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Geotecnica

EN 1998-5 Fondazioni e opere di sostegno

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Pavia - 5 Giugno 2025

EN 1998-5 Project Team 4 - componenti

- Alain Pecker (team leader; **shallow foundations**)
- George Gazetas (**soil-structure interaction; pile foundations**)
- Kyriazis Pitilakis (underground structures)
- Amir Kyinia (liquefaction, slope stability)
- Luigi Callisto (earth retaining structures; overall revision; liaison with SC7)

- Philippe Bisch (chairman of SC8)
- Antonio Correia (secretary of SC8)

Relazione con altri documenti

EN 1998-1-1
5. Site conditions and seismic actions
6. Modelling, analysis, and verifications
   6.4 Force-based approach
   6.5 Non-linear static analysis
   6.6 Response-history analysis

EN 1997 Geotechnical design

Part1
General rules

Part2
Ground properties

Part3
Geotechnical structures

EN 1998-5
Geotechnical aspects, **foundations**, retaining and underground structures

EN 1998-5 Indice

1. Scope
2. Normative references
3. Terms, definitions and symbols
4. Basis of design
5. Seismic action
6. Ground properties
7. Evaluation of the seismic response of the construction site
8. **Soil-structure interaction**
9. **Foundation system**
10. Earth retaining structures
11. Underground structures

(8–9: geotechnical systems)

(10–11: geotechnical structures)

Metodi di analisi e verifiche in fondazione

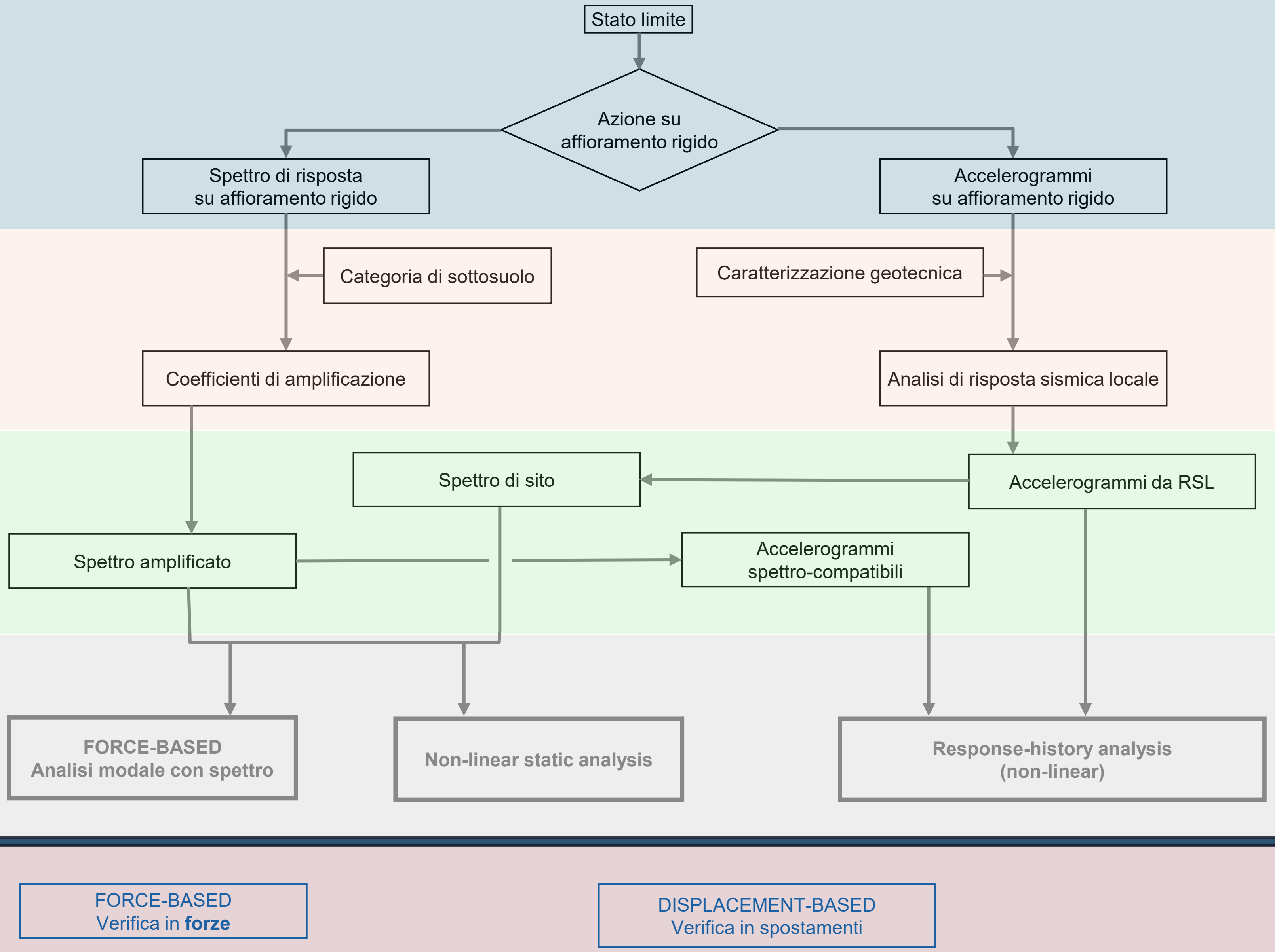
AZIONE SISMICA DI BASE
EN 1998-1-1

RISPOSTA SISMICA SOTTOSUOLO
EN 1997-2
EN 1998-1-1
EN 1998-5
- Siting
- Site-specific response analysis

AZIONE SISMICA SULLA STRUTTURA
EN 1998-1-1

METODI DI ANALISI
EN 1998-1-1
EN 1998-5
8. Soil-structure interaction

VERIFICHE IN FONDAZIONE
EN 1998-5
9. Foundation system



Metodi di analisi e verifiche in fondazione

AZIONE SISMICA DI BASE
EN 1998-1-1

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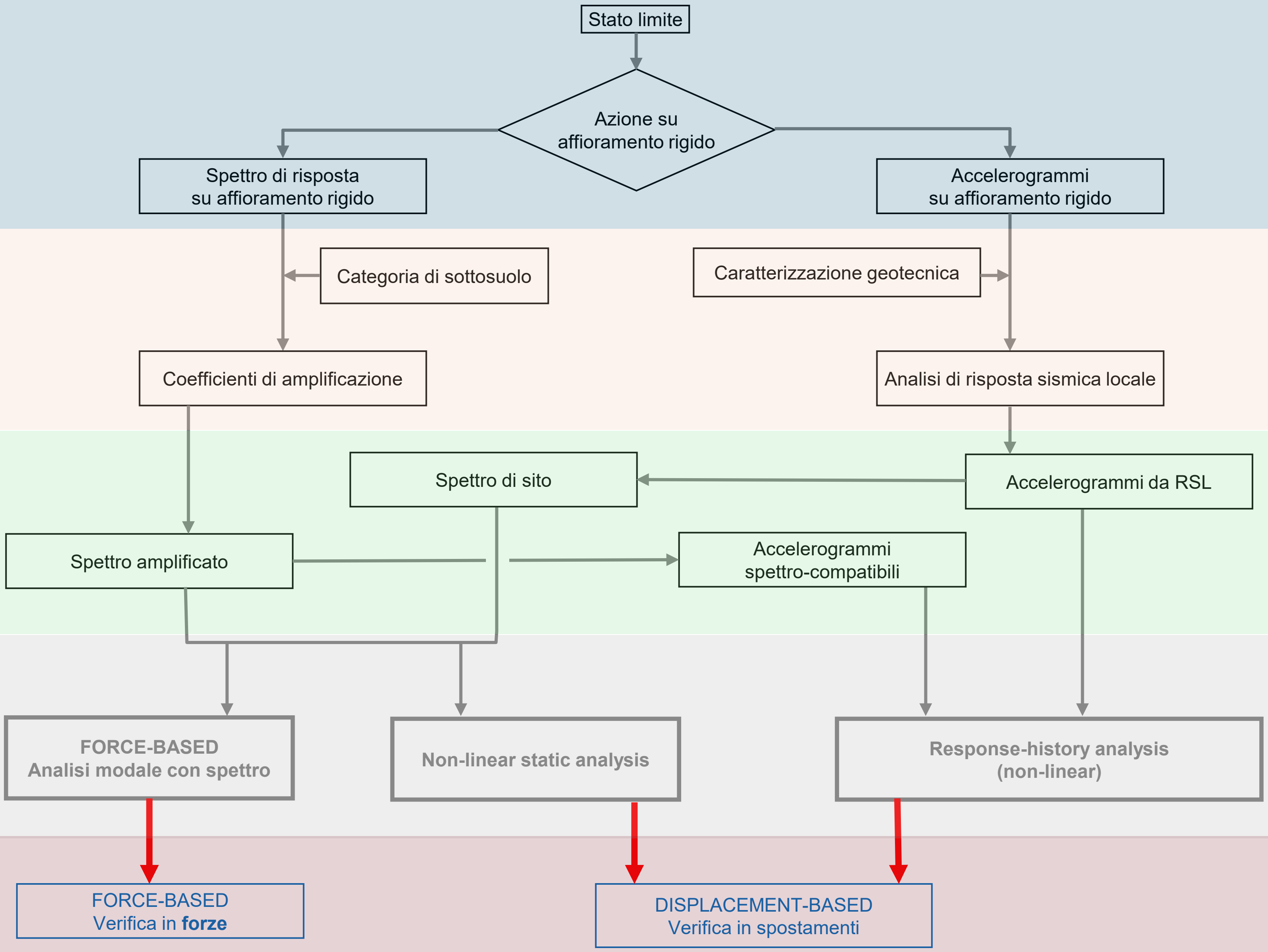


Analisi «force-based»

(EN 1998-5)

8. Soil-structure interaction

8.2 Analysis of inertial effects

8.2.1(1) … including the foundation mass…

8.2.1(2) Ground reaction **may** be represented by springs for all degrees of freedom

Reduced spectrum (EN 1998-1-1)

$$q = q_R \, q_S \, q_D$$

$$\frac{1}{q_{D,SSI}} = 1 - \left(1 - \frac{1}{q_D}\right) \frac{T_1}{\eta T_{SSI}}$$

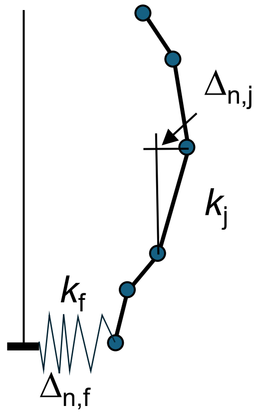
- incremento periodo naturale
- incremento smorzamento (η >1)
- a parità di smorzamento: riduzione *q*

Analisi «force-based»

average weighted damping (Roesset et al. 1972)

$$\eta \longrightarrow \xi = \frac{\sum_i E_{\mathrm{Ei}} \xi_{\mathrm{i}}}{\sum_i E_{\mathrm{Ei}}}$$

$$\xi_{\mathrm{n,\,eq}} = \frac{\sum_{\mathrm{j}} \xi_{\mathrm{j}} k_{\mathrm{j}} \Delta_{\mathrm{n,j}}^2}{\sum_{\mathrm{j}} k_{\mathrm{j}} \Delta_{\mathrm{n,j}}^2}$$



$$\boldsymbol{\phi}_{\mathrm{n}}^{\mathrm{T}} \mathbf{m} \boldsymbol{\phi}_{\mathrm{n}} = 1$$

$\Delta_{n,j}$ relative displacement from normalised modal shape $\phi_{n,j}$

Reduced spectrum (EN 1998-1-1) $q = q_R \, q_S \, q_D$

$$\frac{1}{q_{D,SSI}} = 1 - \left(1 - \frac{1}{q_D}\right) \frac{T_1}{\eta T_{SSI}}$$

- incremento periodo naturale
- incremento smorzamento (η >1)
- a parità di smorzamento: riduzione *q*

Analisi «force-based»

Annex D - Impedance functions for surface and deep foundations

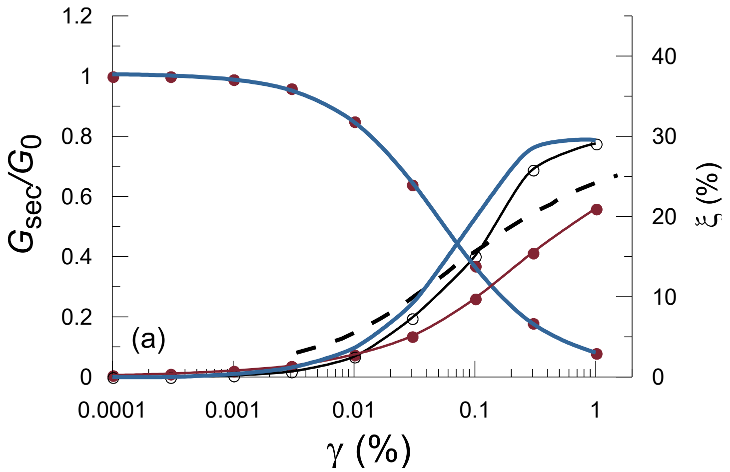
D.3 Impedance of a rectangular foundation on a homogeneous half-space

D.3.1 Stiffness coefficient

(1) The static impedance functions, defined in 8.2(2), of a rectangular foundation at the surface of a homogeneous half-space may be calculated using Formulae (D.1) to (D.6).

$$K_{yy} = \frac{GL}{2-\nu}\left[2+2,5\left(\frac{B}{L}\right)^{0,85}\right] \tag{D.1}$$

(...)



D.5 Static lateral impedance of a single pile in a homogeneous layer

(1) The static impedance functions, defined in 8.2, 8.3 of an isolated flexible pile in a homogeneous layer (see Figure D.4) may be calculated using Formulae (D.19) to (D.21).

$$K_{HH} \cong E_S d\left(\frac{E_P}{E_S}\right)^{0,20} \tag{D.19}$$

(...)

Table 6.1 — Damping ratios and average reduction factors (±one standard deviation) of the normalized secant shear modulus G/G0 within 20 m depth

Seismicity level	150 ≤ v_s < 250 m/s		250 ≤ v_s < 400 m/s		400 ≤ v_s < 800 m/s		800 m/s ≤ v_s	
	G/G_0	ξ	G/G_0	ξ	G/G_0	ξ	G/G_0	ξ
Very low	0,70 (±0,08)	0,04	0,80 (±0,09)	0,03	1,00	0,03	1,00	0,02
Low	0,50 (±0,14)	0,07	0,65 (±0,16)	0,05	0,80 (±0,10)	0,03	1,00	0,02
Moderate	0,30 (±0,10)	0,10	0,50 (±0,20)	0,07	0,70 (±0,10)	0,05	1,00	0,02
High	0,20 (±0,10)	0,20	0,40 (±0,20)	0,12	0,60 (±0,20)	0,10	0,90 (±0,10)	0,02

stima rigidezze secanti
(in assenza di analisi di risposta sismica locale)

9. Foundation system

9.2 Design values of the action effects

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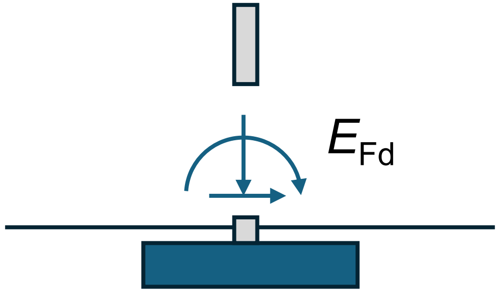
Analisi modale con spettro

FORCE-BASED
Verifica in **forze**



capacity/demand ratio of element dissipative zone

overstrength

$$E_{Fd} = E_{Fd,G} \text{ "+" } \frac{\Omega_d \gamma_{Rd}}{\chi_H} E_{Fd,E}$$

non-seismic

effect of seismic actions (*q*)

DC1: $\Omega_d \gamma_{Rd} = 1$

DC2 and DC3: $\Omega_d \gamma_{Rd} = 1 – 1.25\ q_R$
$\Omega_d \gamma_{Rd} = 1 – 1.2$ for sliding / bearing capacity verifications

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Analisi modale con spettro

↓

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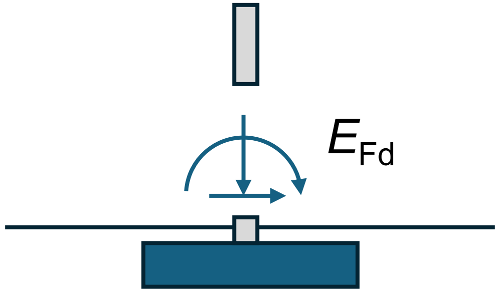
Verifica in **forze**

9. Foundation system

9.2 Design values of the action effects



$$E_{\mathrm{Fd}} = E_{\mathrm{Fd,G}} \text{ "+" } \frac{\Omega_{\mathrm{d}}\gamma_{\mathrm{Rd}}}{\chi_{\mathrm{H}}} E_{\mathrm{Fd,E}}$$

- capacity/demand ratio of element dissipative zone (Ω_d)
- overstrength (γ_{Rd})
- non-seismic ($E_{Fd,G}$)
- effect of seismic actions (*q*) ($E_{Fd,E}$)
- accepted permanent displacements (only for geotechnical verifications) (χ_H)

- elementi strutturali di fondazione sovra-resistenti
- raggiungimento resistenza in fondazione:
  - scorrimento $\Omega_d\ \gamma_{Rd} = 1.0$, $\chi_H \geq 1$
  - carico limite $\Omega_d\ \gamma_{Rd} = 1.2$, $\chi_H \geq 1$

fondazioni superficiali

Table 9.1 — Values of χ_H for sliding analyses

χ_H	**1,25**	**1,5**	**1,75**
Range of permanent displacements (mm)	≤ 15	> 20 to ≤ 50	> 50 to ≤ 100

NOTE Values of χ_H in Table 9.1 are calibrated for the recommended values of material factors and global resistance factors. Values of χ_H for other values of the material factors or global resistance factors are not provided in this standard.

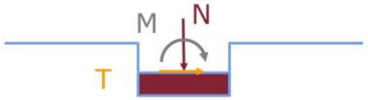
Verifiche in forze

Annex E - Seismic bearing capacity of shallow foundations

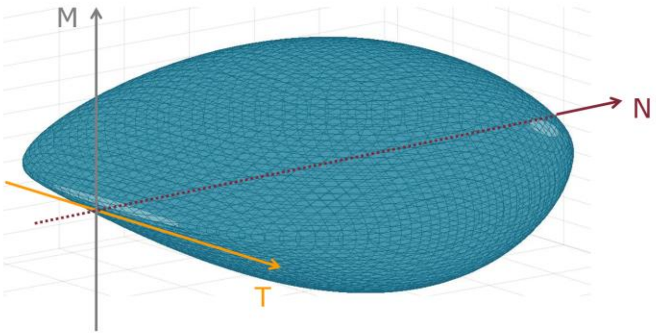
E.3 Surface strip foundation

(1) The stability against seismic bearing capacity failure of a shallow strip footing resting on the surface of homogeneous soil may be checked using Formulae (E.1) and (E.2).

$$\frac{\left(1-e\bar{F}\right)^{c_T}\left(\beta\bar{V}\right)^{c_T}}{\left(\bar{N}\right)^{a}\left[\left(1-m\bar{F}^{k}\right)^{k'}-\bar{N}\right]^{b}}+\frac{\left(1-f\bar{F}\right)^{c'_M}\left(\gamma\bar{M}\right)^{c_M}}{\left(\bar{N}\right)^{c}\left[\left(1-m\bar{F}^{k}\right)^{k'}-\bar{N}\right]^{d}}-1\leq 0 \qquad \text{(E.1)}$$



superficie ultima



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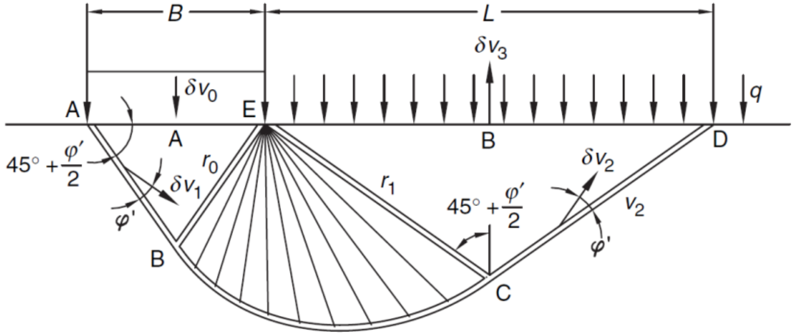
(4) The drained bearing resistance (R_N) to a force acting normal to the base of a spread foundation on soil or fill may be determined using effective stress analysis from:

$$R_N = A'\left(c'N_c b_c d_c g_c i_c s_c + q'N_q b_q d_q g_q i_q s_q + 0.5\gamma^* B' N_\gamma b_\gamma d_\gamma g_\gamma i_\gamma s_\gamma\right) \qquad (5.5)$$

formula trinomia



Nota: $\gamma_{\phi'} = \gamma_{c'} = \gamma_{Cu} = 1$

Verifiche in forze

9.5.4 Design verifications (of pile foundations)

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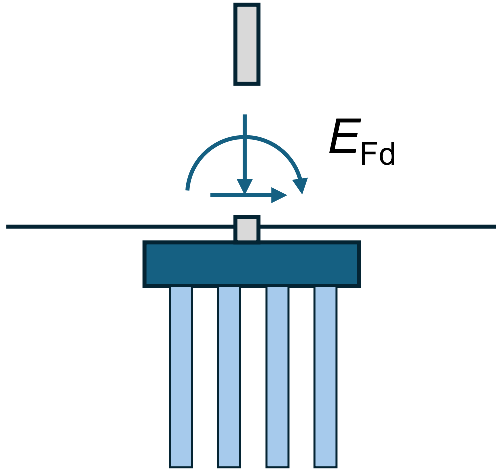
Analisi modale con spettro

FORCE-BASED
Verifica in **forze**

In a force-based approach, the lateral and vertical bearing capacity of the piled foundation should be verified against the ultimate ground resistance (…).

The design value of the action effects should be evaluated as in 9.2, using χ_H = 1.0 for the vertical bearing capacity and **the χ_H values in Table 9.2 for the lateral bearing capacity (…)**

← $\Omega_d\ \gamma_{Rd}$ = 1 if allowed to yield



- limitata plasticizzazione pali

Table 9.2 — Values of χ_H for piles under lateral loading

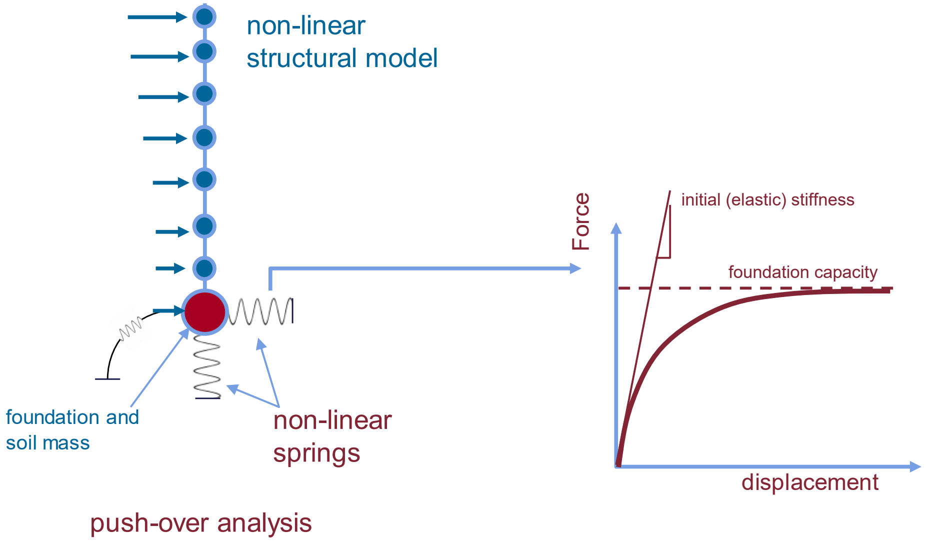
χ_H	1,25	1,5	1,75
Range of permanent displacements (mm)	≤ 15	> 20 to ≤ 50	> 50 to ≤ 100

NOTE Values of χ_H in Table 9.2 are calibrated for the recommended values of material factors and global resistance factors. Values of χ_H for other values of the material factors or global resistance factors are not provided in this standard.

Analisi statica non lineare

6.5 Non-linear static analysis

8. Soil-structure interaction
8.2.3.1 Nonlinear static analysis



(1) In nonlinear static analyses of surface or shallow foundations, **translational and rotational inelastic springs** may be used.

(2) When springs are not used, the lateral force-displacement relation of the soil-foundation system under large deformations may be calculated from a suitable nonlinear static analysis in which the ground is modelled as an inelastic continuum.

(4) Damping due to SSI may be considered with a damping correction applied to the elastic response spectrum (…)

6.6 Response-history analysis

8. Soil-structure interaction
8.2.3.2 Response-history analysis

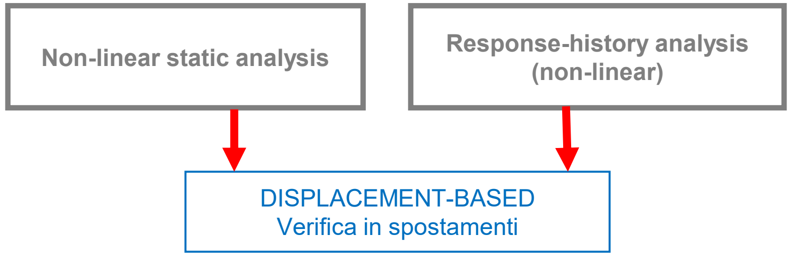
(1) The effect of inertial SSI in response-history analyses **may** be considered by modelling the soil-foundation system with **springs and dashpots** and applying the seismic input motion to the supports of the springs.

(2) A frequency-independent stiffness value may be assigned to each spring, corresponding to the period of the predominant mode accounting for SSI in the considered direction.

NOTE The frequency-dependence of the springs and dashpots can be modelled in response history analyses with lumped models composed of constant springs, dashpots and masses.

- analisi non-lineare con elementi di fondazione lineari?

Verifica fondazioni superficiali in spostamento



9. Foundation system Verifications

9.4. Surface and shallow embedded foundations

9.4.2.1.2 Sliding

(7) In a **displacement-based approach** at the SD or at the NC limit states, sliding may be accepted provided that the calculated displacements due to sliding satisfy both a) and b):

a) are acceptable for the superstructure;

b) do not adversely affect the performance of any lifelines connected to the structure.

Table 9.3 — Plastic hinge strain limits

Pile	In-ground plastic hinge location	Limit State		
		DL	SD	NC
Solid concrete	Hinge forms at depth ≤ 10 d	$\varepsilon_c \leq 0{,}005$ $\varepsilon_{sd} \leq 0{,}015$	$\varepsilon_c \leq (0{,}005+1{,}1\rho_s) \leq 0{,}008$ $\varepsilon_{sd} \leq 0{,}025$	$\varepsilon_c \leq (0{,}005+1{,}1\rho_s) \leq 0{,}025$ $\varepsilon_{sd} \leq 0{,}035$
	Hinge forms at depth > 10 d	$\varepsilon_c \leq 0{,}008$ $\varepsilon_{sd} \leq 0{,}015$	$\varepsilon_c \leq 0{,}012$ $\varepsilon_{sd} \leq 0{,}025$	ε_c no limit $\varepsilon_{sd} \leq 0{,}050$

9. Foundation system Verifications

9.5 Pile foundations

9.5.4 Design verifications

(12) In a displacement-based approach, the verification of the bearing capacity should be made in terms of displacement demands versus capacities of the piled foundation.

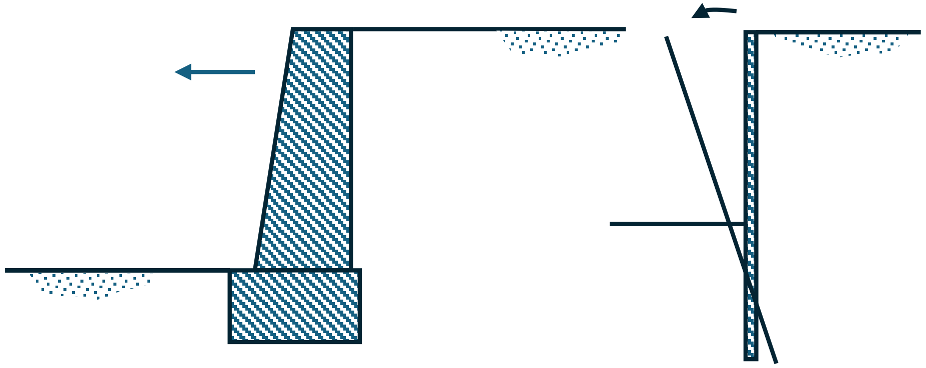
(13) In a displacement-based approach, the deformation capacity may be evaluated from the strain limits given in Table 9.3. For yielding concrete piles, 9.5.5 should be applied.

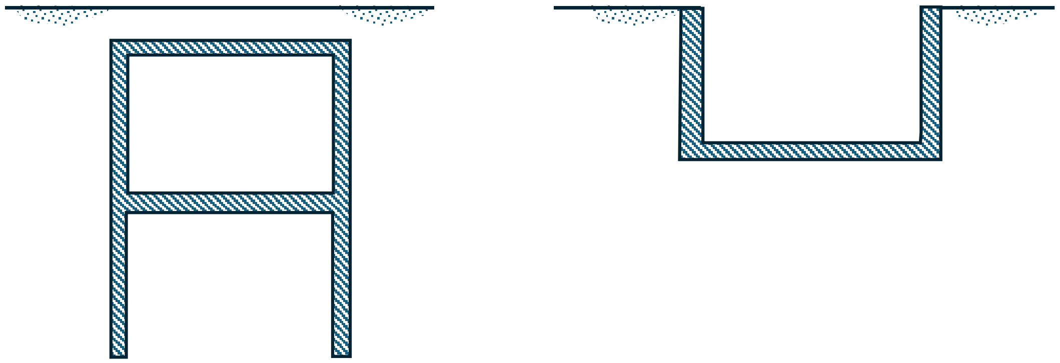
9.5.5 Detailing and minimum reinforcement ratio for reinforced concrete piles

Altre opere (geotechnical structures)

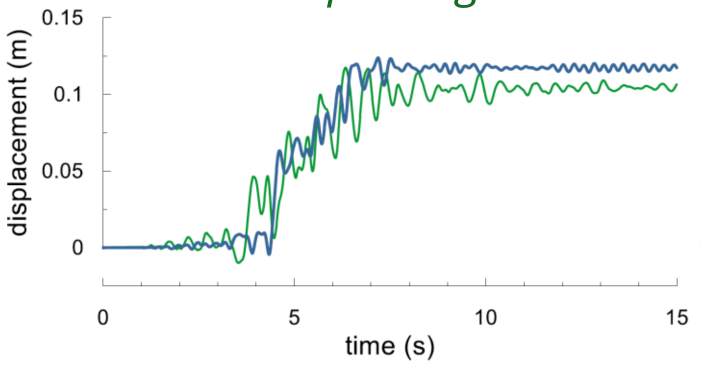
10. Earth retaining structures

- distinzione tra opere *displacing* e *non-displacing*
- *capacity design*: elementi strutturali sovra-resistenti

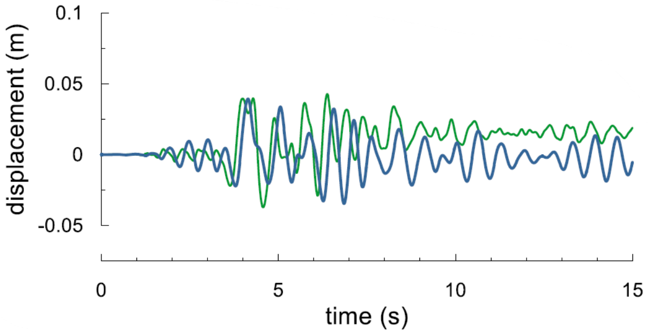




displacing

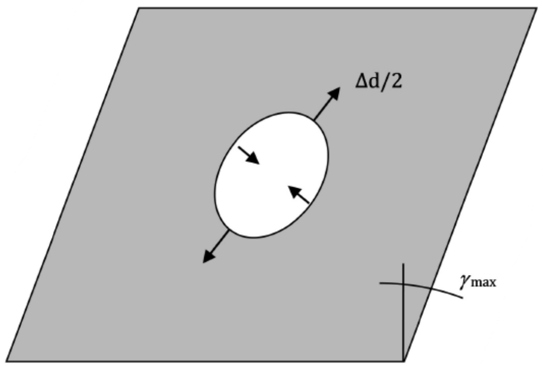


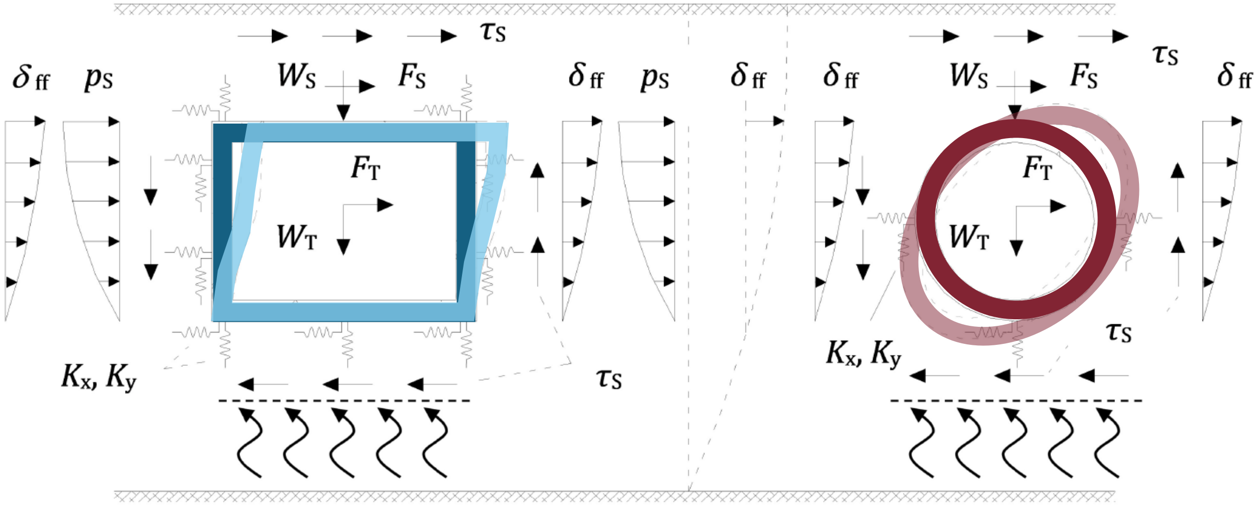
non-displacing



11. Underground structures

- calcolo delle sollecitazioni nei rivestimenti delle gallerie (analisi a spostamenti imposti)





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