

# **PÅLNING ENLIGT NYA EUROKOD – VAD ÄR NYTT?**

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# BAKGRUND

- + Idag finns ett utkast av prEN 1997-3 (geokonstruktioner)
  - + Clause 6: Piled foundations (pålad grundläggning)
  - + Vad får vi ändra:
    - + NDP (national determined parameters), i huvudsak tabellvärden:
      - Partialkoeff., Korrelationsfaktorer
      - Modellfaktorer
      - Övrig tabelltext (förklaringar, begränsningar o dyl)
      - Där det specificeras specifikt i en notering, t ex:

(12) The compressive resistance of an end-bearing pile in coarse soil or rock may be based on a pile driving formula provided the formula has previously been calibrated against the results of static load tests on comparable piles in comparable ground conditions, tested to comparable load levels.
- NOTE The National Annex can give other calibration procedures based on comparable experience.
- + Annex (informativa): kan vi avvisa, godkänna, göra normativa
- + Ändringar (NDP) arbetas fram av IEG och publiceras o fastställs i ett nationellt annex av Transportstyrelsen/Boverket

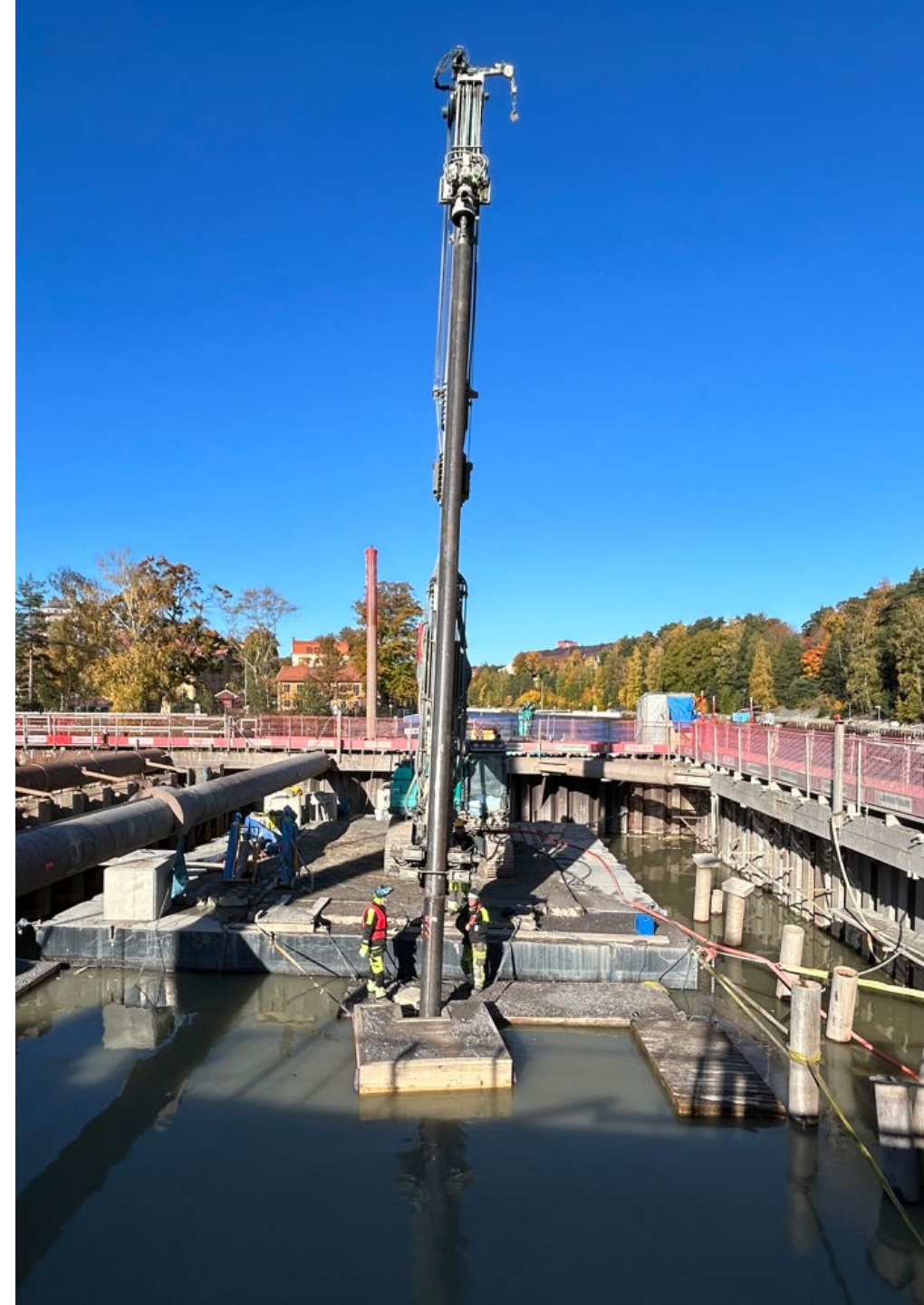
# PÅLDIMENSIONERING

## + Geoteknisk dimensionering

- + Provbelastning
- + Beräkning

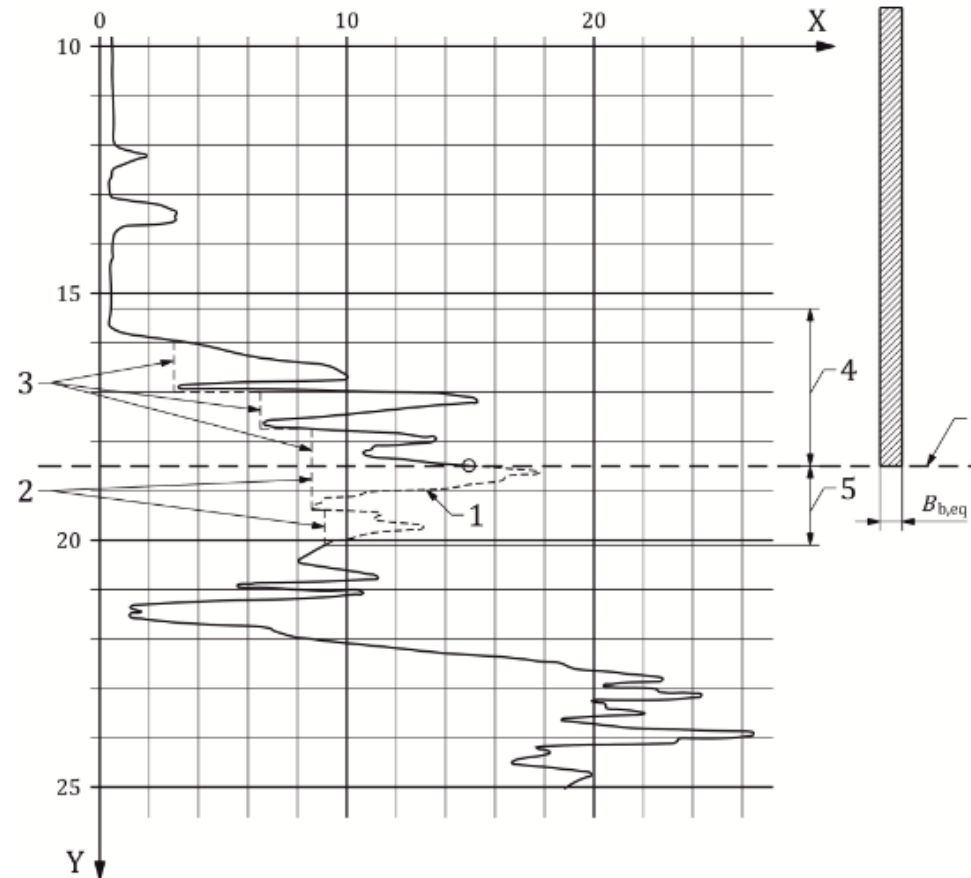
## + Konstruktiv dimensionering

- + Axialbelastning
- + Transversalbelastning

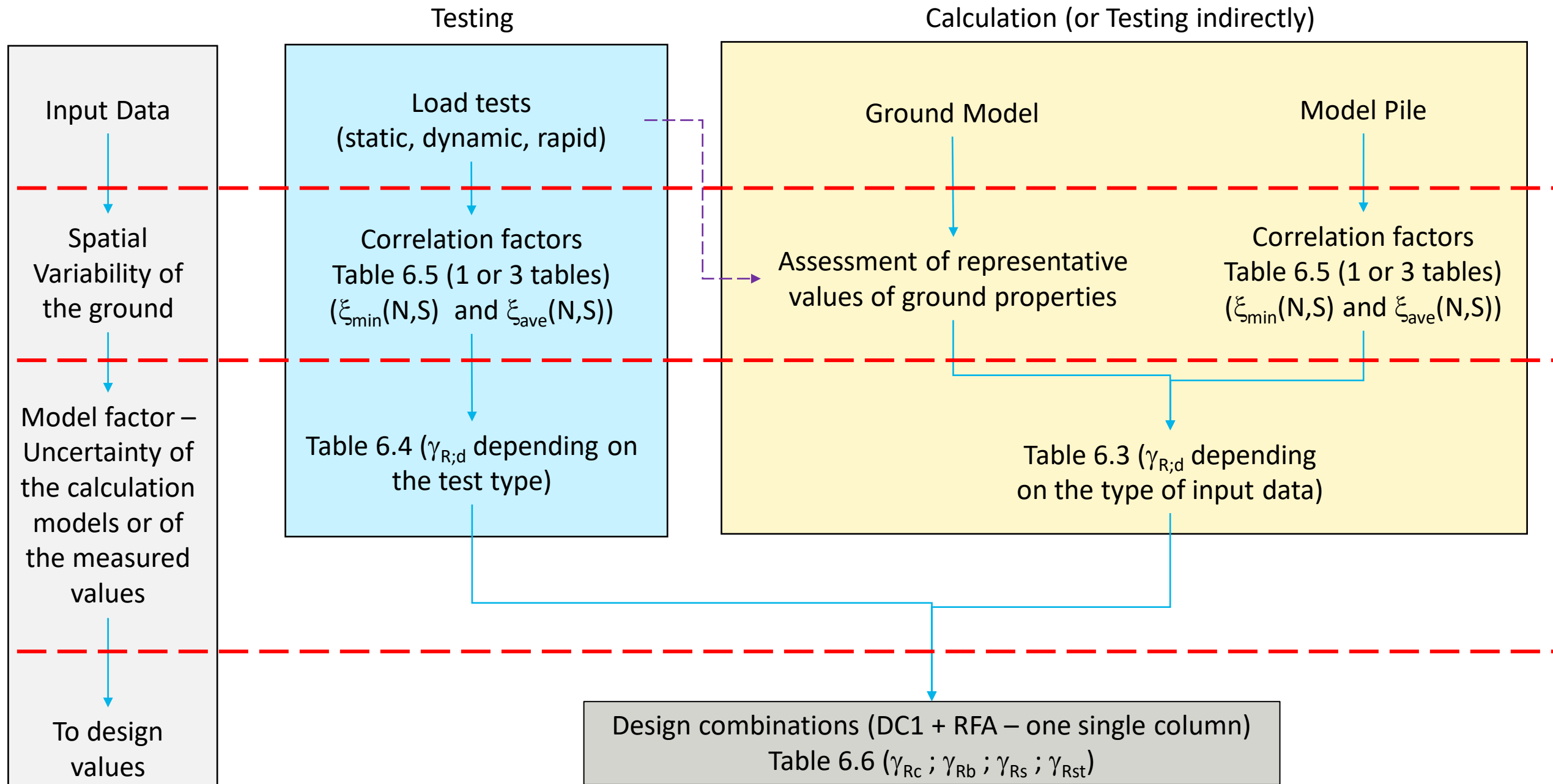


# GEOTEKNISK DIMENSIONERING

## RFA= RESISTANCE FACTOR APPROACH



# Verifications for axially loaded piles (EN 1997-3, Clause 6)



# BERÄKNING, GEOTEKNISK OCH KONSTRUKTIV DIMENSIONERING

Table 6.9 (NDP) — Partial factors for the verification of ultimate resistance of single piles for fundamental (persistent and transient) design situations – Ground Model Method

| Verification of              | Partial factor on                           | Symbol                        | Material factor approach (MFA) – both combinations |     | Resistance factor approach (RFA) |                         |
|------------------------------|---------------------------------------------|-------------------------------|----------------------------------------------------|-----|----------------------------------|-------------------------|
|                              |                                             |                               | (a)                                                | (b) | Pile class                       | Ground Model Method     |
| Axial compressive resistance | Actions; effects of actions <sup>a</sup>    | $\gamma_F$ and $\gamma_E$     | Not Used                                           |     | All                              | VC1                     |
|                              |                                             |                               |                                                    |     |                                  |                         |
|                              | Ground properties <sup>b</sup>              | $\gamma_M$                    |                                                    |     |                                  | Not factored            |
|                              | Base and shaft resistance in compression    | $\gamma_{Rb}$   $\gamma_{Rs}$ |                                                    |     |                                  |                         |
|                              |                                             |                               |                                                    |     | Full displacement                | Base: 1,2   Shaft: 1,05 |
|                              |                                             |                               |                                                    |     | Partial displacement             | 1,3   1,1               |
|                              |                                             |                               |                                                    |     | Replacement                      | 1,4   1,15              |
|                              |                                             |                               |                                                    |     | Unclassified                     | 1,5   1,25              |
|                              | Total resistance in compression             | $\gamma_{Rc}$                 |                                                    |     | Full displacement                | 1,1                     |
|                              |                                             |                               |                                                    |     | Partial displacement             | 1,2                     |
|                              |                                             |                               |                                                    |     | Replacement                      | 1,3 <sup>d</sup>        |
| Axial tensile resistance     | Actions; effects of actions <sup>a</sup>    | $\gamma_F$ ; $\gamma_E$       | Not Used                                           |     | All                              | VC1                     |
|                              | Ground properties <sup>b</sup>              | $\gamma_M$                    |                                                    |     |                                  | Not factored            |
|                              | Shaft resistance in tension                 | $\gamma_{Rst}$                |                                                    |     | Full displacement                | 1,2                     |
|                              |                                             |                               |                                                    |     | Partial displacement             | 1,25                    |
|                              |                                             |                               |                                                    |     | Replacement                      | 1,3                     |
|                              |                                             |                               |                                                    |     | Unclassified                     | 1,5                     |
| Transverse resistance        | Actions and effects of actions <sup>a</sup> | $\gamma_F$ ; $\gamma_E$       | VC4 or VC1                                         | VC3 |                                  | VC4 or VC1              |
|                              | Ground properties <sup>b</sup>              | $\gamma_M$                    | M1                                                 | M2  |                                  | Not factored            |
|                              | Transverse resistance                       | $\gamma_{Rtr}$                | Not factored                                       |     |                                  | 1,4                     |

VC = verification case

VC1:  $1,35G \cdot K_f$  och  $1,5Q \cdot K_f$

Förslag:

- VC1 och M2 (som idag)
- VC4 + M1 (FEM)

Se IEG rapport

# MODELFAKTORER VID BERÄKNING

Table 6.4 (NDP) — Model factor  $\gamma_{Rd}$  for verification of axial pile resistance by calculation

| Verification by                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Based on                                                                                  | Model factor $\gamma_{Rd}$ |                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|----------------------------|--------------------|
| Ground Model Method                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Ultimate Control Tests                                                                    | 1,15                       |                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Extensive <u>comparable</u> <sup>a,b</sup> experience without site-specific Control Tests | 1,3                        |                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Serviceability Control Tests                                                              | 1,35                       |                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | No pile load tests and limited comparable <u>experience</u> <sup>a,c</sup>                | 1,55                       |                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                           | Compressive resistance     | Tensile resistance |
| Model Pile Method                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Menard pressuremeter <sup>f</sup> test <sup>d</sup>                                       | 1,15                       | 1,4                |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Cone penetration test <sup>d</sup>                                                        | 1,1                        | 1,1                |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Profiles of ground properties based on field or laboratory <u>tests</u> <sup>d,e</sup>    | 1,2                        | 1,2                |
| <p><sup>a</sup> Comparable experience assumes documented records (or database) of static pile load test results conducted on similar piles, in similar ground conditions, under similar loading conditions from a certain number of sites <math>n</math>,<br/> <sup>b</sup> Extensive comparable experience assumes <math>n \geq 10</math><br/> <sup>c</sup> Limited comparable experience assumes <math>0 &lt; n &lt; 10</math><br/> <sup>d</sup> Value can be multiplied by 0.9 when accompanied by Ultimate Control Tests<br/> <sup>e</sup> Ground strength properties determined at least every 1,5 m along the vertical profile.<br/> <sup>f</sup> Value of the <u>modelfactor</u> correspond to the calculation method given in Annex C.7</p> |                                                                                           |                            |                    |

Inga  
korrelationskoefficienter

Med  
Korrelationskoefficienter

# MODELLFAKTORER IDAG (IEG TILLÄMPNINGSDOK.)

**Tabell 4.3** Modellosäkerheter för friktionspålar (GEO).

| Beräkningsmodell / provningsmetod                                                                           | Modellfaktorer |
|-------------------------------------------------------------------------------------------------------------|----------------|
|                                                                                                             | $\gamma_{Rd}$  |
| Geostatisk metod enligt API-RP-2A eller enligt Beta-koncept, se PKR <sup>5</sup> 103. (                     | 1,8            |
| Dimensionering baserad på CPT såsom LCPC-metoden och ICP-metoden, se PKR 103                                | 1,4            |
| Dimensionering av pålar baserad på SPT-resultat enligt Decourts-metod, se PKR 103                           | 1,7            |
| Statisk provbelastning                                                                                      | 1,0            |
| Dynamisk provbelastning utvärderad endast med CASE-metoden.                                                 | 1,2            |
| Dynamisk provbelastning med signalmatchning med CAPWAP-analys.                                              | 0,85           |
| Dragbelastning utvärderad från CAPWAP. Dessutom bör en reduktionsfaktor för dragbelastning på 0,7 användas. | 1,3            |
| Påslagningsformler                                                                                          | Tillåts ej     |
| Slagningssimulering (sk WEAP-analys)                                                                        | Tillåts ej     |
| Mantelburna stålkärnepålar utvärderade med wave-up metoden enligt PKR 106 avsnitt 7.6.1.                    | 0,85           |

# MODELFAKTOR VID PROVBELASTNING

| Verification by                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                  | Model factor $\gamma_{Rd}$ |               |                        |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|----------------------------|---------------|------------------------|--|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                  | Fine soils                 | Coarse soils  | Rock mass <sup>c</sup> |  |
| Static load tests                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                  | 1,0                        | 1,0           | 1,0                    |  |
| Rapid load tests (multiple load cycles) <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                  | 1,4                        | 1,1           | 1,2                    |  |
| Rapid load tests (single load cycle) <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                  | 1,4                        | 1,1           | 1,2                    |  |
| Dynamic impact tests (signal matching) <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Shaft resistance | 1,5                        | 1,1           | 1,2                    |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | End resistance   | 1,4                        | 1,25          | 1,25                   |  |
| Dynamic impact tests (multiple blow) <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Shaft resistance | 1,5                        | 1,1           | 1,2                    |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | End resistance   | 1,4                        | 1,2           | 1,2                    |  |
| Dynamic impact tests (closed form solutions) <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Shaft resistance | Not permitted              | Not permitted | Not permitted          |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | End resistance   | Not permitted              | 1,3           | 1,3                    |  |
| Wave equation analysis                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                  | Not permitted              | 1,6           | 1,5                    |  |
| Pile driving formulae                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                  | Not permitted              | 1,8           | 1,7                    |  |
| <p><sup>a</sup> When dynamic impact tests or rapid load tests are not calibrated by site-specific static load testing, but by comparable experience only (see Table 6.4 (NDP)), the values for <math>\gamma_{Rd}</math> are increased by::</p> <p>+0,1 when calibration is based on extensive comparable experience;</p> <p>+0,25 when calibration is based on limited comparable experience.</p> <p><sup>b</sup> When dynamic impact tests or rapid load tests are carried out on cast-in-place piles, the values for <math>\gamma_{Rd}</math> are increased by 0,2</p> <p><sup>c</sup> If the test results demonstrate an elastic behaviour without any significant permanent movement, the model factors can be decreased by 0,1 as long as the model factor remains greater than or equal to 1,0.#</p> |                  |                            |               |                        |  |

# DIMENSIONERING PROVNING -JÄMFÖRELSE

$$R_d = \frac{R_m}{\gamma_R \cdot \gamma_{Rd} \cdot \xi}$$

|                                          |                              |                    |
|------------------------------------------|------------------------------|--------------------|
| Spetsburen slagen påle, sjunkning < 2 mm |                              |                    |
| CASE-metoden, 3 st mätta                 |                              |                    |
|                                          | <b>Idag (nationellt val)</b> | <b>Eurokod 2.0</b> |
| Partialkoeff.                            | 1,2                          | 1,1                |
| Modellfaktor                             | 0,85                         | 1,3-0,1+0,1=1,3    |
| Korrelationskoeff.                       | 1,6                          | 1,32               |
| <b>Totalsäkerhet på bärförmåga</b>       | <b>1,63</b>                  | <b>1,89</b>        |

+0,1 ingen korrelation med statiskt provbelastning  
-0,1 liten sjunkning (ej mobiliserad bärförmåga)

Table 6.8 (NDP) — Correlation factors for design by testing with rapid load or dynamic impact test

| Correlation Factor <sup>a</sup> | Correlation Factor <sup>b</sup> | Number of tests |      |      |      |      |      |      |      |
|---------------------------------|---------------------------------|-----------------|------|------|------|------|------|------|------|
|                                 |                                 | 1               | 2    | 3    | 4    | 5    | 7    | 10   | ≥ 20 |
| Rapid load test                 | $\xi_{mean}$                    | 1,4             | 1,36 | 1,32 | 1,29 | 1,28 | 1,25 | 1,23 | 1,19 |
|                                 | $\xi_{min}$                     | 1,4             | 1,28 | 1,23 | 1,19 | 1,15 | 1,13 | 1,1  | 1,06 |
| Dynamic impact test             | $\xi_{mean}$                    | 1,4             | 1,36 | 1,32 | 1,29 | 1,28 | 1,25 | 1,23 | 1,19 |
|                                 | $\xi_{min}$                     | 1,4             | 1,28 | 1,23 | 1,19 | 1,15 | 1,13 | 1,1  | 1,06 |

<sup>a</sup> If all piles in a group are tested, use  $\xi_{mean} = 1,0$  provided load can be transferred through the pile cap. For individually tested piles, use  $\xi_{mean} = \xi_{min} = 1,0$ .

<sup>b</sup> The correlation factors given are based on a coefficient of variation of pile load test results of 12 %.

från dynamiska provbelastningar (n = antal provade pålar)

| $\xi$ för n | 3 <sup>8</sup> | 4    | ≥ 5  | ≥ 10 | ≥ 15 | ≥ 20 | ≥ 40 | Samtliga pålar |
|-------------|----------------|------|------|------|------|------|------|----------------|
| $\xi_5$     | 1,60           | 1,55 | 1,50 | 1,45 | 1,42 | 1,40 | 1,35 | 1,30           |
| $\xi_6$     | 1,50           | 1,45 | 1,35 | 1,30 | 1,25 | 1,25 | 1,25 | 1,25           |

# BERÄKNINGSMODELLER I ANNEXET (INFORMATIVT)

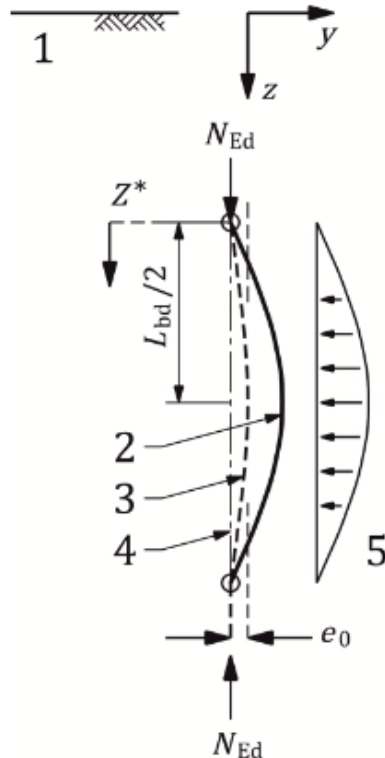
- + Klassificering mht massundanträngning
- + Spets- resp mantelmotstånd baserad på jord och bergparametrar
- + Bärförmåga från CPT
- + Bärförmåga från Menard pressometer
- + Bärförmåga för grävpålar från empiriska tabellvärden
- + **Påhängslast, rigorös och förenklat betraktelsesätt**
- + Pålgrupper utsatta för axiellt drag
- + Sättning av enskild påle med last-förskjutnings-funktioner
- + **Transversell deformation av enskild påle med last-förskjutnings-funktioner (används även för knäckning)**
- + Bärförmåga vid cyklisk belastning

Table C.1 — Examples of piles in different classes

| Pile type          | Class             | Example                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Displacement piles | Full displacement | Driven cast-in-place concrete piles<br>Solid section precast concrete piles<br>Driven closed-ended tubular steel piles<br>Driven closed-ended tubular precast concrete piles<br>Driven open-ended tubular steel piles (plugged)<br>Driven open-ended tubular precast concrete piles (plugged)<br>Driven steel H-section piles (plugged)<br>Micropiles<br>Driven timber piles<br>Cast-in-place concrete screw piles |

# KONSTRUKTIV DIMENSIONERING

## MFA= MATERIAL FACTOR APPROACH

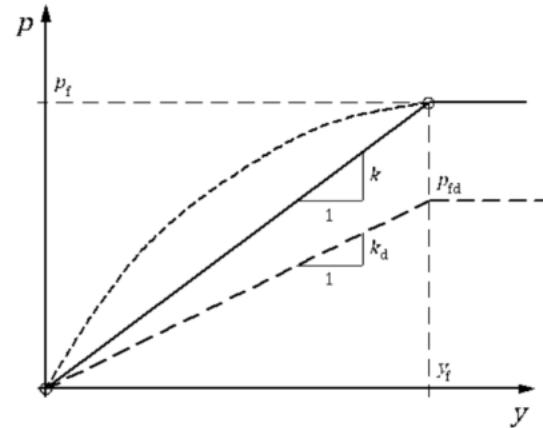


- (5) For structural resistance of a fully embedded pile subjected to compression should be verified by **theory of second order** when it has a high slenderness ratio ( $\lambda$ ), or a high ratio of design axial load to the critical buckling load ( $N_{Ed}/N_{cr}$ ).

**Beräkningsmodell finns i Annexet (informativt)**

# JORDMODELL SOM IDAG MEN...

NOTE Figure C.8 illustration of the bilinear model for transversely loaded piles.



Dimensionerande värde på  
gränstrycket ( $6c_{ud}$  eller  $9c_{ud}$ )

## Key

- $y$  transverse deflection of the pile
- $p$  lateral pressure
- $p_f$  lateral pressure of the ground at failure

Fast värde på  
gränsutböjningen, t ex  $0,12 \cdot B$

(4) To account for limited soil resistance close to the ground surface  $p_{f,d}$  may be determined from:

$$p_{f,d} = c_{ud} \cdot \left( 2 + \frac{2}{3} \cdot \frac{z}{B} \right) + \sigma'_z \quad (C.18)$$

# GRÄNSUTBÖJNING, ERFARENHETSVÄRDEN

Table C.11 — Values of transverse displacement  $y_f$ .

| Soil conditions                | $y_f$    |
|--------------------------------|----------|
| Coarse soils                   | $0,1 B$  |
| Fine soils, long-term loading  | $0,12 B$ |
| Fine soils, short-term loading | $0,05 B$ |

← Nytt

← 0,045B idag

# NY JORDMODELL, FRIKTIONSJORD (DRÄNERAT FALL)

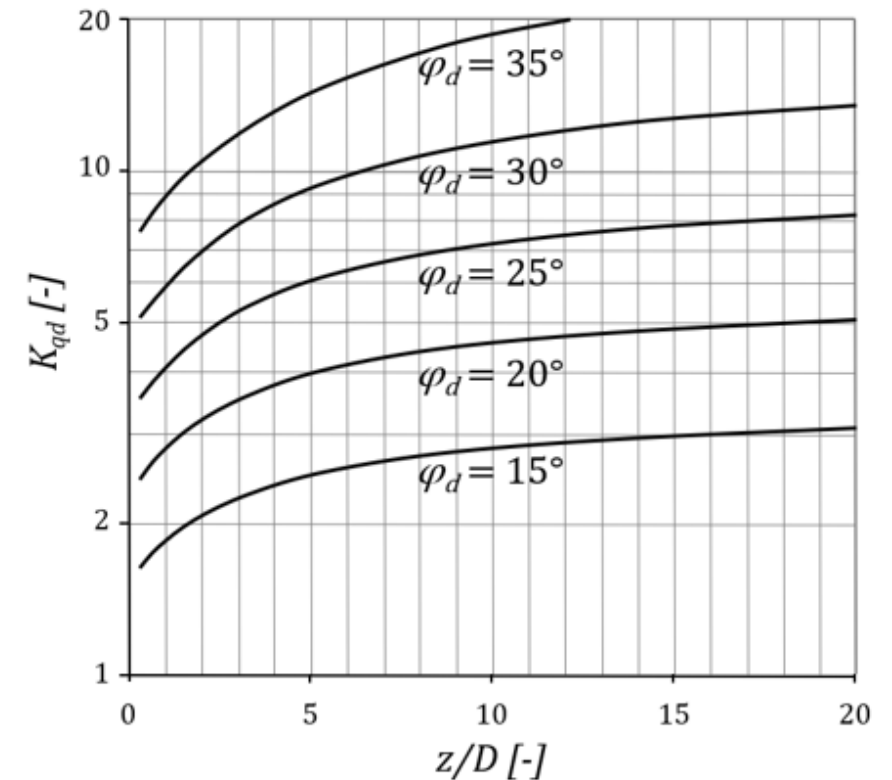
## C.12.3 P-y curves from drained soil properties

- (1) For drained soil conditions the ultimate transverse ground resistance may be determined using formula (C.17)

$$p_{fd} = K_{qd} \cdot \sigma'_z + K_{cd} \cdot c'_d$$

where

|                  |                                                                        |
|------------------|------------------------------------------------------------------------|
| $p_{fd}$         | is the design lateral pressure of the ground at failure;               |
| $c'_d$           | is the design effective cohesion of the ground;                        |
| $\sigma'_z$      | is the effective vertical stress of the soil at the depth $z$ ;        |
| $K_{qd}, K_{cd}$ | are coefficients for calculation the ultimate drained soil resistance. |



# BERÄKNINGSMODELL, SKILLNADER MOT IDAG

- + Finns ingen beräkningsmodell för knäckning i jord i nuvarande Eurokod, bara att det inte behövs kontrolleras om  $c_u > 10$  kPa
- + I nya Eurokod: gränser när man inte behöver kontrollera enligt 2a ordningen, baserat på slankhetstalet, eller för stål  $N_{ed}/N_{cr} > 0,1$
- + I övrigt är beräkningsmodellen identisk med hur vi gör i idag.
- + Det finns dock ingen beräkningsmodell för att hantera ekvivalent bäddmodul när vi överskrider gränstöjningen  $y_f$
- + Detta tillåts däremot om bäddmodulet ger ekvivalent sidomotstånd längs knäcklängden (detta är också det nya sättet som föreslås i PK 108)

# BERÄKNINGSMODELLEN

## KÄNDA FORMLER, NÅGOT OMSKRIVNA BARA:

+ Dimensionerande knäcklast:  $N_{b,Rd} = N_{cr,d} \left( \frac{y_f}{y_f + e_{0d}} \right) = 2 EI \frac{\pi^2}{L_{bd}^2} \left( \frac{y_f}{y_f + e_{0d}} \right)$

+ Knäcklängd:  $L_{bd} = \pi \cdot \sqrt[4]{\frac{EI}{k_d \cdot B}}$

+ Sidoutböjning orsakad  $E_d$ :  $y = \frac{N_{Ed}}{N_{cr,d} - N_{Ed}} e_{0d}$

+ Momentet i pålen:  $M_{N,Ed} = N_{Ed} \cdot \frac{e_{0d} + y}{2} = \frac{N_{Ed} e_{0d}}{2 \left( 1 - \frac{N_{Ed}}{N_{cr,d}} \right)}$

+ Max last mht till stukning (Iteration):  $N_{Ed,lim} = \frac{N_{cr,d}}{1 + \frac{N_{cr,d} \cdot e_{0d}}{2 M_{N,Rd}}}$

# ANTAGNA INITIALKROKIGHETER EFTER INSTALLATION

Table C.13.1 (NDP) — Design values of initial deflection  $e_{0d}$

| Pile type                                                | no joints    | one joint <sup>a</sup> |
|----------------------------------------------------------|--------------|------------------------|
| bored (drilled) steel and composite steel-concrete piles | $L_{bd}/400$ | $L_{bd} / 200$         |
| driven steel and composite steel-concrete piles          | $L_{bd}/300$ | $L_{bd} / 150$         |
| precast concrete piles                                   | $L_{bd}/300$ | $L_{bd} / 150$         |
| cast-in-place concrete piles                             | $L_{bd}/150$ |                        |
| timber piles                                             | $L_{bd}/100$ | $L_{bd} / 50$          |
| <sup>a</sup> within the buckling length                  |              |                        |

# SLUTORD

- + Sista utkastet av EN1997-1,2 och 3 klart och interngranskat, dec 2023
- + Omröstning hos medlemsstater, fastställd 2026?
- + Mycket arbete återstår för NDP inom IEG (tillämpningsdokument)
- + Boverket och Transportstyrelsen tar fram nationella annex (NDP)- Ett annex?
- + 2028 är senast Eurokod + nationell bilaga ska vara implementerad och gällande i Sverige
- + Det är ändringar i alla eurokoder, men mest i EN1997