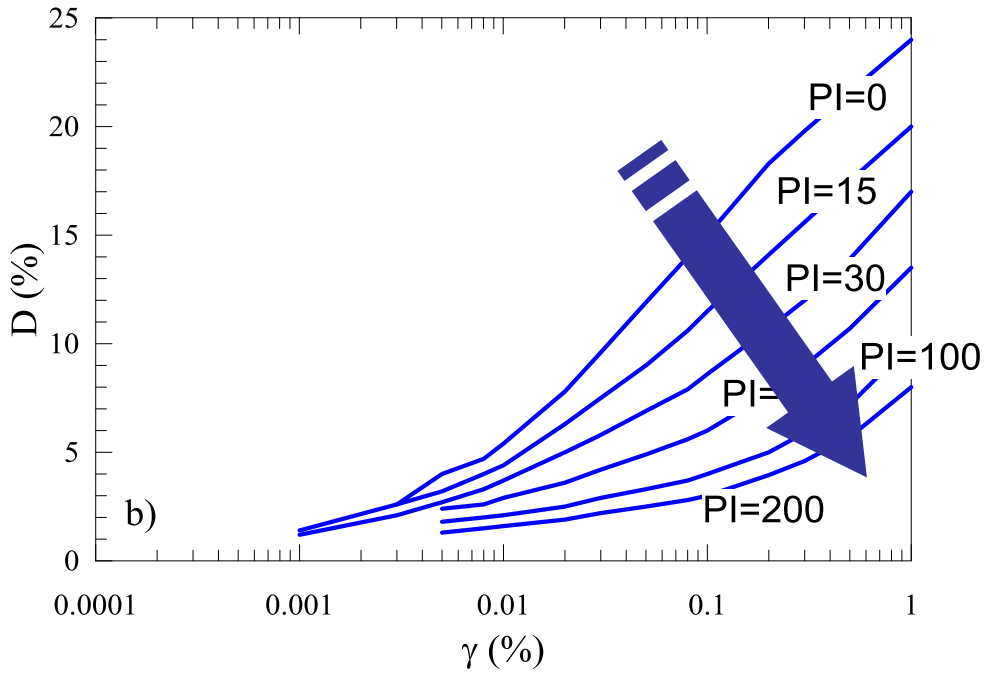


# $G/G_0$-$\gamma$ and D-$\gamma$ curves

## *Natural, fine-grained, saturated soils*

### Effect of plasticity index PI



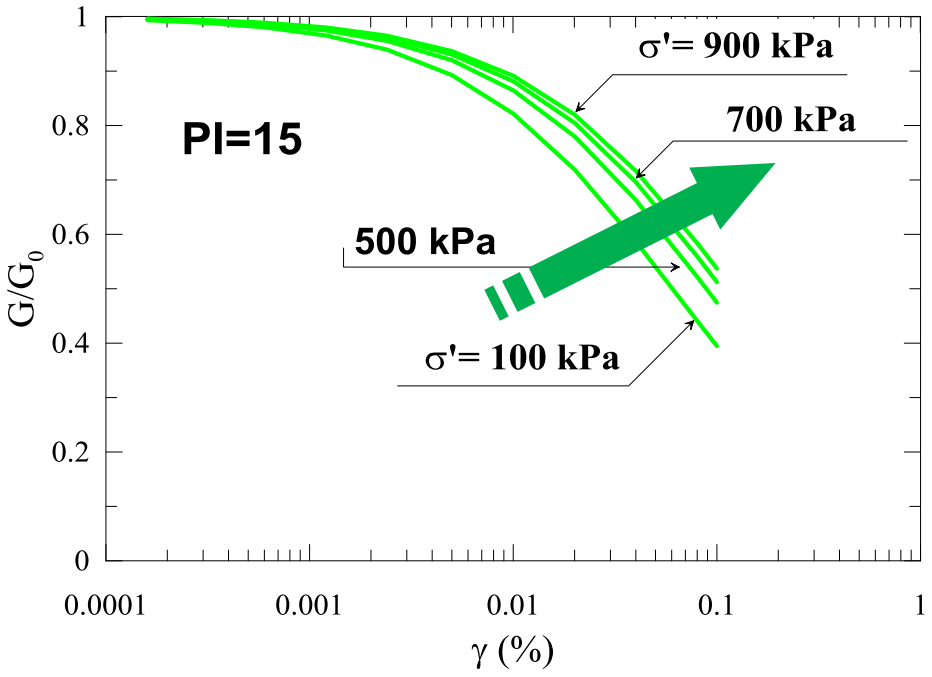



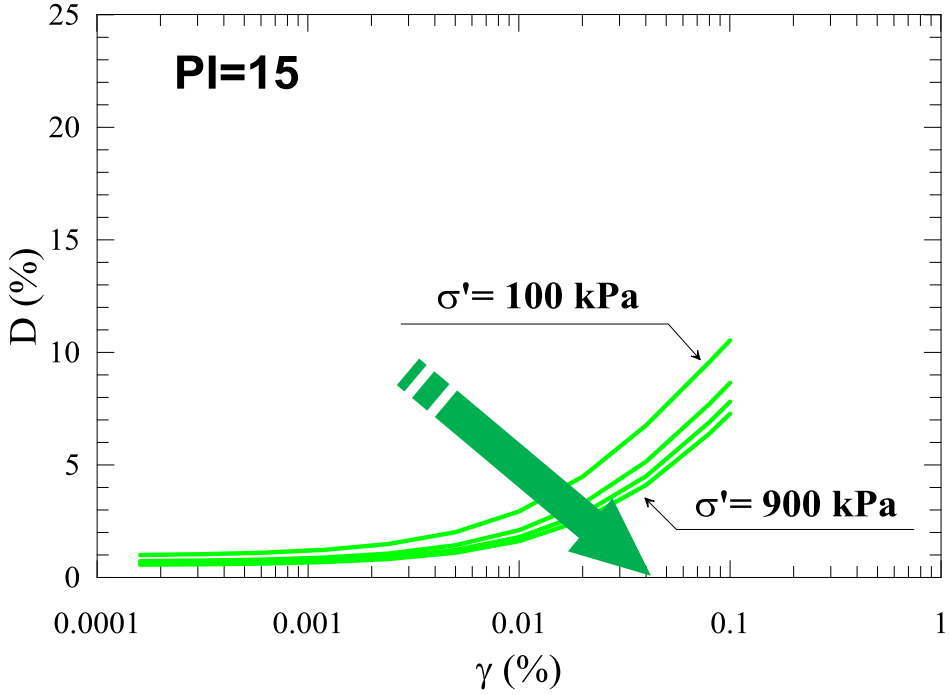

Vucetic & Dobry (1991)

# $G/G_0$-$\gamma$ and D-$\gamma$ curves

## *Natural, fine-grained, saturated soils*

**Four-parameter model**: most influencial parameters on $G/G_0$-$\gamma$ and D-$\gamma$ curves are **plasticity index** and **confining presssure**



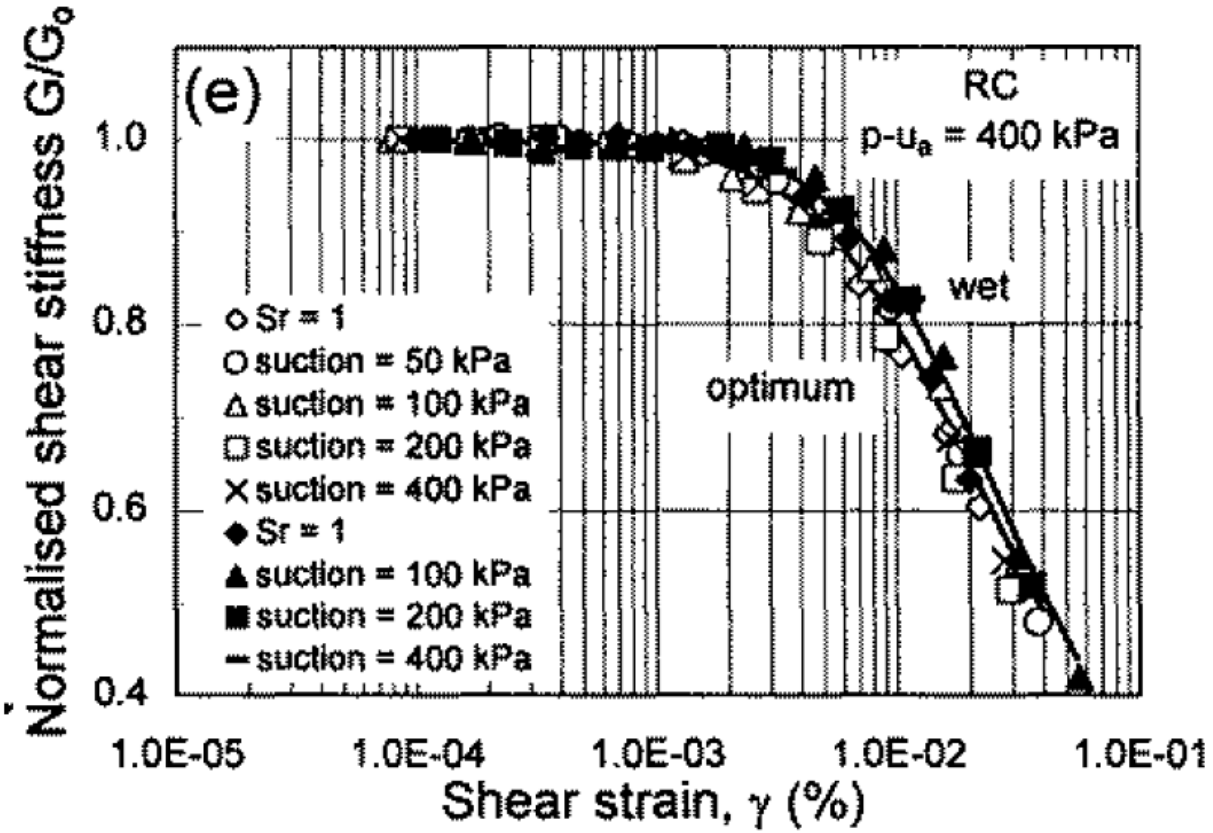




Darendeli (2001)

# $G/G_0$-$\gamma$ curves

## *Lab-compacted soils*

**Partially saturated and saturated, Metramo silty clayey sand using a suction-controlled RC/TS apparatus**

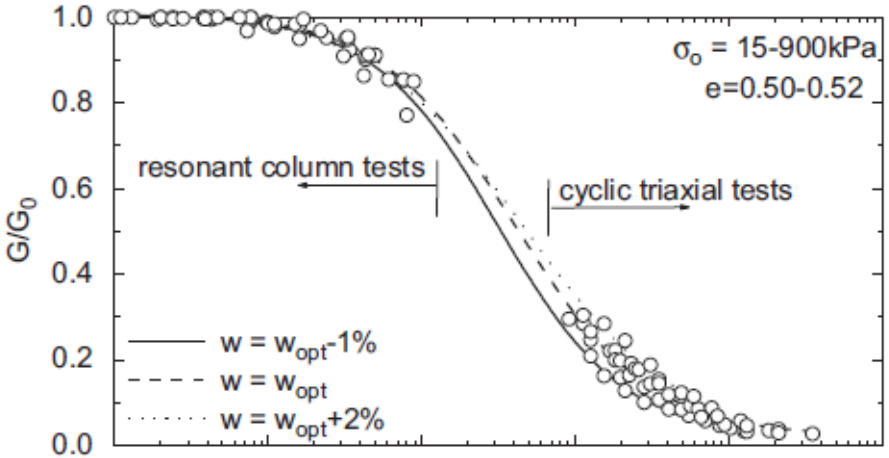


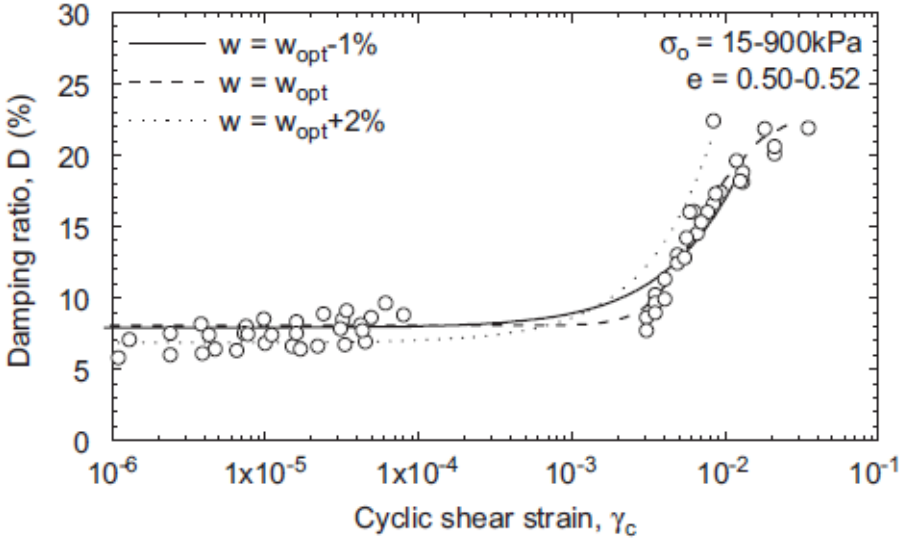

Vinale et al. (2001)

# $G/G_0$-$\gamma$ curves

## *Lab-compacted soils*

- ✓ sandy-silty clay using RC/TS and CTX apparatus
- ✓ soil compacted at $w_{opt}$, $w_{opt}$-1% and $w_{opt}$+2%
- ✓ high range of confining stress (15-900 kPa)



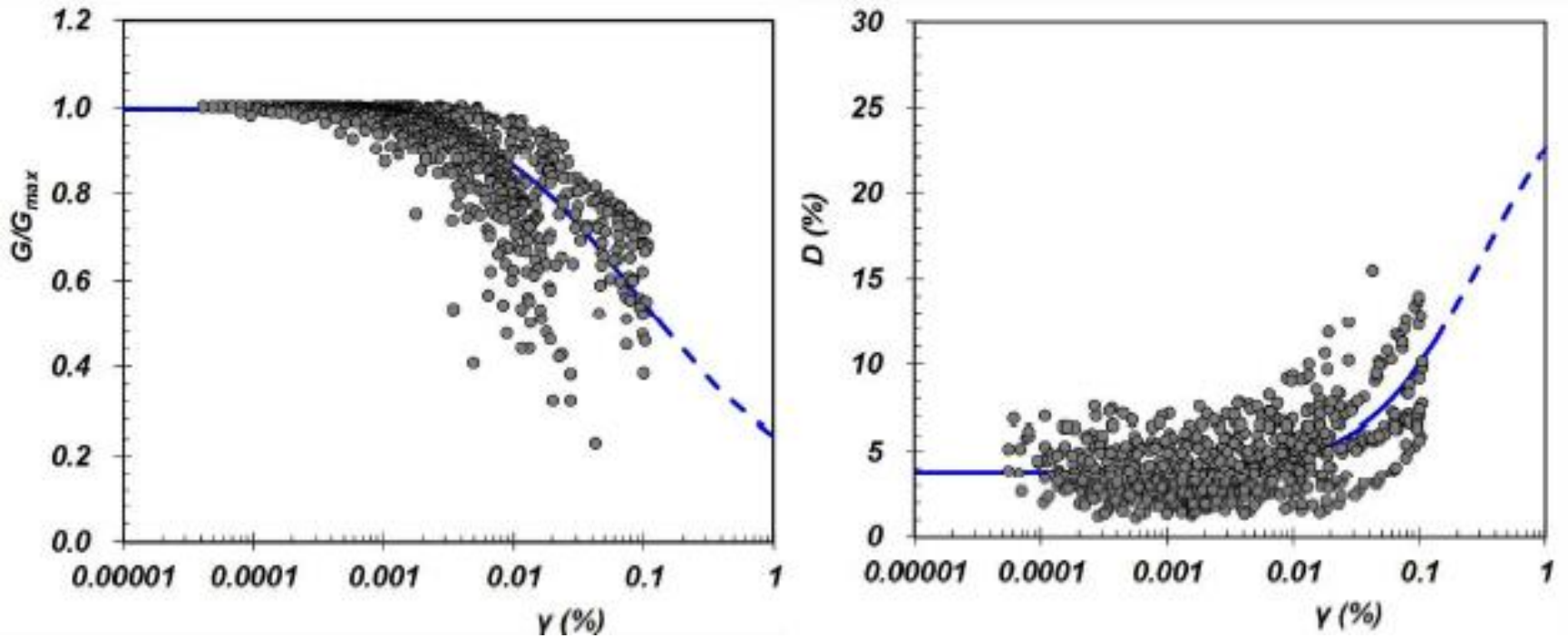




Xenaki & Athanasopoulos (2008)

# $G/G_0$-$\gamma$ and D-$\gamma$ curves

## *Field-compacted, undisturbed core samples*

- ✓ Undisturbed samples from 13 Korean dams
- ✓ RC tests on 17 undisturbed and 14 reconstituted
- ✓ Plasticity index PI=4-50; confining stress $\sigma'_m$<400 kPa




Park & Kishida (2018)

# Italian earth-core rockfill dams

## List of dams examined

| # | Dam | Construction period | $H_{max}$ (m) | Reference |
|---|---|---|---|---|
| 1 | Angitola (VV) | 1960-1966 | 22.8<br>22.6 | unpublished |
| 2 | Bilancino (FI) | 1988-1995 | 42 | Mancuso et al. (1993) |
| 3 | Camastra (PZ) | 1963-1964 | 54 | Pagano et al. (2008) |
| 4 | Farneto (CS) | 1970-1980 | 27.7 | unpublished |
| 5 | Montedoglio (AR) | 1977-1986 | 64.3 | Lanzo et al. (2015) |
| 6 | Penne (PE) | 1966-1969 | 35.7 | unpublished |
| 7 | Poggio Cancelli (AQ) | 1950-1951<br>1964-1971 | 27.3 | unpublished |
| 8 | Polverina (MC) | 1963-1967 | 27.5 | unpublished |
| 9 | San Pietro (AV) | 1958-1964 | 49 | Calabresi et al. (2004) |
| 10 | San Pietro in Villa (AR) | 1980-1993 | 6.30 | unpublished |

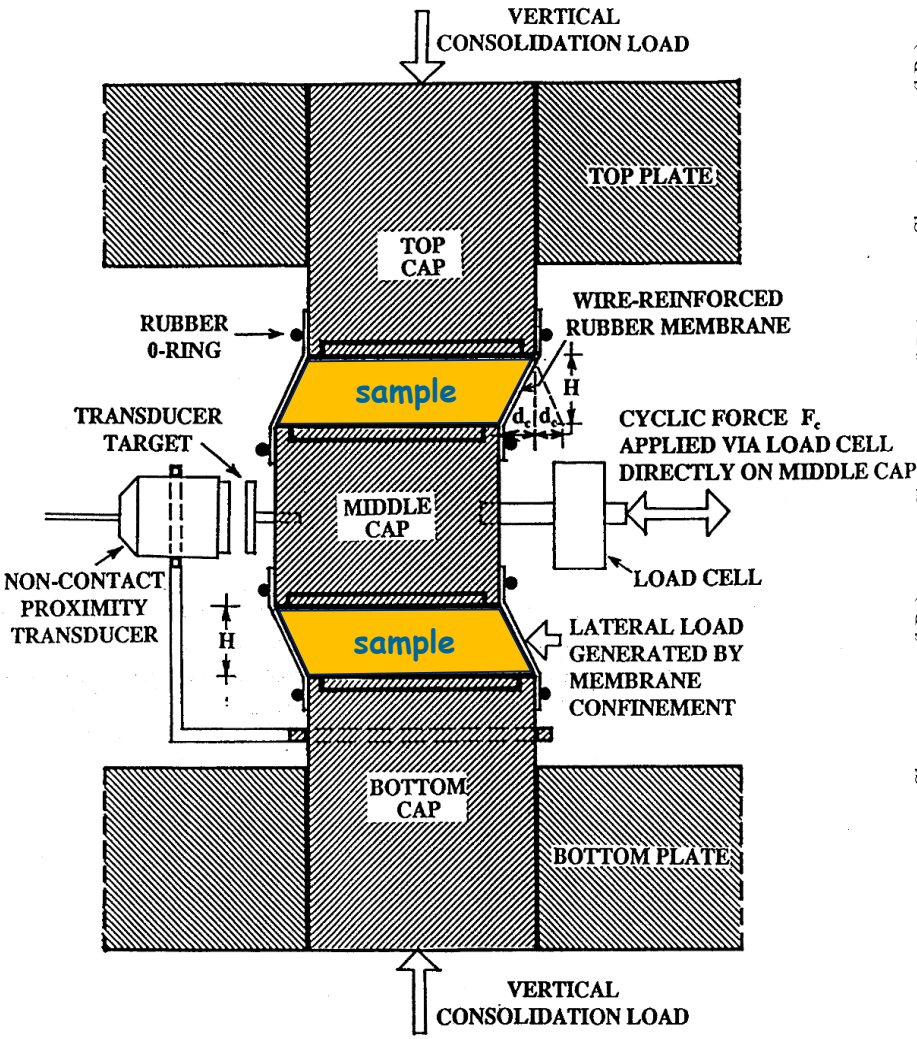
# Italian earth-core rockfill dams

## Field and laboratory tests

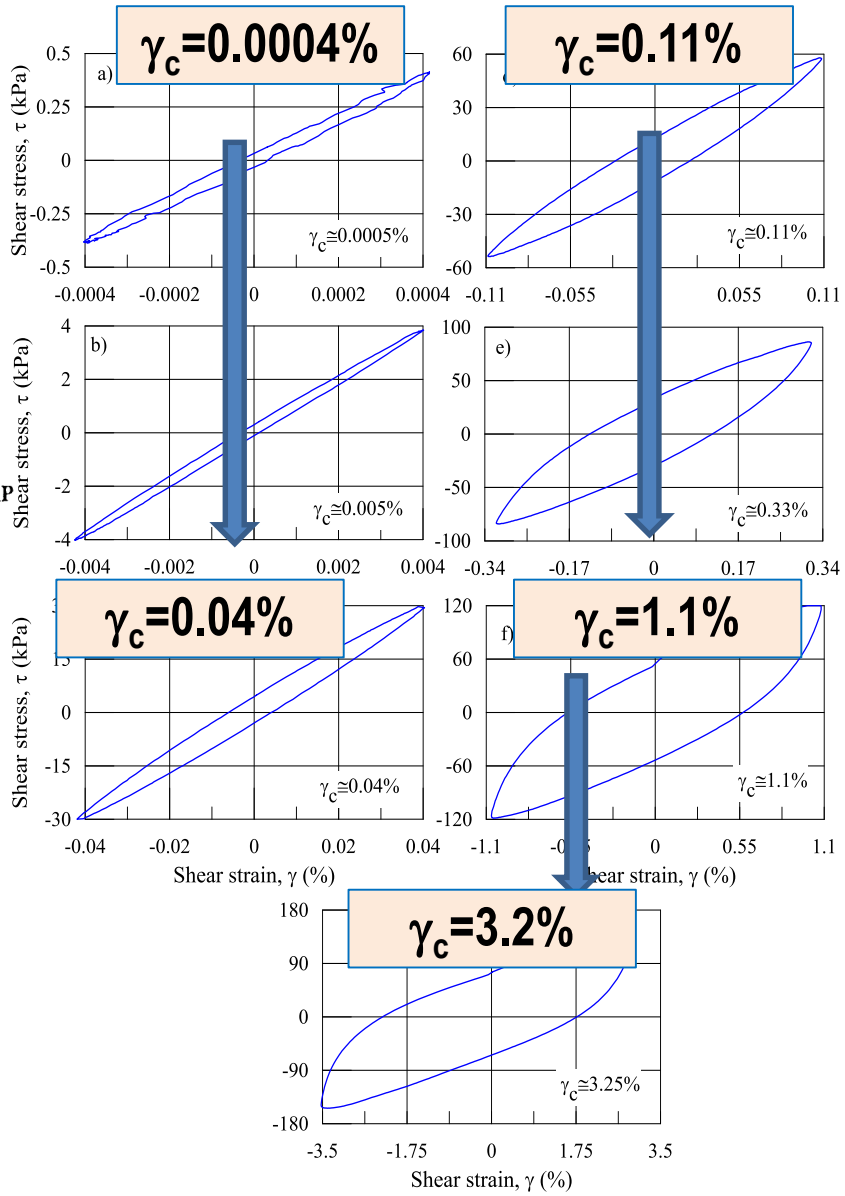
| # | Dam | In situ dynamic | Laboratory cyclic/dynamic |
|---|---|---|---|
| 1 | Angitola (VV) | **DH**, **SCPT** | **DSDSS** |
| 2 | Bilancino (FI) | **DH** | RC/TS |
| 3 | Camastra (PZ) | SDMT | - |
| 4 | Farneto (CS) | **CH** | RC/TS |
| 5 | Montedoglio (AR) | **CH** | **DSDSS** |
| 6 | Penne (PE) | **-** | **DSDSS** |
| 7 | Poggio Cancelli (AQ) | **CH** | RC/TS |
| 8 | Polverina (MC) | **CH** | **DSDSS**, RC/TS |
| 9 | San Pietro (AV) | **CH** | RC/TS |
| 10 | San Pietro in Villa (AR) | **CH** | **DSDSS** |
| **In situ tests**: DH=Down-Hole, CH=Cross-Hole, SCPT= Seismic cone, SDMT=Seismic dilatometer. | | | |
| **Cyclic/Dynamic tests**: DSDSS (Double Specimen Direct Simple Shear); RC=Resonant Column; TS=Torsional Shear | | | |

# The DSDSS device

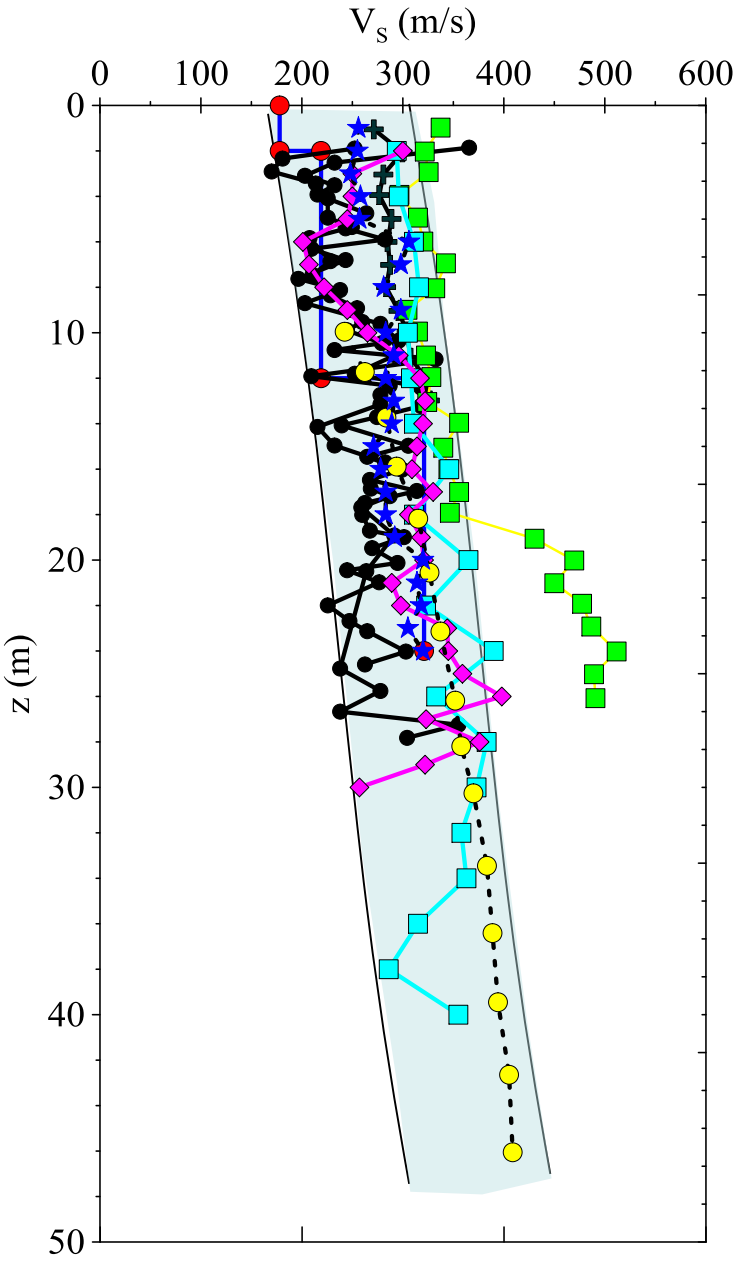
## Double Specimen Direct Simple Shear (DSDSS)




Doroudian and Vucetic (1995)



# Italian earth-core rockfill dams



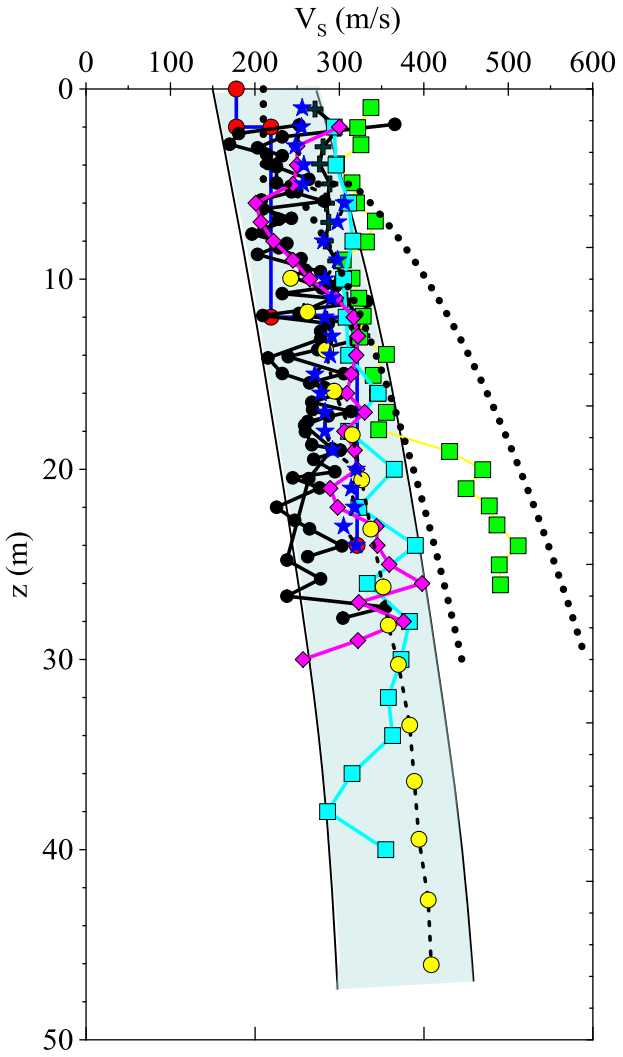

## Vs profiles in the core materials

- Angitola DH
- Bilancino CH
- Camastra SDMT
- Farneto del Principe CH
- Montedoglio CH
- Poggio Cancelli CH
- Polverina CH
- San Pietro CH
- San Pietro in Villa CH

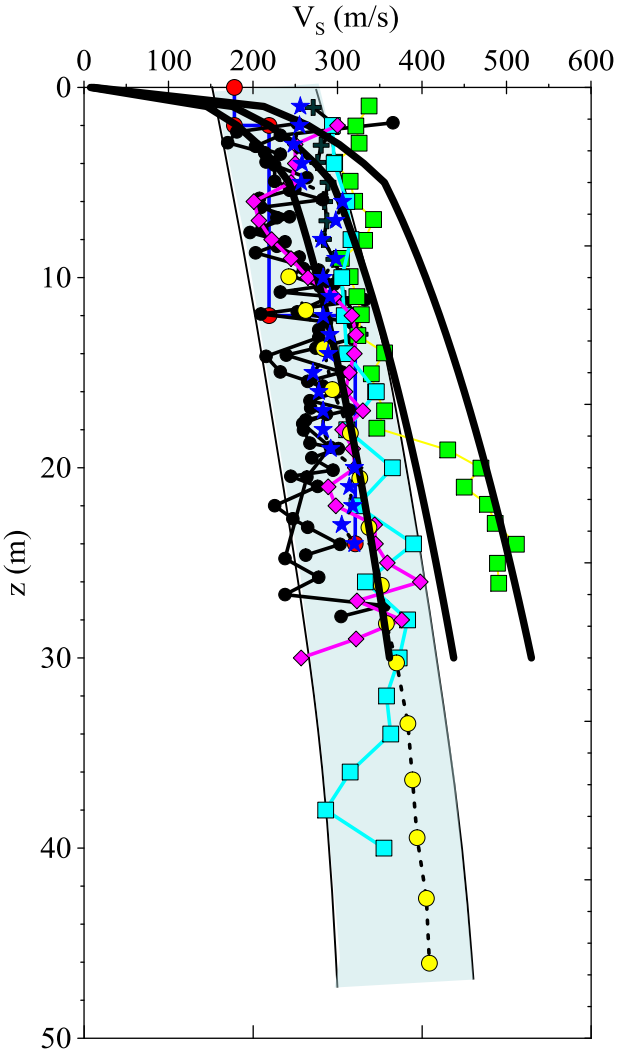
# Italian earth-core rockfill (ECR) dams

## Italian data vs. empirical correlations

### Sawada e Takahashi (1975)

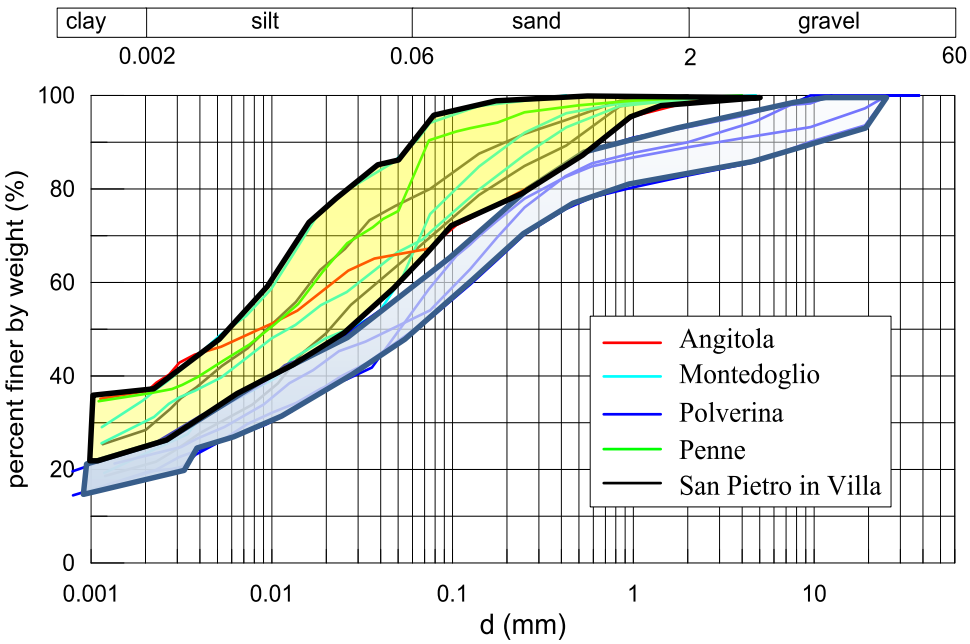


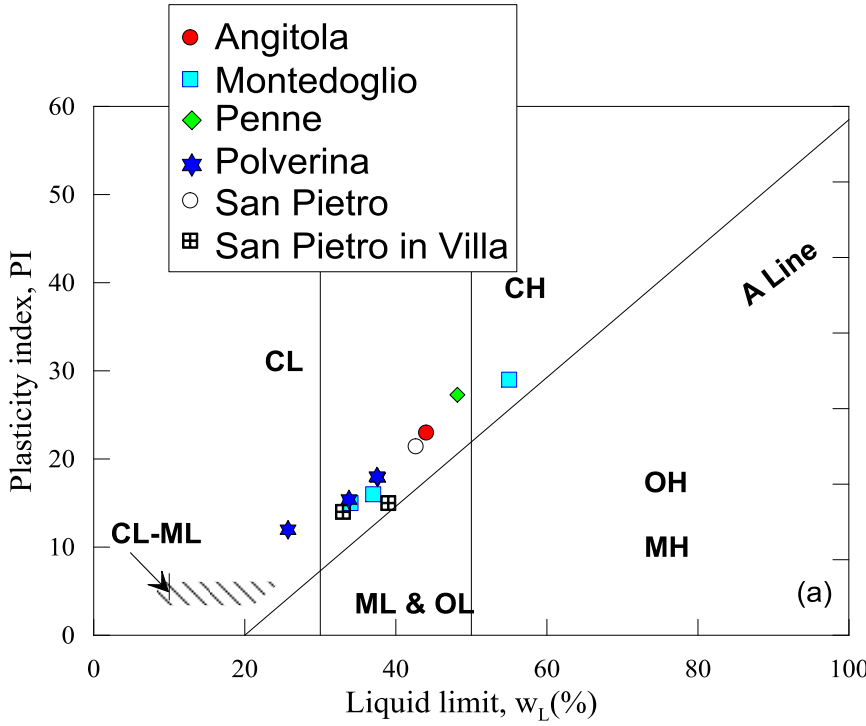

### Park e Kishida (2018)



# Core materials of Italian zoned dams

## Grain size distributions



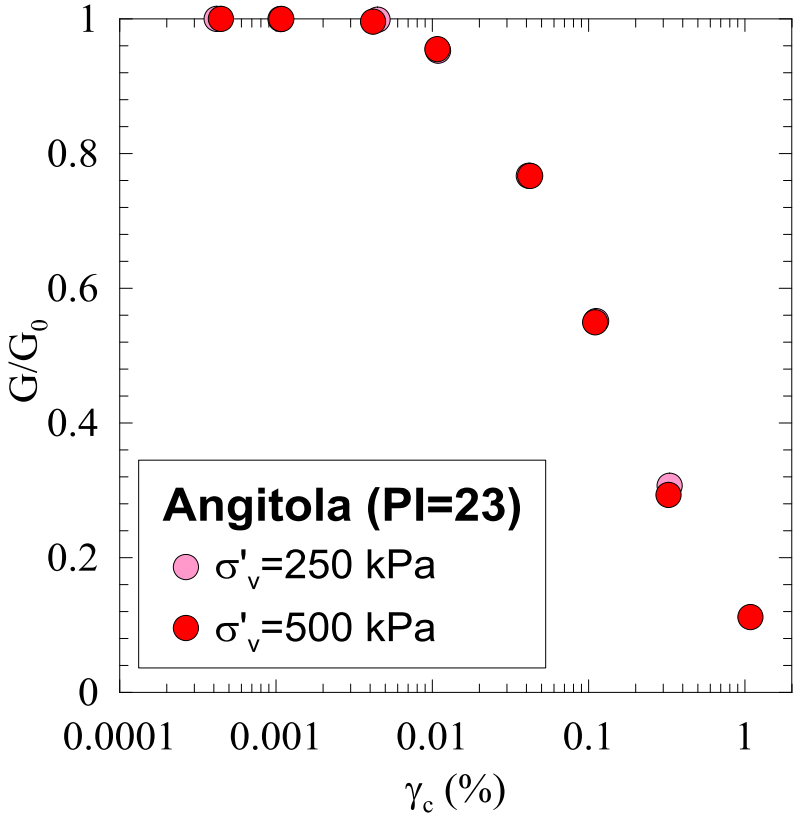

**Sandy-clayey silt**

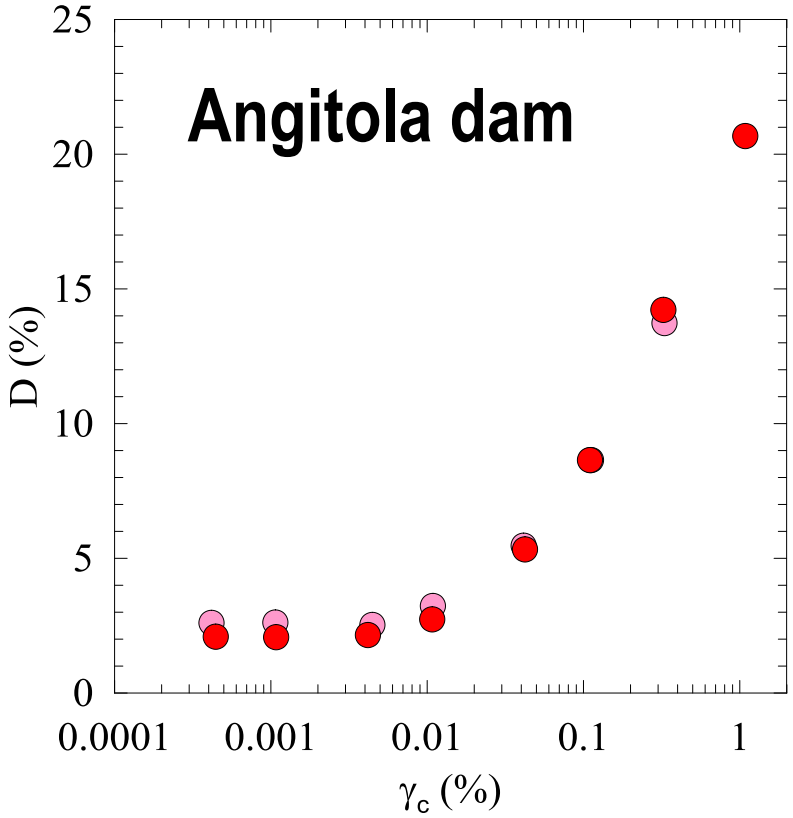
**PI=12-30**

# Core materials of Italian zoned dams

## Results of cyclic DSDSS tests

- ✓ Nonlinear stiffness and damping properties from DSDSS test results on undisturbed core samples (**PI=23**)

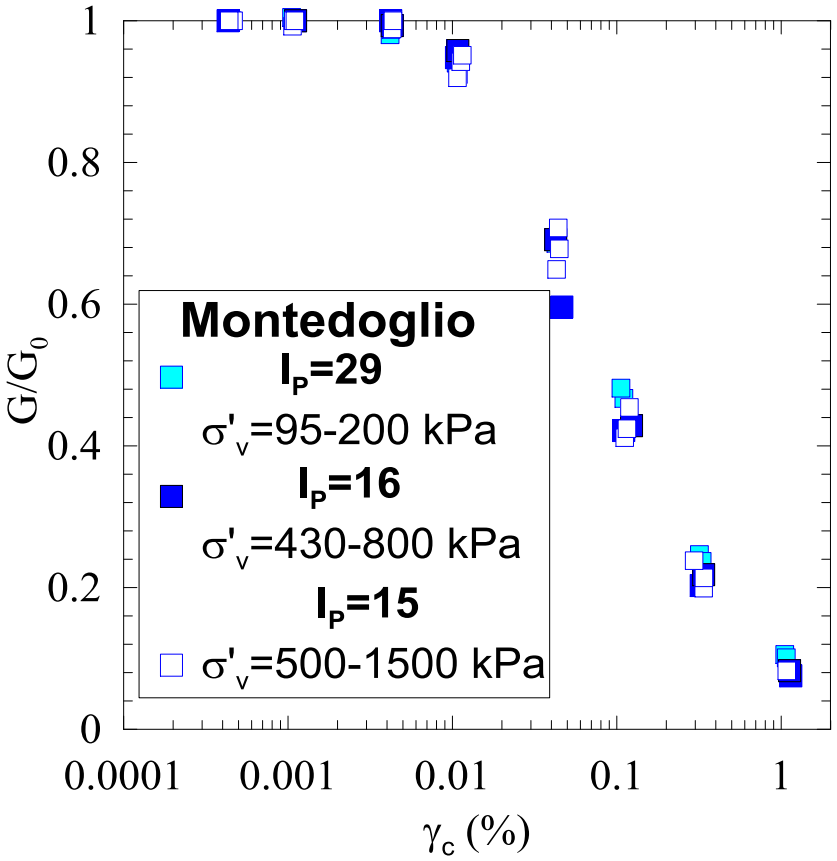


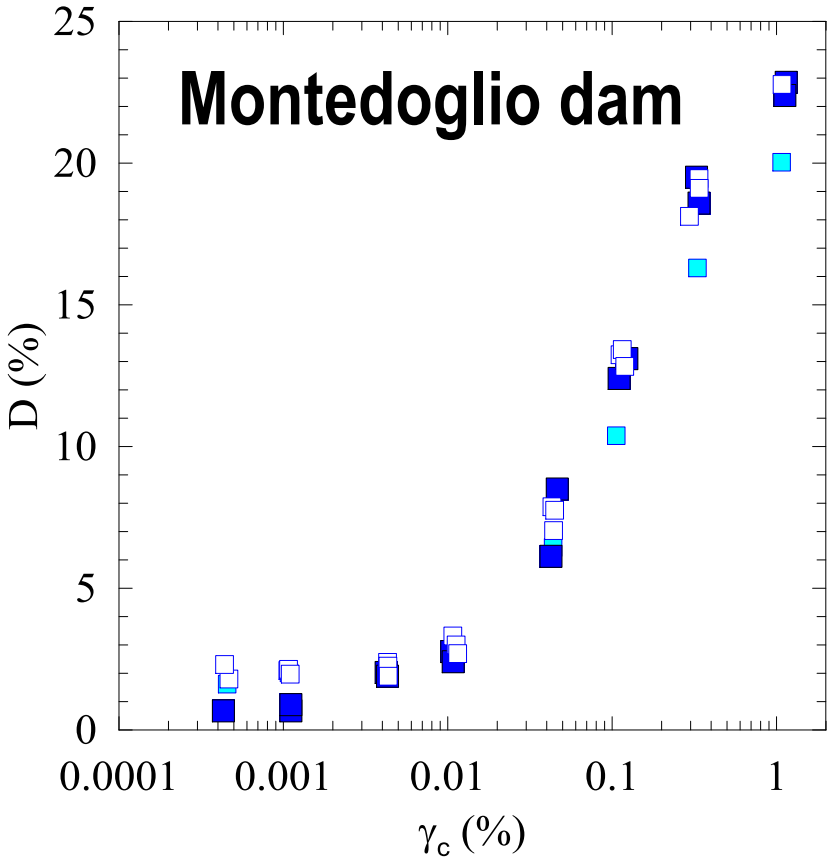



# Core materials of Italian zoned dams

## Results of cyclic DSDSS tests

- ✓ Nonlinear stiffness and damping properties from DSDSS test results on undisturbed core samples (**PI=15-29**)

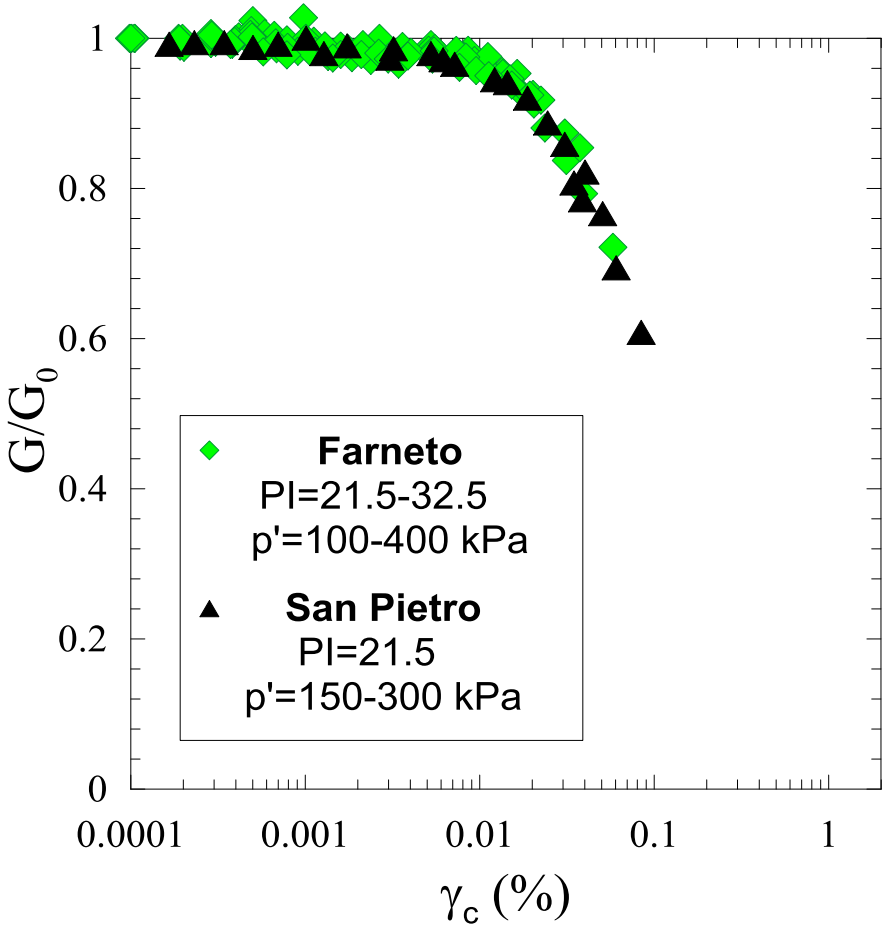


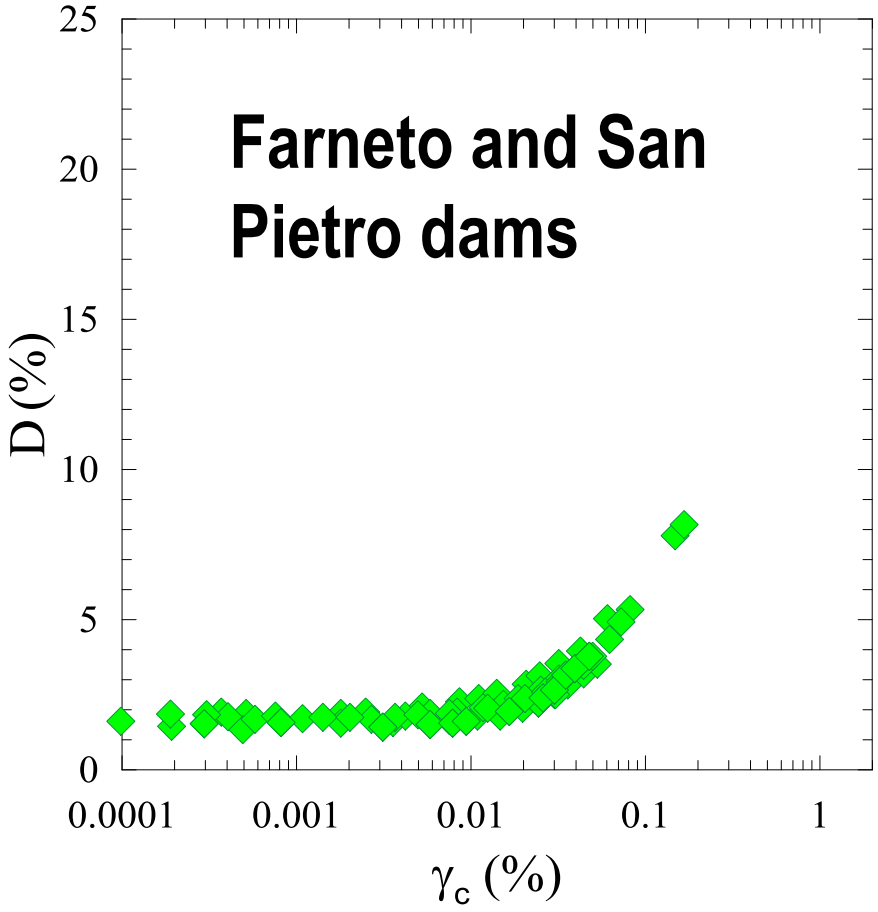



# Core materials of Italian zoned dams

## Resonant Column (RC) and Torsional Shear (TS) tests

- ✓ Nonlinear stiffness and damping properties for Farneto (PI=22-32) and San Pietro (PI=22) dams



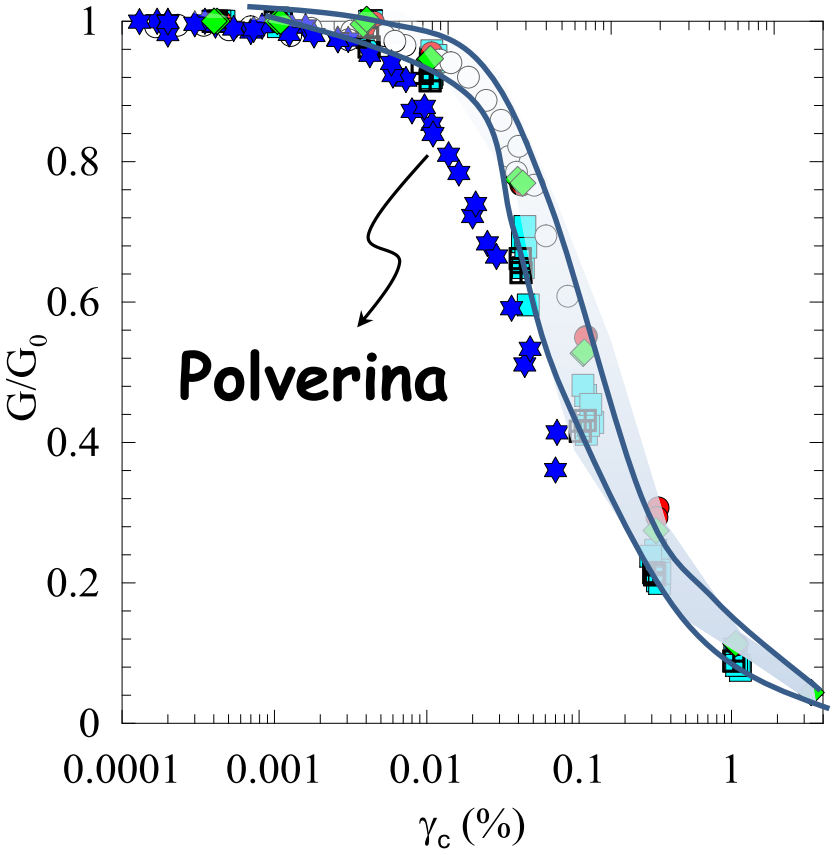



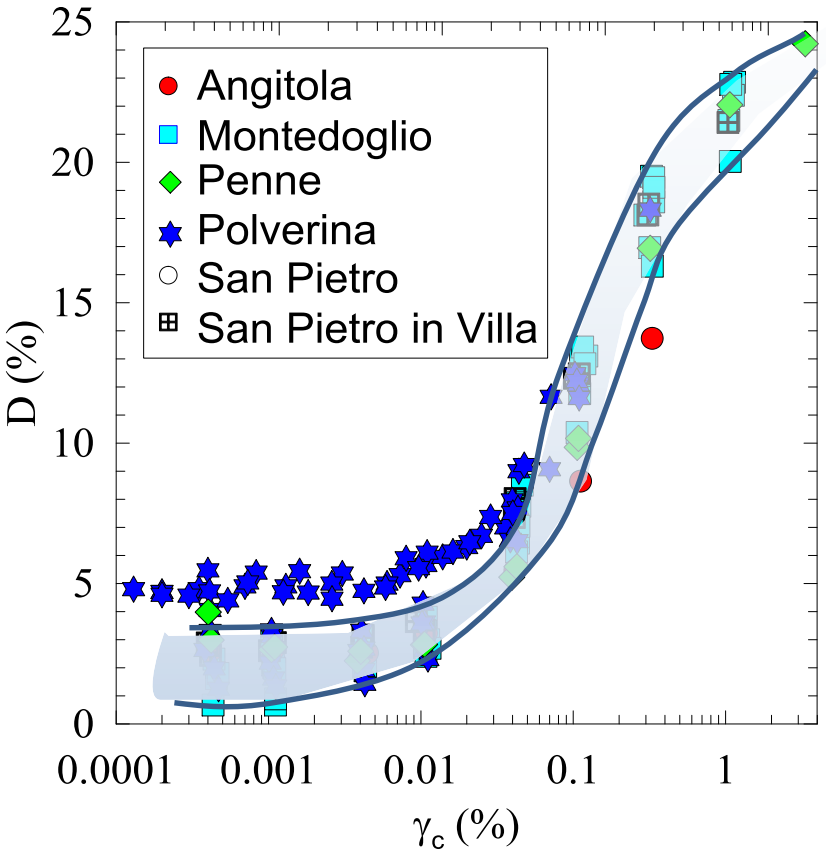

*(data of Farneto dam are courtesy of Prof. Dente, Univ. of Calabria)*

# Core materials of Italian zoned dams

## Cyclic and dynamic test results

- ✓ Nonlinear stiffness and damping properties of core material of Italian dams



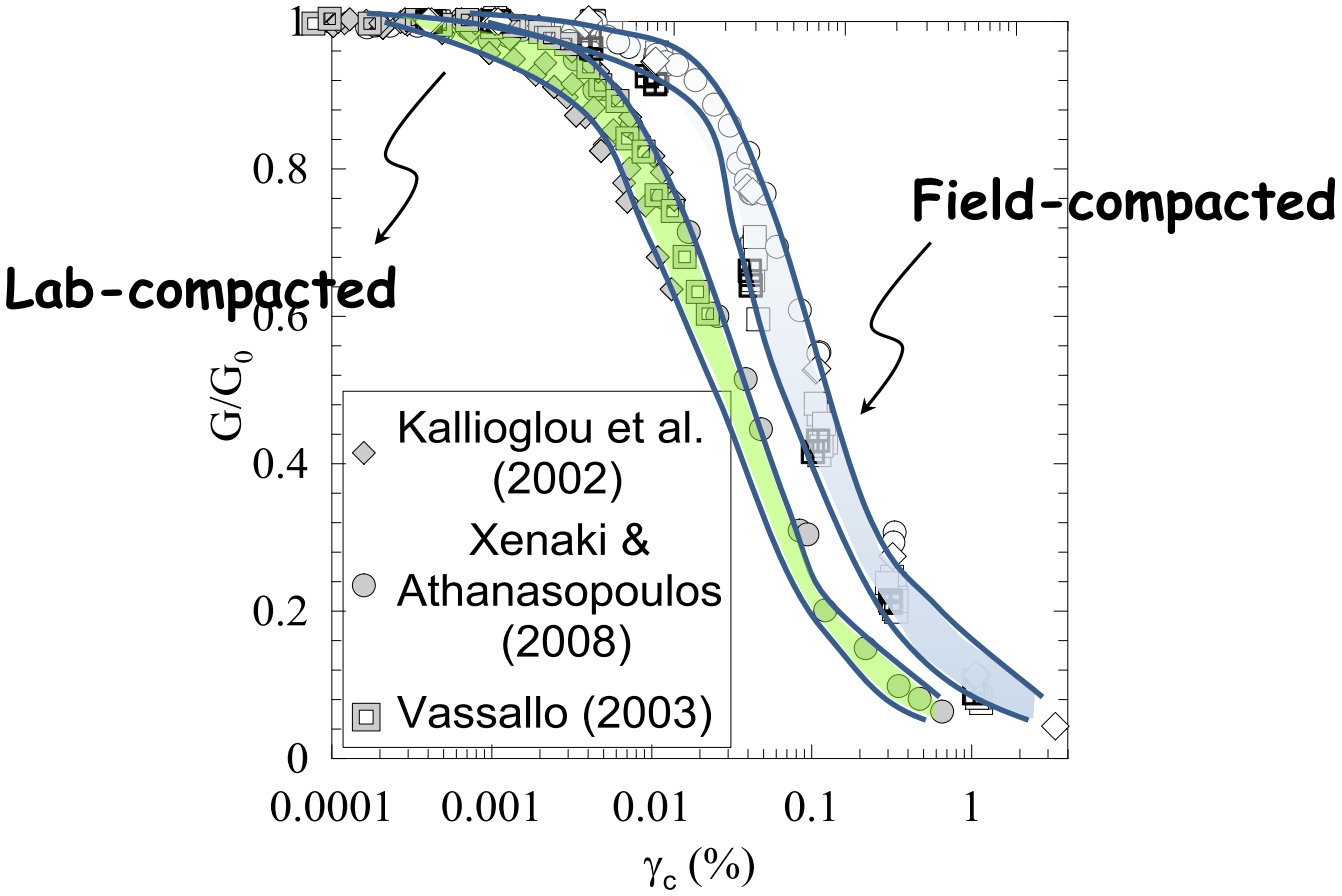



# Core materials of Italian zoned dams

## Nonlinear stiffness and damping properties

✓Lab-compacted vs field-compacted core materials

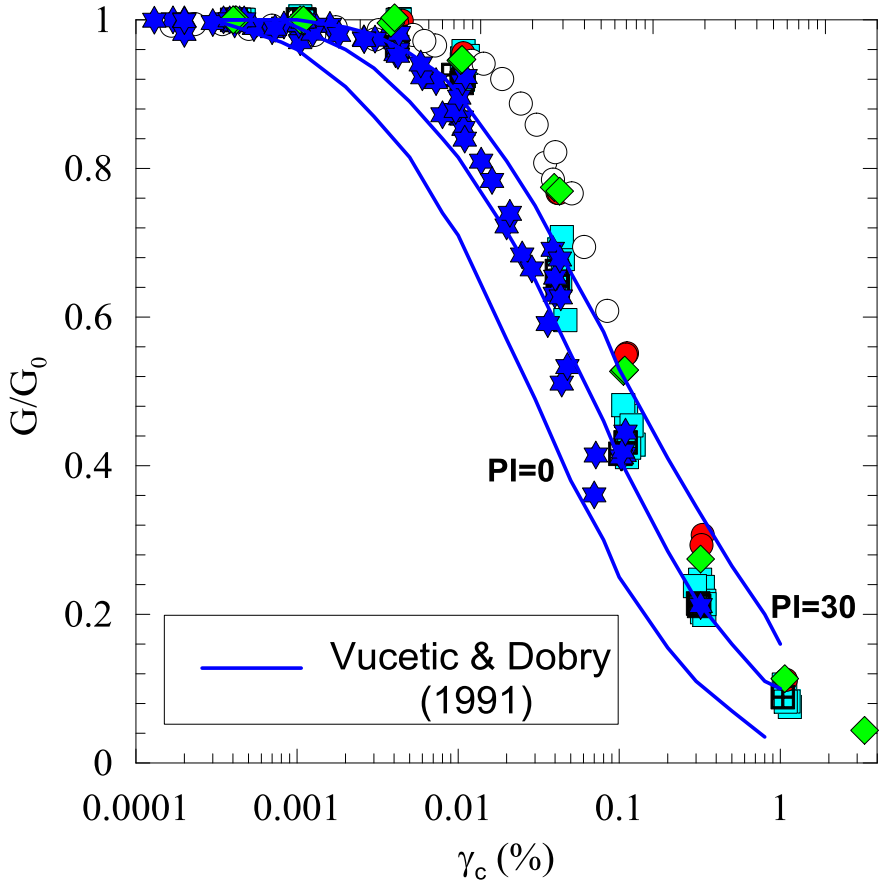
**Data with PI=15-30**

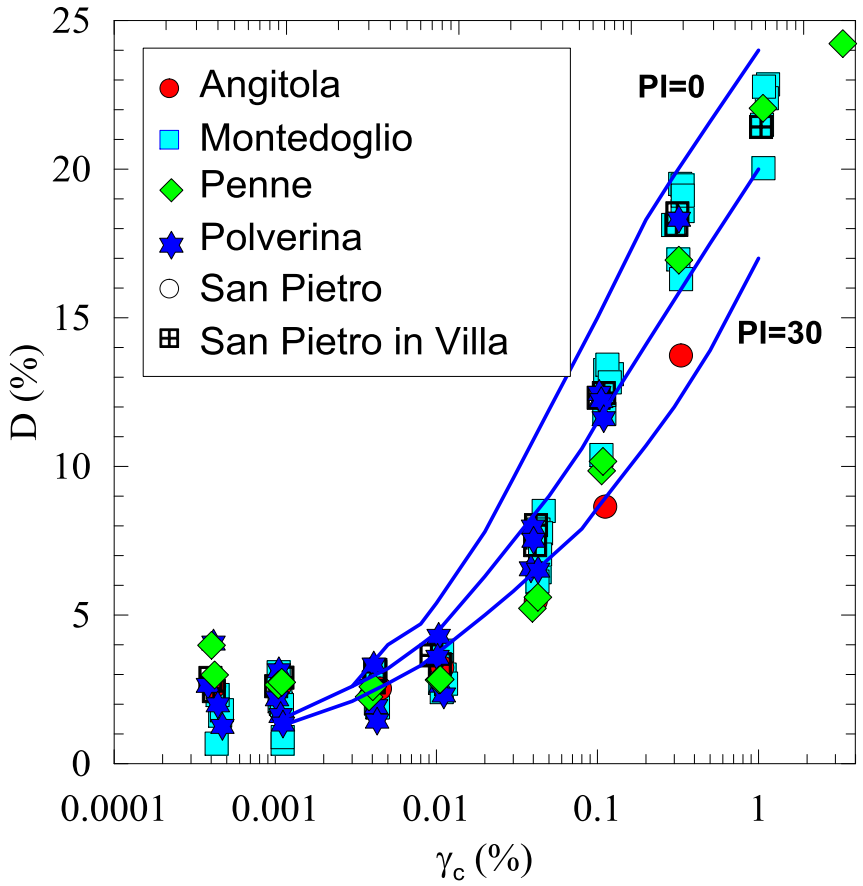


# Core materials of Italian zoned dams

## Results of cyclic and dynamic tests

## Comparison with Vucetic & Dobry curves

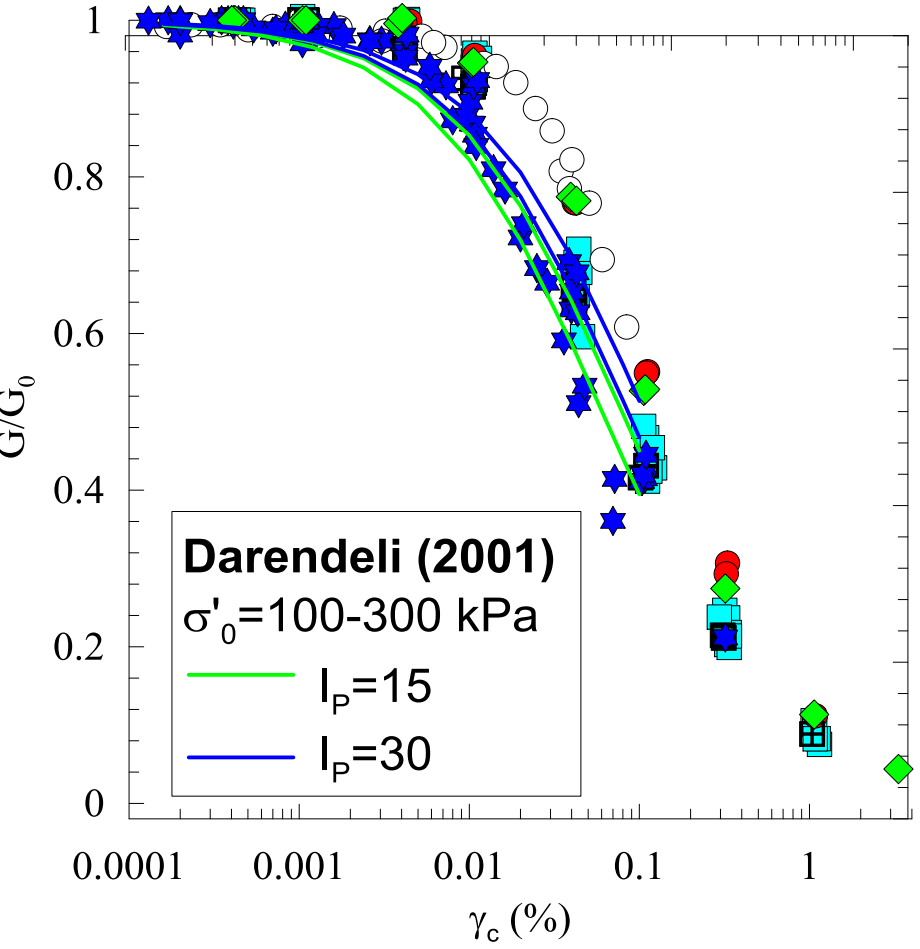


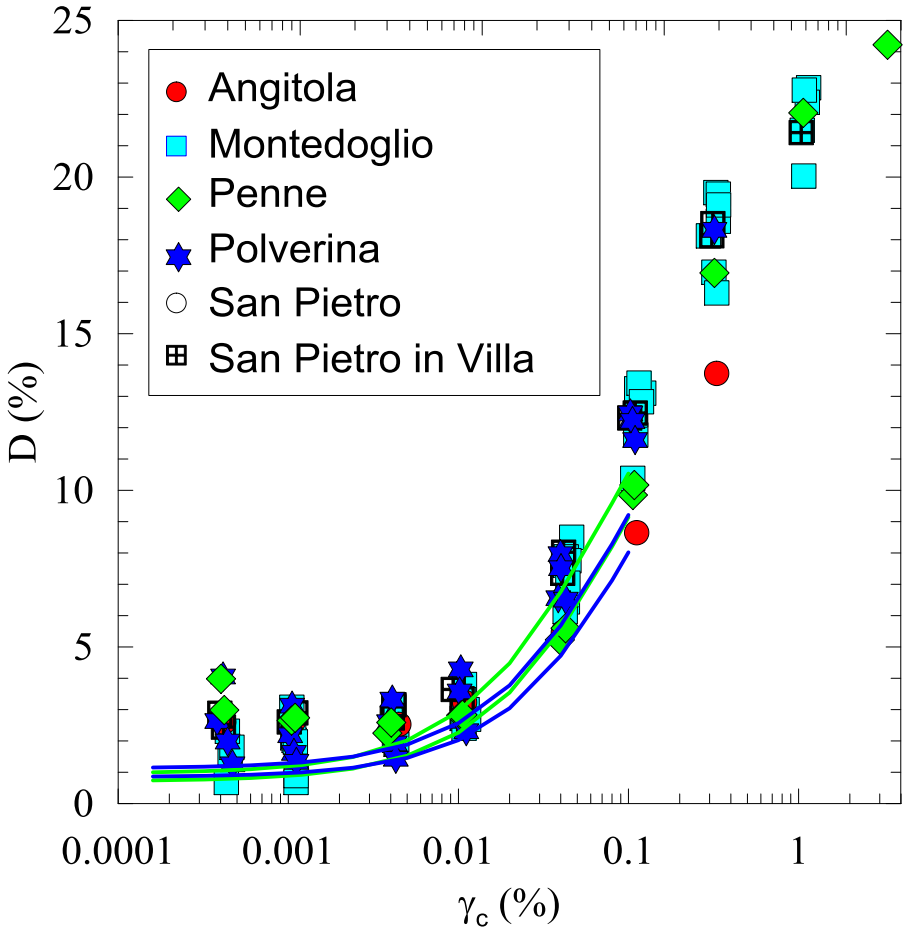



# Core materials of Italian zoned dams

## Results of cyclic and dynamic tests

## Comparison with Darendeli curves



# Final remarks

The use of dynamic analyses of embankments dams is increasing significantly in engineering practice, therefore a proper characterization of dynamic properties of dam body is needed. Data on dynamic properties of core materials is extremely limited.

Based on the results on the core of Italian dams:

- ✓ Vs measured data does not satisfactory agree with empirical correlations
- ✓ G/G0-$\gamma$ and D-$\gamma$ curves from lab tests on undisturbed samples do not follow trends typical of natural saturated fine-grained soils.
- *for medium plasticity soils (PI=15-30), there is no significant effect of plasticity index and confining stress*
- *lab-compacted modulus reduction curves show higher nonlinearity than undisturbed core materials*
- *the use of predictive models (Vucetic & Dobry and Darendeli) is questionable.*

Site-specific laboratory tests are recommended to model the nonlinear deformation behavior of core materials

Thank you!!