



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Development of the Load-Deformation Curve for Bridge Piers Subjected to Ship Impact

Feld, Tove

Publication date:
1999

Document Version
Early version, also known as pre-print

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Feld, T. (1999). *Development of the Load-Deformation Curve for Bridge Piers Subjected to Ship Impact*. Geotechnical Engineering Group. AAU Geotechnical Engineering Papers : Foundation Engineering Paper Vol. R 9902 No. 13

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- ? Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- ? You may not further distribute the material or use it for any profit-making activity or commercial gain
- ? You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Development of the load-deformation curve for bridge piers subjected to ship impact

T. Feld

June 1999

Foundation Engineering Paper No 13



**GEOTECHNICAL ENGINEERING GROUP
AALBORG UNIVERSITY DENMARK**

Feld, T. (1999). Development of the load-deformation curve for bridge piers subjected to ship impact.

AAU Geotechnical Engineering Papers, ISSN 1398-6465 R9902.

Foundation Engineering Paper No 13

The paper has been published in *Proc. XII Eur. Conf. Soil Mech. Geotechn. Eng.* 7-10 June 1999, Vol. 1, pp. 737-742.

© 1999 AAU Geotechnical Engineering Group.

Except for fair copying, no part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the Geotechnical Engineering Group.

Papers or other contributions in AAU Geotechnical Engineering Papers and the statements made or opinions expressed therein are published on the understanding that the author of the contribution is solely responsible for the opinions expressed in it and that its publication does not necessarily imply that such statements or opinions are or reflect the views of the AAU Geotechnical Engineering Group.

The AAU Geotechnical Engineering Papers - AGEP - are issued for early dissemination and book keeping of research results from the Geotechnical Engineering Group at Aalborg University (Department of Civil Engineering). Moreover, the papers accommodate proliferation and documentation of field and laboratory test series not directly suited for publication in journals or proceedings.

The papers are numbered ISSN 1398-6465 R<two digit year code><two digit consecutive number>. For internal purposes the papers are, further, submitted with coloured covers in the following series:

Series	Colour
Laboratory testing papers	sand
Field testing papers	grey
Manuals & guides	red
Soil Mechanics papers	blue
Foundation Engineering papers	green
Engineering Geology papers	yellow
Environmental Engineering papers	brown

In general the AGEP papers are submitted to journals, conferences or scientific meetings and hence, whenever possible, reference should be given to the final publication (journal, proceeding etc.) and not to the AGEPPaper.

Development of the load-deformation curve for bridge piers subjected to ship impact

Développement de la courbe charge-déformation pour des piles du pont exposés à la collision du navire.

T. Feld
RAMBØLL, Copenhagen, Denmark

Keywords: Bridge, ship impact, load-deformation, piers, pile groups

ABSTRACT: On behalf of the Danish Ministry of Traffic a number of existing bridges in Denmark, have been examined against ship impacts. Several bridge piers were supported by pile groups, and part of the analysis was to determine the load-deformation curve for the piers, adjusting for pile group effect, partly mobilized earth pressure, the withhold of the bridge and applying plasticity theory. The establishment of the load-deformation curve at two different locations, respectively wood and concrete piles, using a PC-version of a non-linear structural program, is presented in this paper.

RESUME: Au nom du Ministère des Transports un nombre de ponts existants au Danemark ont été examinés considérant des collisions du navire. Plusieurs des piles du pont étaient appuyés par des groupes de piles, et une partie de l'analyse était exécutée pour déterminer la courbe charge-déformation pour les piles, adaptée à l'effet de la groupe de piles, pression des terres partiellement mobilisée, la raideur du pont et la théorie de plasticité en vigueur. L'établissement de la courbe charge-déformation sur deux localités différentes, des piles en bois et en béton, respectivement, utilisant une version PC d'un programme structural non linéaire, est présenté dans le present papier.

1 BASIS FOR INVESTIGATIONS

Prior to 1964 bridges in Denmark were not required by the Danish Codes to be examined in the design to withstand ship impact. In 1996 the Danish Ministry of Traffic started an investigation round, examining existing bridges in Denmark, towards their capacity in case of ship impacts or different iceloads. Several bridges were supported or partly supported by pile groups.

Two bridges in the southern part of Denmark, Svendborg Sound Bridge and the Langeland Bridge, see Figure 1, were picked for a more detailed analysis.

1.1 *The Langeland Bridge, across the Rudkøbing Channel*

The work on the Langeland Bridge was initiated in spring 1960 and the bridge was open for traffic in November 1962. The bridge is an arched concrete bridge, 774 m long, with abutments on both sides 425 m and 560 m long respectively. Due to findings of plastic clay, a number of the bridge piers were placed on piles.

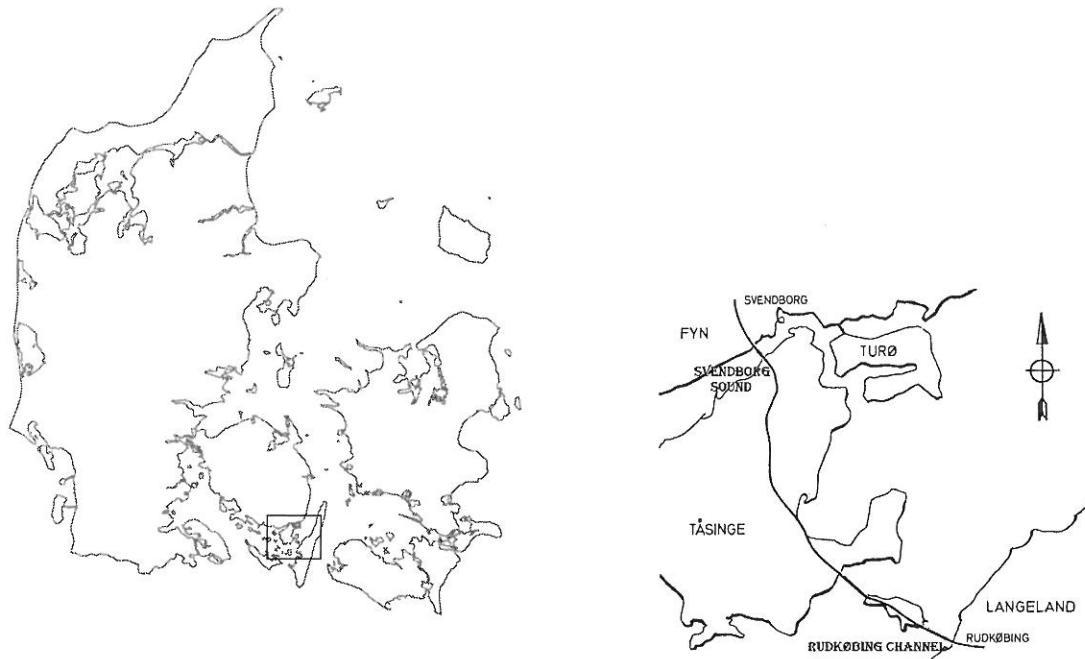


Figure 1. Location of the Svendborg Sound and Rudkøbing Channel

1.2 *The Svendborg Sound Bridge*

Svendborg Sound Bridge is a 1220 m long concrete suspension bridge, with girders resting on slender piers, to obtain an elegant structure that would dictate the landscape as little as possible.

The geological profile and the bridge being several times statically undetermined, lead to a foundation of the bridge, where one side of the bridge is directly founded on the clay till, the other side placed on piled foundations from this point forward, only the piled solution will be dealt with.

2 SOIL PROFILES

For each of the bridges, the original geotechnical investigations were revisited, and a design profile for the most critical piers was created, the profiles are shown in Figures 2 and 3.

The design soil profile with characteristic soil parameters forms the basis for all analyses: ULS, SLS and ALS. The ship impact analysis would range as an ALS (Accidental Limit State), where the settlement analysis would be characterized as SLS (Serviceability Limit State).

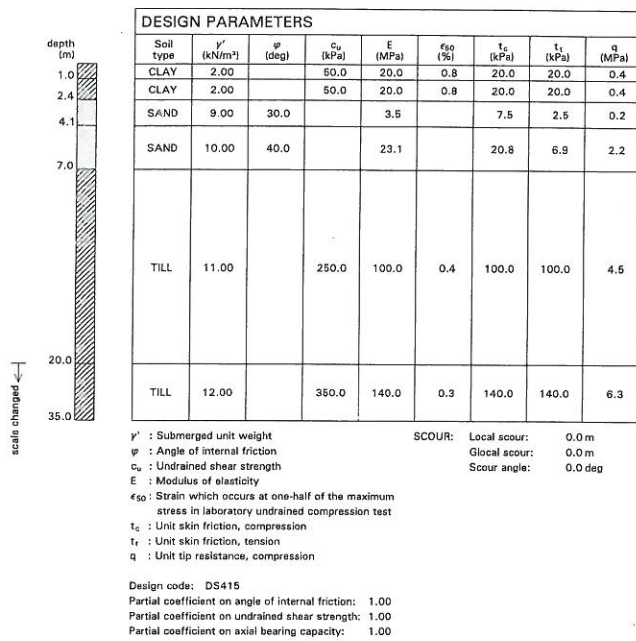


Figure 2. Characteristic Design Soil Profile, Svendborg Sound Bridge

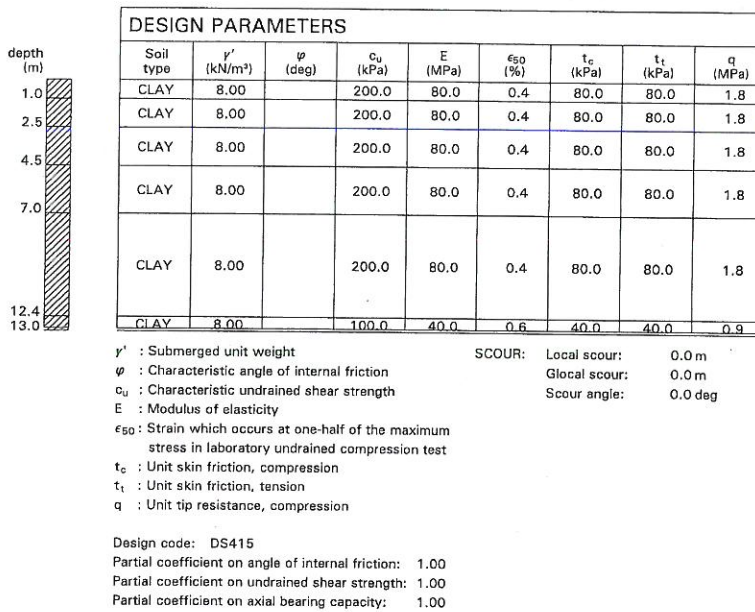


Figure 3. Characteristic Design Soil Profile, Langeland Bridge, across the Rudkøbing Channel

3 PILES

The timber piles used at the Langeland bridge, are Danish Pine with a mean diameter of 36 cm. In the model the piles are models as circular wooden piles with a diameter of 360 mm.

4.2 Loads and corrections influencing the model

The interaction between the piles, corresponding to a distance of 6 times the pile diameter, was accounted for. When a fully activated passive earth pressure, corresponding to a deformation of 1% of the foundation wall height (at approx. 15 mm deformation), occurred the model was corrected for an earth pressure resultant acting on the front of the foundation.

The model was loaded for dead weight of the bridge structure and a load acting at the point of the ship impact, dealing with directions, seabed locations etc. This ship impact was increased stepwise and a load-deformation curve was established. In Figure 6 the load-deformation curve is depicted for the ship impact at the Langeland Bridge.

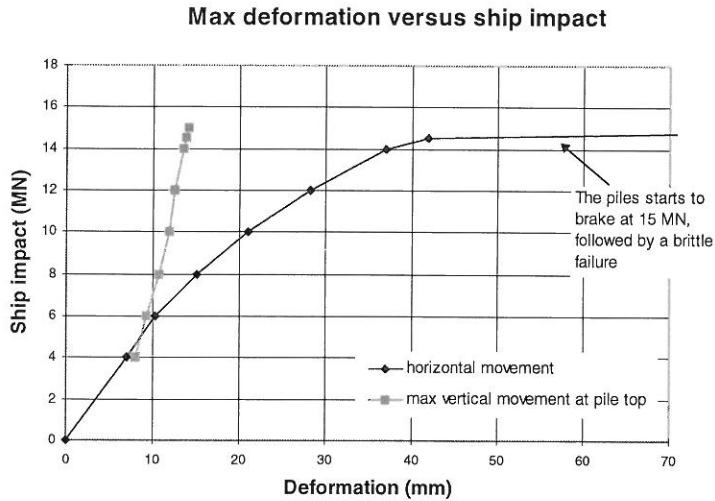


Figure 6. Vertical and horizontal deformation of the foundation illustrated as function of the ship impact at the Langeland Bridge, acting 6.5 m above the foundation level.

The model in PCPILE showed that the first wooden piles reached their maximum capacity at a ship impact of 15 MN, the piles were then removed and replaced with a resulting moment corresponding to the moment in the top of the pile caused by the ship impact.

The load was redistributed and if the foundation had additionally capacity the load was increased. For the wooden pile solution, the maximum capacity was reached instantaneously and a brittle failure occurred. The bending moment and corresponding normal force in all piles are illustrated for a ship impact of 15 MN in Figure 7, corresponding to the time when the first 4 piles starts to yield, and when all the tension piles are removed

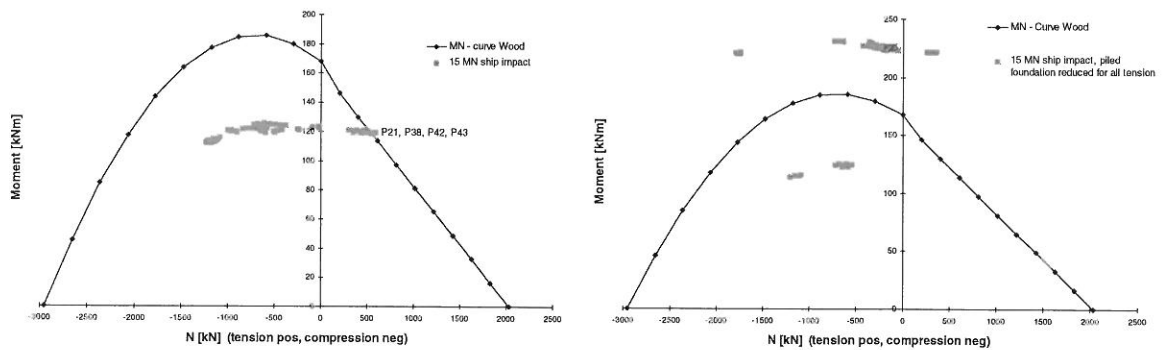


Figure 7. The bending moment and corresponding normal force for a ship impact of 15 MN. (a) in all piles, (b) when all tension piles are removed.

5 PLASTICITY THEORY

For the concrete piles at Svendborg Sound, the model was transferred to the ROSAP program when the first piles reached their first yield point. This Translation allowed for equipping the piles with a pivot at the yield point and a moment corresponding to the present bending moment.

All piles were left in the model, the load was increased and pivots applied until the on pile had 2 yield points. At this impact the foundation had reached the maximum capacity and the foundation would collapse.

The load-deformation curve for the horizontal movement of the piled foundation is shown in Figure 8 together with the bending moment-normal force diagram for the poorest loaded piles.

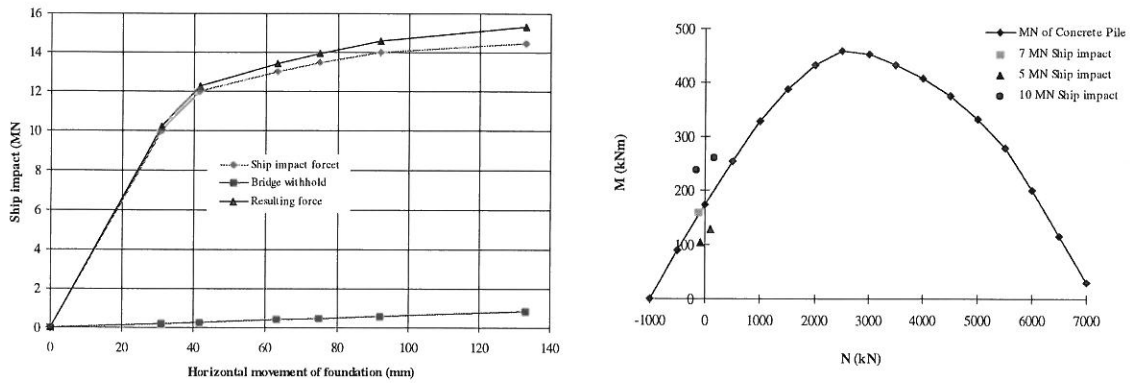


Figure 8. (a) Load-deformation curve for horizontal movement of the piled foundation. (b) bending moment-normal force curve for the poorest loaded piles at respectively 5, 7 and 10 MN ship impact

6 CONCLUSION

The load-deformation curve was established for both foundation types based on the given geometry, incorporating both pile group effect, withhold from earth pressure and bridge.

When a piled foundation is placed on prestressed concrete piles it has proven evident that applying plasticity theory on the steel enlarges the bearing capacity of the piles, thus the load deformation curves can be extended and as a result the bridge is enabled to absorb larger ship impacts.

The outcome of the investigation of the two bridges proved that the bridge across the Rudkøbing Channel could withstand a larger ship impact than the statistically determined design impact, where the analysis of the Svendborg Sound bridge resulted in the design and placement of two new protective caissons.

REFERENCES

RAMBØLL. PC-Pile Users Manual

AGEP: Foundation Engineering papers

- 1 Sørensen, C.S., Steenfelt, J.S., Mortensen, J.K. (1995). Foundation for the East Bridge for the Storebælt Link. *Proc. 11th Eur. Conf. Soil Mech. & Fndn. Engng. Copenhagen*. Danish Geotechnical Society, Bulletin 11, Vol 5, pp 5.31-5.42. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9506.
- 2 Steenfelt, J.S., Hansen, H.K. (1995). Key Note Address: The Storebælt Link - a geotechnical view. *Proc. 11th Eur. Conf. Soil Mech. & Fndn. Engng. Copenhagen*. Danish Geotechnical Society, Bulletin 11, Vol 10, pp 10.11-10.40. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9509.
- 3 Feld, T., Sørensen, C.S. (1996). Structure-Foundation Interaction on the Storebælt Link East Bridge. *Proc. Int. Conf. for Bridge and Struct. Eng., Copenhagen*, pp 809-818. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9601.
- 4 Sørensen, C.S., Jensen B.S. (1996). Fod-pælens bæreevnetilvækst. *Proc. Nordic Geotechnical Meeting, NGM-96, Reykjavik*, Vol 1, pp 253-258. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9606.
- 5 Sørensen, C.S., Faber, M.H., Stenstrup, B. (1997). Reliability Based Reassessment of an Existing Pile Foundation. *Proc. XIV Int. Conf. on Soil Mechanics and Foundation Eng., Hamburg*, Sept. 6-12 - 1997, pp 1197-1200. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9709.
- 6 Steenfelt, J.S. (1997). Type A prediction of settlements for railway box culvert in road embankment on clay till. *Proc. XIVth International Conference on Soil Mechanics and Foundation Engineering, Hamburg*, Vol 2, pp 1037-1044. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9710.
- 7 Sørensen, C.S., Steenfelt, J.S., Mortensen, J.K., Hansen, Aa., Gluver, H. (1998). Foundation of the East Bridge. In *"East Bridge"*, published by A/S Storebæltsforbindelsen, pp 97-110, ISBN 87-89366-91-3. Also in *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9813.
- 8 Sørensen, C.S., Hededal, O. (1999). Geotechnical design considerations for Storebælt East Bridge and Øresund Bridge. *Proc. IABSE Colloquium, Foundation for Major Bridges-Design and Construction*, New Delhi, India, pp. 25-30 . *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9817.
- 9 Hededal, O., Sørensen, C.S. (1999). Elasto-plastic foundation analysis of ship collision to The Øresund High Bridge. *Proc. IABSE Colloquium, Foundation for Major Bridges-Design and Construction*, New Delhi, India, pp. 175-180. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9818.
- 10 Sørensen, C.S., Bisgaard, A., Hededal, O. (1999). Foundation of the Øresund Bridge. *Proc. XIIth Eur. Conf. Soil Mech. Geotechn. Eng.*, 7- 10 June 1999, Vol. 1, pp. 609-616. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9819.
- 11 Steenfelt, J.S., Jørgensen, M.B., Jørgensen, P.O. (1999). Preloaded motorway embankments - an environmentally sound solution for soft soil areas. *Proc. XIIth Eur. Conf. Soil Mech. Geotechn. Eng.*, 7- 10 June 1999, Vol. 3, pp. 1583-1592. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9820.

AGEP: Foundation Engineering papers

- 12 Feld, T., Petersen, S.J. (1999). Establishment of Foundation Design Parameters for Limestone. *Proc. IABSE Colloquium, Foundation for Major Bridges - Design and Construction*, New Delhi, India, 24-26 Feb. 99, pp. 51-56. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9901.
- 13 Feld, T. (1999). Development of the load-deformation curve for bridge piers subjected to ship impact. Published in *Proc. XIIIth Eur. Conf. Soil Mech. Geotechn. Eng.*, 7- 10 June 1999, Vol. 1, pp. 737-742. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9902.
- 14 Rasmussen, J.L., Feld, T. (1999). Pile Driving Fatigue Damage. A Case Story. Published in *Proc. XIIth Eur. Conf. Soil Mech. Geotechn. Eng.*, 7- 10 June 1999, Vol. 2, pp. 577-582. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9903.
- 15 Feld, T., Rasmussen, J.L., Sørensen, P.H. (1999). Structural and Economic Optimization of Offshore Wind Turbine Support Structure and Foundation. Published in *Proc. OMAE-99, 18th Int. Conf. on Offshore Mechanics and Arctic Engineering*, St.Johns Nfld. Canada July 99. Vol. ?, pp. ? *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R9904.
- 16 Sørensen, C.S., Jensen, B.S. (2000). Skråningsstabilitet. Accepted for publication in *Proc. Nordic Geotechnical Meeting, NGM-2000*, Helsinki, June 5.-7.2000. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R2004.
- 17 Jensen, B.S., Sørensen, C.S. (2000). Effektivisering af forbelastning ved anvendelse af vertikaldræn. Accepted for publication in *Proc. Nordic Geotechnical Meeting, NGM-2000*, Helsinki, June 5.-7.2000. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R2005.
- 18 Feld, T., Leth, C.T., Mikkelsen, H., Steenfelt, J.S. (2000). Nyt laboratorieudstyr til simulering af dynamisk påvirkede sugebøttefundamenter. Accepted for publication in *Proc. Nordic Geotechnical Meeting, NGM-2000*, Helsinki, June 5.-7.2000. *AAU Geotechnical Engineering Papers*, ISSN 1398-6465 R2006.