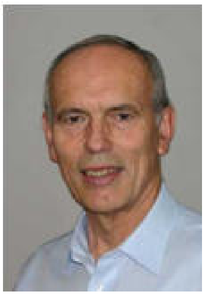
FATIGUE ASSESSMENT OF GROUTED CONNECTIONS FROM HIGH-STRENGTH CONCRETE IN OFFSHORE WIND POWER PLANTS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Abstract

The article describes the fatigue assessment of high-strength concrete grouted connection in offshore wind farms. The assessment is performed using nonlinear analysis by the finite element method based on global assessment according to the model code 2010. The accuracy of the numerical model is verified by the experimental data from the Hannover university.

Keywords: high-strength concrete, grouted connection, fatigue of reinforced concrete structures, offshore wind power plants

1 Introduction

In European union and especially in Germany, large number of offshore wind power plants have been developed in recent years in Baltic and North sea. The authors participated in the design of grouted connections of these structures. A typical grouted connection is used for the attachment of the supporting structure with the ground piles. The steel ground pile is inserted into the seabed. The upper structure supports the power generator and typically consists of a monopile or a truss structures, whose bottom parts are inserted into the ground piles. The resulting space between the steel pipes is filled with high-strength concrete. In order to increase the shear capacity of the grouted connection, the walls of the steel elements are enhanced with a shear key composed of weld beads. This connection needs to be checked for the ultimate and fatigue limit state. This paper discusses the fatigue assessment, when the standard approach based on Wöhler's curve (see Fig. 2) is not suitable for the numerical assessment based on the finite element method. The stress

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concentration near the shear key causes the stress values to be strongly dependent on the finite element size. The current practice recommends to use stress values for the fatigue assessment away from the shear keys, where they are not affected by the stress concentration. This approach is rather arbitrary, and eliminates the most critical safety region from the assessment. The authors propose a fatigue assessment approach based on the global assessment according to the international fib model code 2010 [1], which is suitable for the application in the finite element method using a nonlinear model [2]. The nonlinear numerical model is verified using experimental data of grouted joints from the University of Hannover [3]. The proposed method was applied for the design and assessment of grouted connections in an offshore power plant in Baltic sea (see Fig 1).

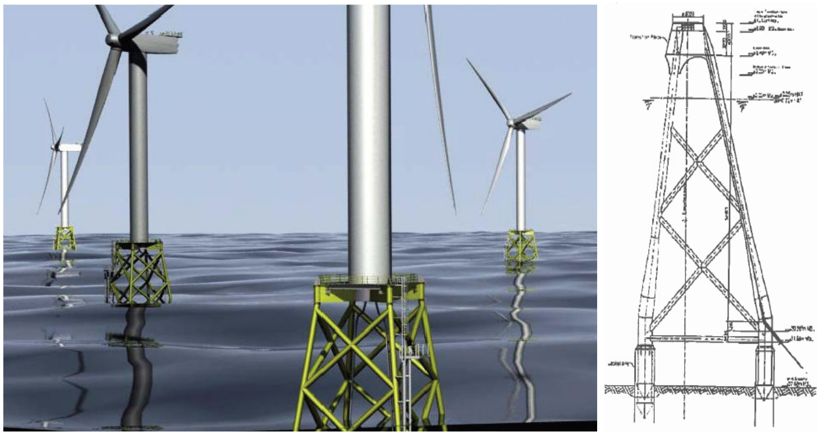

Fig. 1 The typical geometry of the support structure of offshore wind power plants

2 Fatigue assessment

The fatigue assessment is based on the approach presented in [4], which is very similar to the Eurocode method in the article 6.8.5 from EN 1992-1-1. For concrete below water surface, the absolute value of the compressive stress for number of cycles up to $2 \cdot 10^8$ should be limited by the expression:

$$\sigma_{c,\max} \leq 0.35\, f_{cd,fat} \tag{1}$$

where $f_{cd,fat}$ is given by:

$$f_{cd,fat} = 0.85 \beta_{cc} f_{ck,cyl} \left(1 - \frac{f_{ck,cyl}}{400}\right) \frac{1}{\gamma_c \gamma'_c} \tag{2}$$

In the above formula, β_{cc} represents the coefficient for concrete age at the time of the first load cycle, $f_{ck,cyl}$ is the characteristic cylindrical compressive strength, γ_c is the partial safety factor for concrete and γ'_c is the additional safety coefficient for high-strength concrete. For the purpose of the global fatigue assessment, it is possible to interpret the criterion as a reduction of concrete compressive strength, and the concrete stress-strain diagram can be modified as shown in Fig. 2. This modified stress-strain law can be used in the global assessment by nonlinear analysis. This approach enables to consider the significant compressive crushing, which occurs due to the cycling loading near the shear keys. The global assessment verifies if the structure is able to sustain the resulting

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redistribution of internal forces, and it takes into account the development of plastic strains near the shear keys and the diagonal cracks in the grout. The consequence is the hardening of the grout material due to the tri-axial stress state.

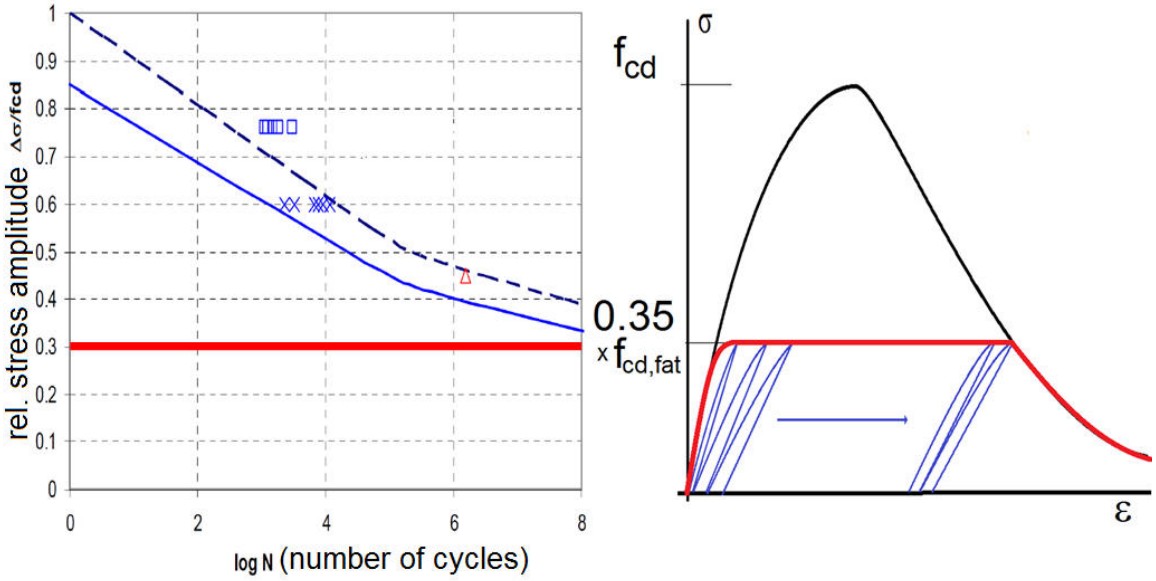

Fig. 2 Limit stress value according to [4] and its application as a modified stress-strain law

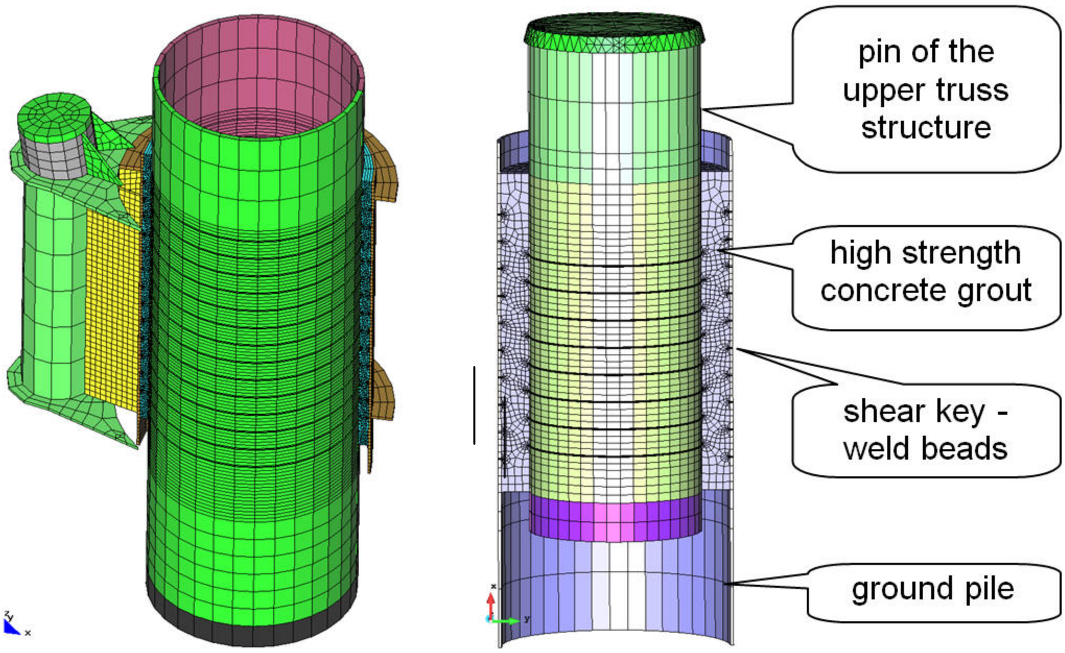

Fig. 3 The finite element model for two types of grouted connection

Fig. 3 shows numerical models for two typical types of grouted connection arrangements. The typical results from the nonlinear finite element analysis are shown in Fig. 4. The figure (a) depicts the location and orientation of cracks after the application of shrinkage. The figure (b) shows the final failure mode, when the ultimate load capacity is reached. The inclined crack in Fig. 4a is caused by the consideration of initial imperfections in the relative position and inclination of the connected steel pipes. The final global assessment is

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described in the load-displacement diagram Fig. 5. For the successful assessment of the grouted connection it is necessary that the global relative load reaches the level >1.

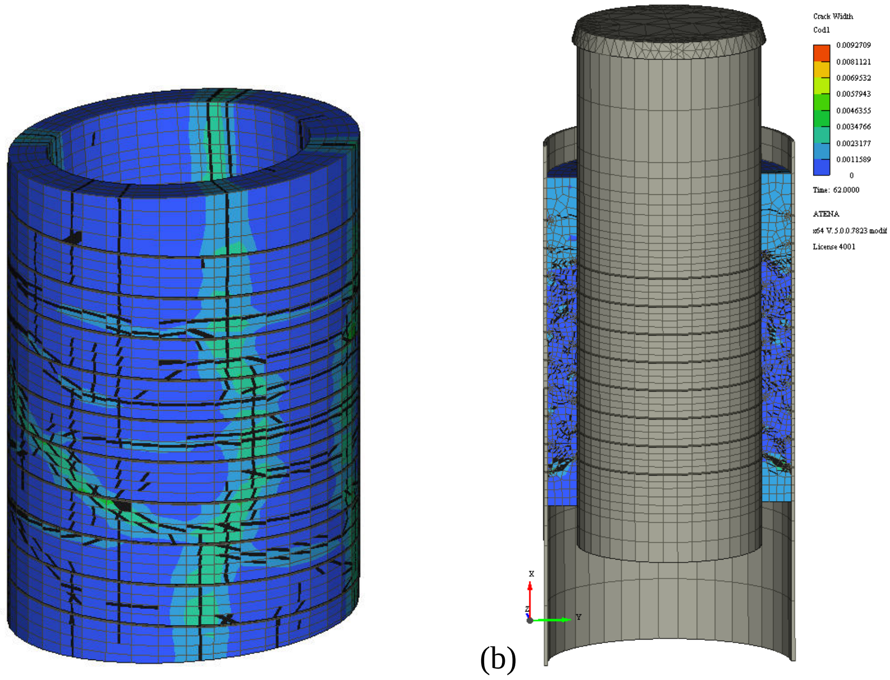
(a) (b)

Fig. 5 (a) Shrinkage cracks (b) the final failure mode at peak load

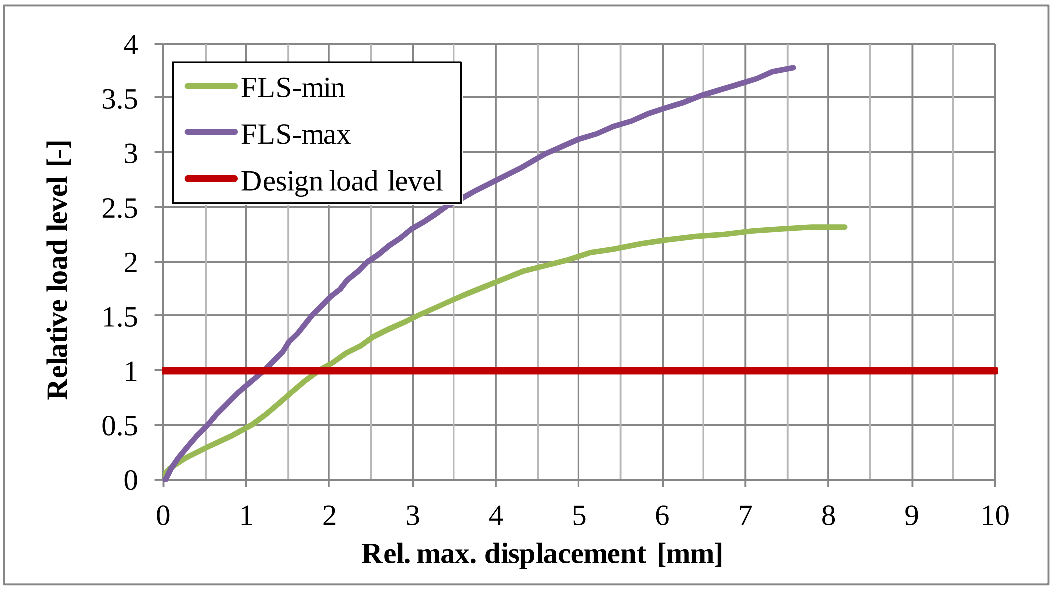

Fig. 6 Load-displacement curve for the global fatigue assessment

3 Nonlinear model validation

The nonlinear model was verified using the experimental results from the doctoral theses of Anders [3]. The final failure of the experimental specimen is compared with the results of nonlinear analysis in Fig. 6. The resulting load-displacement diagram is compared in

Fig. 7. The slightly lower strength in the analysis can be explained by very conservative properties that were assumed for the steel-concrete contact in order to ensure that same assumptions are used as in the practical application to offshore power plants.

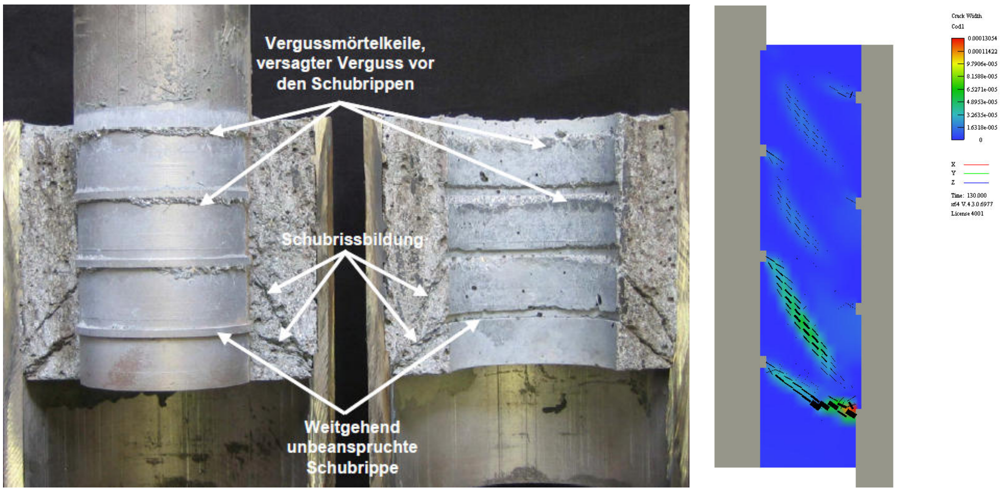

Fig. 6 Failure mode in (a) experiment (Anders [3]) (b) analysis by ATENA

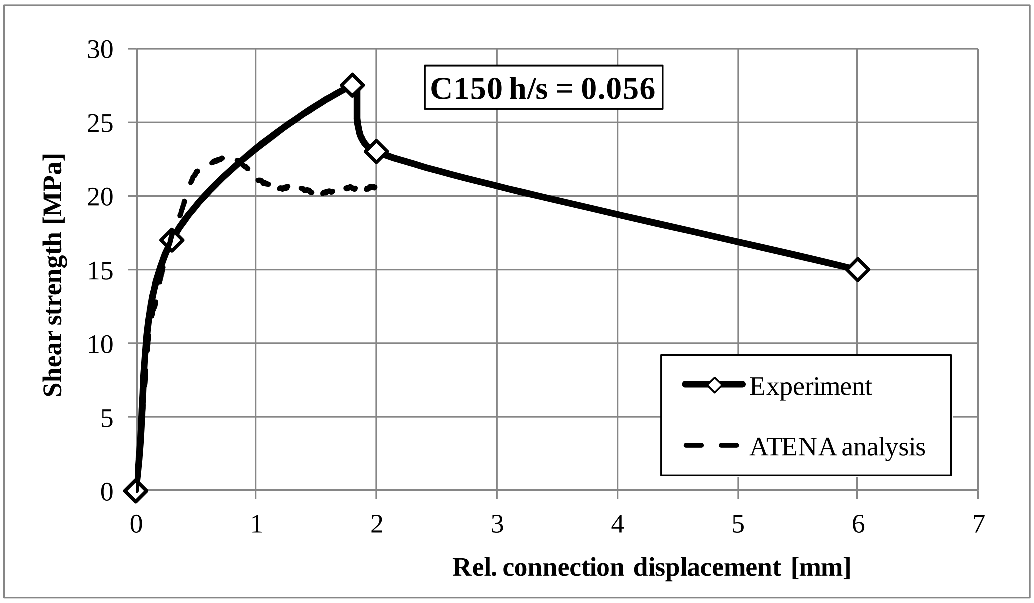

Fig. 7 Comparison of experimental (Anders [3]) and numerical response curves

4 Conclusions

The article describes a fatigue assessment of high-strength concrete grouted connection of offshore power plants. The proposed approach is based on the global assessment according to fib Model Code 2010 [1]. The stress-strain diagram for the grout fatigue assessment is reduced to match the code requirements. The proposed approach enables the verification of the grouted connection with shear keys, which takes into account the development of diagonal cracks and concrete crushing near the shear keys. It captures the

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significant redistribution of internal forces and the material hardening due to the development of large plastic strains near the shear keys.

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Literature

[1] fib – Model Code 2010, federation internationale du beton, 2010, bulletin 56, ISBN 978-2-88394-096-3
[2] Červenka, J., Pappanikolaou, V. 2008. Three dimensional combined fracture-plastic material model for concrete. Int. J. of Plasticity, Vol. 24, 12, 2008, ISSN 0749-6419, pp. 2192-2220
[3] Anders, S., Betontechnologische Einflüsse auf das Tragverhalten von Grouted Joints, Dr. Ing. Dissertation, 2007, Universität Hannover
[4] König, G.; Danielewicz, I.: Ermüdungsfestigkeit von Stahlbeton- und Spannbetonbauteilen

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