Baltic Piling Days 2012

Safety Concepts and Dynamic Pile Load Tests

Dr.-Ing. Oswald Klingmüller
Chairman of the German Committee for Dynamic Pile Testing
Subcommittee to the German Piling Committee of the German Geotechnical Society

GSP
Gesellschaft für Schwingungsuntersuchungen und dynamische Prüfmethoden mbH Mannheim
www.gsp-mannheim.de ok@gsp-mannheim.de
Representative of PDI for the German speaking Countries and Benelux

EC7

7.4.1 Design methods

- the results of dynamic load tests whose validity has been demonstrated by static load tests in comparable situations;

7.5.3 Dynamic load tests

(1) Dynamic load tests may be used to estimate the compressive resistance provided an adequate site investigation has been carried out and the method has been calibrated against static load tests on the same type of pile, of similar length and cross-section, and in comparable soil conditions, (see 7.6.2.4 to 7.6.2.6).

7.6.2.4 Ultimate compressive resistance from dynamic impact tests

(1)P Where a dynamic impact (hammer blow) pile test [measurement of strain and acceleration versus time during the impact event (see 7.5.3(1))] is used to assess the resistance of individual compression piles, the validity of the result shall have been demonstrated by previous evidence of acceptable performance in static load tests on the same pile type of similar length and cross-section and in similar ground conditions.

EC7

7.6.2.5
Ultimate compressive resistance by applying pile driving formulae

(2)P If pile driving formulae are used to assess the ultimate compressive resistance of individual piles in a foundation, the validity of the formulae shall have been demonstrated by previous experimental evidence of acceptable performance in static load tests on the same type of pile, of similar length and cross-section, and in similar ground conditions.

7.6.2.6 Ultimate compressive resistance from wave equation analysis

(2)P Where wave equation analysis is used to assess the resistance of individual compression piles, the validity of the analysis shall have been demonstrated by previous evidence of acceptable performance in static load tests on the same pile type, of similar length and crosssection, and in similar ground conditions.

Correlation factors ξ

EN 1997-1:2004 (E)

Table A.11 - Correlation factors ξ to derive characteristic values from dynamic impact tests (*n* - number of tested piles)

ξ for *n* =	≥ 2	≥ 5	≥ 10	≥ 15	≥ 20
ξ_5	1,60	1,50	1,45	1,42	1,40
ξ_6	1,50	1,35	1,30	1,25	1,25

a The ξ-values in the table are valid for dynamic impact tests.

b The ξ-values may be multiplied with a model factor of 0,85 when using dynamic impact tests with signal matching.

c The ξ-values should be multiplied with a model factor of 1,10 when using a pile driving formula with measurement of the quasi-elastic pile head displacement during the impact.

d The ξ-values shall be multiplied with a model factor of 1,20 when using a pile driving formula without measurement of the quasi-elastic pile head displacement during the impact.

e If different piles exist in the foundation, groups of similar piles should be considered separately when selecting the number n of test piles.

EC7 – implicit hierarchy of testing and evaluation methods with respect to assumed reliablility

Dynamic Impact Tests

1. **Driving formula**
2. **Driving formula with measured elastic deformation**
3. **Wave equation analysis (of blow count)**

Dynamic Impact Load Test (measurements at pile top required)

4. **Evaluation by closed formula based on wave equation (e.g. CASE) utilizing empirical value for the damping**
5. **Evaluation by modeling of the pile in the soil by signal matching (e.g. CAPWAP), determination of skin friction distribution**

German National Application Document

Correlation factors : $\xi_i = (\xi_{o,i} + \Delta\xi) \cdot \eta_D$

Correlation factors $\xi_{o,i}$ and model factors η_D according to table A7.2

Calibration increase $\Delta\xi$ acc. to A7.2 in GNAD:

– $\Delta\xi$ = 0: calibration of dynamic load tests by static load tests on same site;

– $\Delta\xi$ = 0,10: calibration of dynamic load tests by static load tests on comparable site;

– $\Delta\xi$ = 0,40 calibration of dynamic load tests by static load tests on comparable site; only signal matching procedures applicable

Equivalent Global Safety Factors for Signal Matching (CAPWAP®)

Load factor : 1,35 for permanent load, 1,5 for variable load
Average 1,4 for factored action

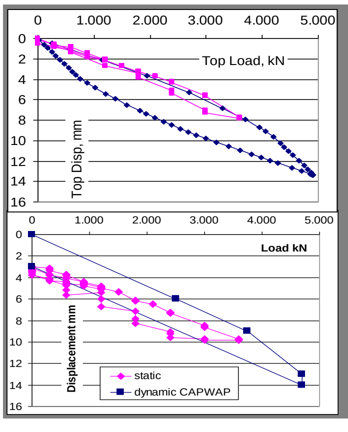
Resistance factor γR = 1,1 acc. to tables A6 to A8 of EC7

Minimum

γ = (1,25 + 0,0) * 0,85 * 1,1 * 1,4 = **1,63**

Maximum

γ = (1,60 + 0,4) * 0,85 * 1,1 * 1,4 = **2,62**



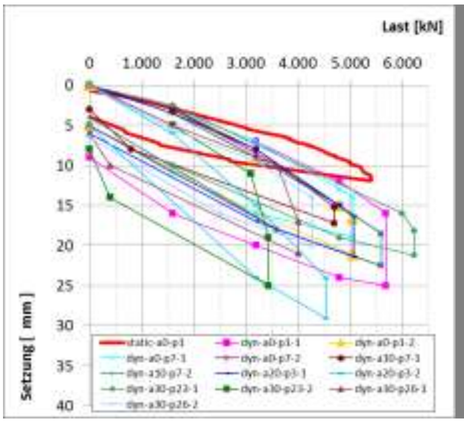
Correlation of static and dynamic pile load test

load settlement diagramms

precast concrete piles

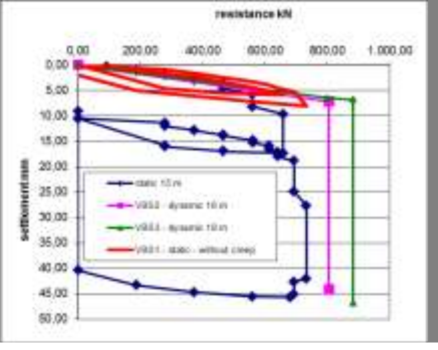
dense sand

L = 16 m

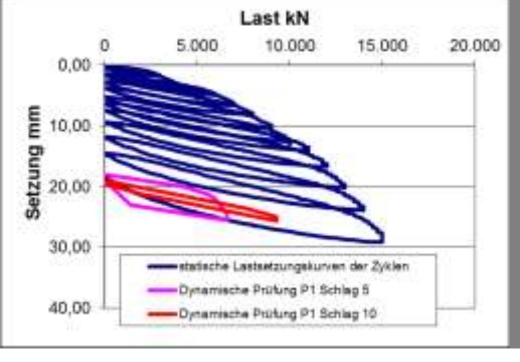


Ikpa steel closed end

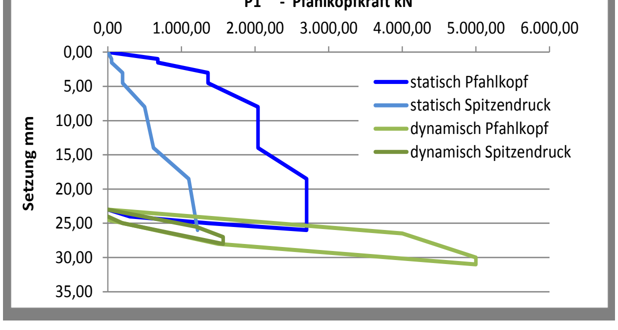
Test piles in soft clay (lake shore)



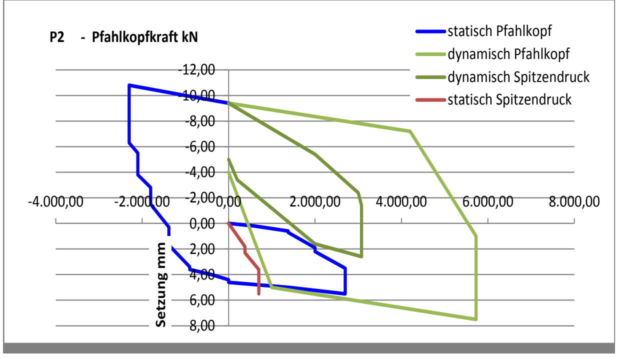
Test piles in hard clay



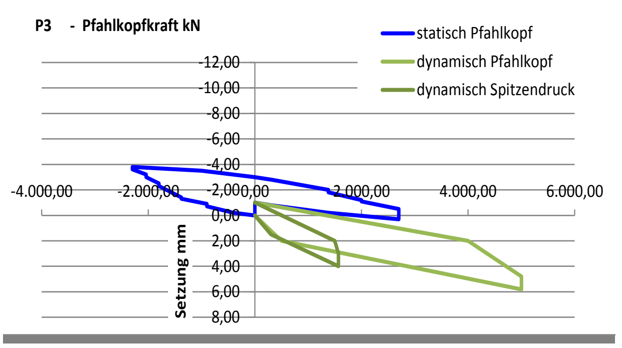
Case study 3 cast-in-place-piles



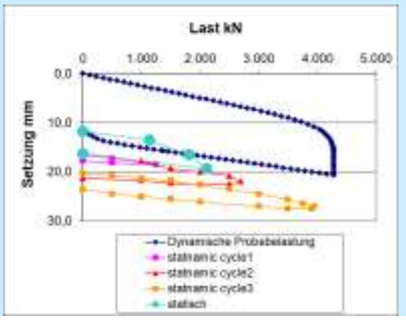
Case study 3 cast-in-place-piles



Case study 3 cast-in-place-piles



comparison dynamic load test static load test - statnamic load test



Offshore – wind energy

project areas in German parts of North Sea and Baltic Sea

requirements
- Dynamic load tests at > 10 % of piles
- mininum 2 at each geological situation
- Restrike-Tests recommended

Offshore – wind energy

- *first activity 2005*
- *no enforcement of testing by authorities*
- *monitoring not done because of bad wheather condition*

Dynamic Pile test for Offshore Wind Turbines

2005 : cabled sensors

Since 2010 wireless

Dynamic Pile test for Offshore Wind Turbines

Underwater sensors

Dynamic Pile test for Offshore Wind Turbines

Requirements of BSH since 2011

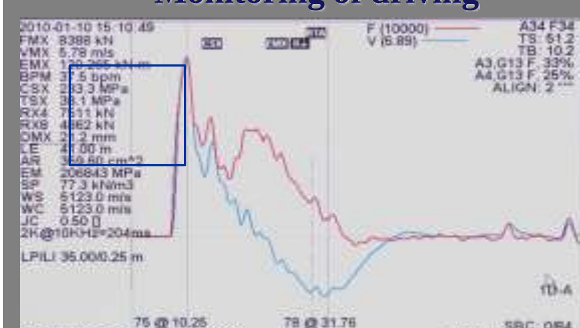
(federal office for sea traffic and hydrology)

Dynamic test of axially loaded piles

Instead of calibration at static tests for piles in glacial sand a $\Delta\xi = 0{,}1$ is allowed

Monopiles: Monitoring may be required for verification of stress and fatigue

Monitoring of driving



Monitoring of driving

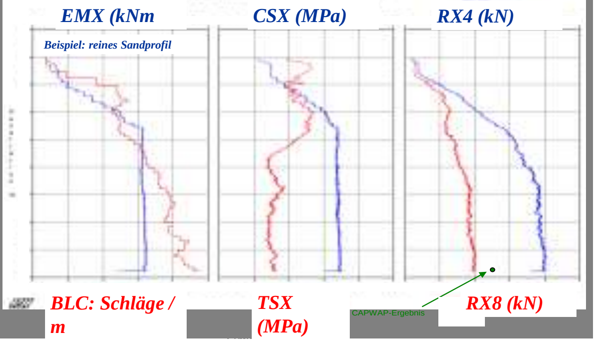
EMX – applied energy - control of hammer performance

CSX – max compression stress in sensor level
TSX – max tension stress in sensor level
verification of fatigue and lifetime
required by regulations

RX4 – upper bpound of resistance
RX8 – lower bound of resistance
control of driving formula

Dynamische Probebelastung - Windpark BARD Offshore 1

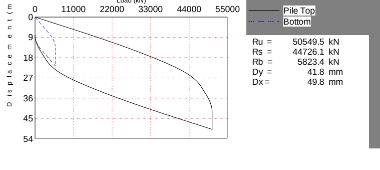
Erweiterte Rammprotokolle – über Einbindung oder



Result of signal matching
Modeling of pile in the soil

RU – ultimate capacity
RS – total skin friction
RT – tip resistance

Load settlement graph



GSP

Gesellschaft für Schwingungsuntersuchungen und dynamische Prüfmethoden mbH Mannheim
consultants for vibration analysis and dynamic testing methods

Dynamic pile load tests - onshore and offshore, driven and cast-in-place
Driveability analysis
„Low-Strain“ Integrity testing
Deep foundation conultancy

Vibration measurements and analysis

GSP
Managing director: Dr.-Ing. Oswald Klingmüller
Steubenstr. 46 • 68163 Mannheim
Telefon 0049 621 / 33 13 61 • Fax 0049621 / 34 35 8
www.gsp-mannheim.de • ok@gsp-mannheim.de
Representative of Pile Dynamics Inc., Cleveland, Ohio
(www.pile.com)