On Gust Buffeting Design of Slender Chimneys - Building Interference and Fatigue

by

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born 28 November 1985

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Von der Fakultät Architektur, Bauingenieurwesen und Umweltwissenschaften
der Technischen Universität Carolo-Wilhelmina zu Braunschweig
zur Erlangung des Grades eines Doktoringenieurs (Dr.-Ing.)
genehmigte Dissertation

Eingereicht am:	23. April 2014
Disputation am:	31. Oktober 2014
Berichterstatter:	Prof. Dr.-Ing. Dr.-Ing. E.h. Udo Peil Prof. Dr.-Ing. Hans-Jürgen Niemann

Schriftenreihe des Instituts für Stahlbau

Heft 2

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Shaker Verlag
Aachen 2015

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Braunschweig, Techn. Univ., Diss., 2014

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Printed in Germany.

ISBN 978-3-8440-3538-4
ISSN 2198-8722

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

I dedicate this work to all the things, that my parents had to give up in order to invest in my education and in the education of my siblings.

'Ceterum censeo Carthaginem esse delendam'.

Cato the Elder (3rd century BC)

Acknowledgements

First of all I want to thank my tutor Univ.-Prof. Dr.-Ing. Dr.-Ing. E.h. Udo Peil for giving me the possibility to write this PhD work at the Institute of Steel Structures of the Technische Universität Braunschweig. It was a privilege for me to carry out this work as a member of his wind engineering team. I will always remember the conversations we had about music, politics, the correct use of the German language and his interest in learning about the Basque language. Therefore, the fruitful cooperation with Prof. Peil was not only focused on wind engineering, but also on not less important cultural aspects.

I express my gratitude to the Basque Government for the sponsorship of the work between 2010 and 2014. Specially, I am grateful to Prof. Pedro Luis Arias Ergueta for his support and interest in the research project during these last years. I would like to thank Ms. Lourdes Arana Uli for her fundamental support in funding possibilities for a doctoral project. I express also my gratitude to CICIND for the financial support of the research projects associated with this work. A special mention also to Prof. Iñigo Puente from TECNUN University of Navarra for introducing me in the research field and convincing how useful is a PhD thesis for an engineer.

All my gratitude to Univ.-Prof. Dr. sc. techn. Klaus Thiele for his support, interesting questions and recommendations during the last years of the project. Special thanks to Prof. Dr.-Ing. Hans-Jürgen Niemann from Ruhr-Universität Bochum, for his interest in the research and for evaluating the presented work. Due to his international reputation in wind engineering, it is an honour for me that he accepted to support this work.

The most important scientific support I had here during the last four years was given by Dr.-Ing. Mathias Clobes. We had many inspiring discussions and his ideas have always been vital for the progress of the work. I remember his motivation during my first months in Braunschweig; allowing me to travel with him to international conferences, in particular to St. Petersburg in May 2011. That was my first international experience and I will never forget it.

Thomas Höbbel M.Sc. has also been very helpful during this time, having a parallel trajectory and being a co-worker during the construction of the wind tunnel.

Special thanks are addressed to Dr.-Ing. Frank Kemper from RTWH Aachen, who selflessly helped me during the development of the chapter regarding the wind-induced fatigue. I want to thank Prof. Giovanni Solari from Genoa University for providing me advices about the gust response factor approach and for accessing me additional literature. I would also like to acknowledge Prof. Dr. Bernd Leitl from Universität Hamburg for the useful advices provided for the construction of the wind tunnel, as well as for allowing us to visit the facilities of the Meteorological Institute.

I will emphasize the excellent atmosphere at the Institute of Steel Structures provided by people like Dipl.-Ing. Oliver Steiln, Dr.-Ing. Andreas Willecke, Dr.-Ing. Arno Kirch, Dipl.-Ing. Florian Minuth-Hadi, Dipl.-Ing. Julian Unglaub, Dr.-Ing. Jorge Muñoz Barrantes, Dipl.-Ing. Ingo Schendel, Ding Cai M.Sc. etc. Thank you for your friendly company. I am also grateful to Eric Kuate Simo M.Sc. due to his work as loyal student assistant since the beginning of the work. Dipl.-Ing. Nahia Jimenez de Pablo and Fabian Fengler M.Sc. have also supported this work with their interesting contributions to the institute. I would also like to mention the comprehensive effort made by my friend Christian Simon, who thoroughly proofread the grammar, syntax and style of this work. My gratitude to Jose Mari Sasieta for his drawings, that aim to combine nature, wind and art inside a scientific book.

This work is the summary of a personal effort during the last years, but also a long-term educational investment of my parents Ana and Isidro. Without their daily support, perseverance and discipline this work would not have been possible.

Finally, I want to acknowledge my girlfriend Alina for her personal, emotional and intellectual support during these last years. I have no words to express my gratitude to her.

Hodei Aizpurua Aldasoro
Hamburg, March 2014

Abstract

This work describes the experimental and numerical investigation about the improvement of the buffeting wind design of industrial slender chimneys considering interference effects and long-term wind profile statistics.

The first part of the investigations is related to the along-wind response design of slender chimneys considering the frequent perturbations on the wind field associated with the interference effect. This phenomenon occurs always in the presence of nearby buildings and its importance increases if the slenderness of the chimney becomes larger. The experimental study is carried out in the boundary layer wind tunnel of the Institute of Steel Structures of the TU Braunschweig. To simulate the effect of power houses on the wind flow, a parametric study on the building shape has been carried out. Different building shapes, positions of the chimney and wind directions have been considered. For each configuration, the wind field characteristics acting on the chimney have been measured. Using this information, the buffeting response of a 150 m high propped chimney has been numerically calculated assuming quasi-steady wind loading. The results show a significant increase of the bending moment at the roof support with respect to the undisturbed flow associated with the Eurocode 1. The aerodynamic admittance function under disturbed wind conditions has been also determined experimentally. The wind load acting on a chimney model is calculated again in the wind tunnel using the high frequency force balance technique. The results obtained demonstrate that the aerodynamic admittance function does not vary with respect to the undisturbed configuration. The design approach in Eurocode 1 is based on a procedure proposed by Solari and cannot be implemented when chimneys are supported at the top of the building, since there is no constant sign in the mode shape. The proposed modification takes into account the roof supported structural system as well as the corrected wind profiles and turbulence spectra due to the interference effect. In other words, a linear mode shape from the top of the building to the top of the chimney is chosen. The study reveals a big dependency of the gust response factor on the cantilevered length of the propped chimney. Finally, an increasing factor that fully covers the interference effect as well as the change of the structural configuration for different eigenfrequencies and heights is proposed. It has to be applied to correct the calculation following the Eurocode 1 procedure for the cantilevered length of the chimney.

On the contrary to the first part of the investigations associated with extreme wind situations, the second part covers the fatigue life prognosis considering low and moderate wind conditions. Using the useful information about long-term wind statistics provided by previous works, a realistic analysis of the expected fatigue damage is carried out. The wind data measured in Gartow, a rural area located in Northern Germany with a roughness grade equivalent to an industrial area, was useful to classify the mean wind speed profiles in six different shapes. To study the fatigue prognosis, a Monte-Carlo simulation has been carried out using a large number of synthetic profiles generated from the presented statistics. For each generated wind profile, the buffeting response of a 150 m tall chimney is individually calculated in the frequency domain. Starting from the spectral information of the bending moment obtained at the foundation, the Dirlik method has been applied to calculate the probability distribution of the stress amplitudes in order to study the expected fatigue damage of the structure. From these results, load collectives for a lifetime of 50 years have been generated. The consideration of six wind classes c yields to a more economic design as compared to a scenario where only the logarithmic wind profile shape is considered. The damping, eigenfrequency and wind statistics at site Gartow have a direct influence on the shape of the load collective, thus the unique application of the proposal given in the Eurocode for each structure and site can produce a largely overestimated fatigue prognosis.

Zusammenfassung

Für schwingungsanfällige Tragwerke wie hohe Stahlschornsteine ist die böige Windeinwirkung bemessungsrelevant. Im Rahmen dieser Arbeit wurden experimentelle und numerische Untersuchungen zur Böenbeanspruchung durchgeführt. Hierbei wurde ein besonderer Blick auf dem Einfluss von Interferenzeffekten durch benachbarte Bebauung, sowie eine Ermüdungsprognose unter Berücksichtigung von realistischen Windprofilen geworfen.

Häufig werden Schornsteine an unmittelbar neben hohen Bauwerken errichtet. Diese benachbarten Gebäude beeinflussen die Windbelastung auf den Schornstein in Abhängigkeit von dessen dynamischen Eigenschaften deutlich, es kann zu höheren Beanspruchungen gegenüber der Windsituation ohne das benachbarte Gebäude kommen. Es hat darüber hinaus wirtschaftliche Vorteile, den Stahlschornstein mit dem benachbarten Gebäude zu verbinden damit das statische System vom Kragarm zum günstigeren Einfeldträger mit Kragarm zu verändern. Am Institut für Stahlbau der Technischen Universität Braunschweig wurden Untersuchungen an mastäblichen Modellen im Grenzschichtwindkanal durchgeführt. Dabei wurden die Gebäudeform, Position des Schornsteins bezüglich des Gebäudes sowie Windrichtung variiert. Für jede Konfiguration wird das gestörte Windfeld gemessen. Mit dieser Information wurden eine dynamische Berechnungen für verschiedene Modellschornsteine unter Böenrregung unter Verwendung des quasi-stationärem Windlastansatzes durchgeführt. Hierbei zeigt sich, dass das benachbarte Bauwerk, in Abhängigkeit von Windwinkel und Position des Schornsteines, die für die Beanspruchung des Schornsteins magebende Windstruktur stark beeinflusst und damit zu einer bemessungsrelevanten Erhöhung der Beanspruchung führt. Um einen direkten Vergleich zwischen die vorliegenden Untersuchungen und dem in Eurocode EN 1991-1-4 verankerten Verfahren zur Ermittlung des Böenreakstionsfaktors zu ermöglichen, sind Informationen die aerodynamische Admittanzfunktion notwendig. Zur Bestimmung dieser Admittanzfunktion wurden im Windkanal die Windkräfte an einem Schornsteinmodell mit Hilfe einer Windkanalwaage erfasst. Die Ergebnisse zeigen keinen deutlichen Einfluss des Interferenzeffektes auf den Verlauf der aerodynamischen Admittanzfunktion. Das in EN 1991-1-4 beschriebener Verfahren zur Böenerregung gilt jedoch nur für ein vertikales Kragsystem unter Berücksichtigung der Grundschwingungsform. Eine Anwendung auf den Fall einer seitlichen Verbindung des Schornsteines mit dem Gebäude und das so veränderte statische System ist jedoch nicht möglich. In dieser Arbeit wird ein Verfahren zur Ermittlung des

Böenreaktionsfaktors vorgeschlagen, das die Interferenzeffekte sowie das veränderlichen statischen System berücksichtigt.

Darüber hinaus wird in dieser Arbeit ein Beitrag zur Ermüdung von Stahlschornsteine unter Böerregung vorgestellt. Mit Hilfe von statistischen Auswertungen gemessener Windprofile wird eine verbesserte Prognose der Lebensdauer durchgeführt. Grundlage dieser Statistik sind die Langzeitmessdaten am Mast Gartow II der seit mehr als 20 Jahre vom Institut für Stahlbau betrieben wird. Die Unterteilung der gemessenen Windprofile in sechs verschiedenen Windprofilklassen auf Basis einer vorangegangenen Arbeit wird im Rahmen einer Monte-Carlo Simulation der Böerregung eines Stahlschornsteines berücksichtigt. Die Berechnung erfolgte im Frequenzbereich mit entsprechend der Langzeitstatistik variierenden Windprofilformen. Die Häufigkeitsverteilung der Doppelspannungsamplitude wurde aus den Antwortspektren mittels der Methode nach Dirlik bestimmt. Diese Methode erlaubt die Bestimmung der Wahrscheinlichkeitsdichtefunktion der Doppelspannungsamplitude, unabhängig von der Bandbreite des Antwortprozesses. Die Lastkollektive nach EN 1991-1-4 basieren hingegen auf der Annahme einer schmalbandigen Antwortprozesses für einen Einfreiheitsgradschwinger. Die Betrachtung sechs unterschiedlicher Windprofilformen, fhrt zu einer Reduzierung der erwarteten Ermüdungsbeanspruchung der Struktur während ihrer Lebensdauer. Windstatistik und strukturelle Parameter sind entscheidend um eine realistische Lebensdauer prognostizieren zu können.

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