Reliability-based importance assessment of the components in the probabilistic wind load model for static structural members

July 20, 2017

Abstract

Abstract, to be added[NEM]

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Keywords: wind engineering, structural reliability, probabilistic wind load model, wind-directionality, structural components

1 Introduction

1.1 Motivation

Wind is the governing environmental action for many structures; particularly for structural members which can be especially vulnerable to wind loading [ref]. In practice, these structural members are designed using semi-probabilistic design methods, such as partial factor design, or load resistance factor design. To guarantee a safe design these semi-probabilistic methods are (should be) calibrated to codified target reliability levels. For this reliability-based calibration physical models and probabilistic models are needed. The former captures the underlying physical phenomena while the latter accounts for the associated uncertainties. In respect of structural members subject to wind the probabilistic model of the wind load typically dominates the reliability; therefore, its correct modeling is of crucial importance. The widely accepted and applied Davenport wind load chain (DWLC) is considered here as the starting point of our investigation. The probabilistic description of uncertainties in this wind load chain is still under active debate despite the numerous advances in wind engineering [ref]. For instance, the decision on which distribution type to be used for wind extremes can lead to an order of magnitude difference in calculated failure probabilities [ref]. Other decisions and modeling choices can have similar bearing on the calculated failure probability. Therefore, it is of great importance to explore these decisions and associated uncertainties. Furthermore, some aspects, such as the effect of wind directionality and handling of statistical uncertainties, are not yet sufficiently explored. These issues are of particular interest for standardization committees which have few well-reasoned guidance on probabilistic wind load models. Hence the aim of this paper is to investigate the effect of some modeling choices and prevalently overlooked aspects in a comprehensive framework by assessing their practical, engineering relevance.

1.2 Problem statement

The typical approach in investigating the inuence of modeling choices in the probabilistic wind load chain (DWLC) concentrates on the in-depth analysis of selected links in the chain. Due to this isolated treatment the modeling choices are often compared on the basis of measures with low to moderate engineering relevance, e.g. using statistical goodness-of-fit measures [ref] or comparing representative fractiles [ref]. Given that design methods should ensure a minimum target reliability level we adapt structural reliability as a measure with high practical relevance to evaluate modeling choices. This entails that all relevant parameters in the structural reliability problem be represented with probabilistic models, e.g. modeled as random variables. Although there are studies that consider all relevant parameters with probabilistic models they lack the comparison of alternative modeling choices []. Furthermore, certain aspects of the wind load chain have received less attention, for example the effect of wind directionality and statistical uncertainties due to the scarcity of data are often neglected [ref]. A more detailed overview of previous works is given in Section 2.

The shortcomings of previous studies can be categorized as: (i) not all links in the wind load chain are represented with probabilistic models; (ii) alternative modeling choices are not compared; (iii) measures with low or moderate engineering relevance are used to compare the modeling choices. This paper attempts to address these shortcomings; however, it is acknowledged that such broad questions cannot be thoroughly covered and answered in a single paper. Our main contributions are (i) the proposal of a framework (with accompanied computer code) that represent all relevant parameters as random variables; and (ii) the comparison of selected modeling choices, e.g. distribution type, wind directionality, and statistical uncertainties, on structural reliability.

Accordingly the primary research questions of this paper are formulated as:

What is the effect of probabilistic modeling decisions in the Davenport wind load chain, such as wind directionality and statistical uncertainties, on the reliability of structural members? Which components and decisions are the most important ones?

As side product of answering the primary questions one can answer to the following secondary questions as well. These are more relevant for practitioners and standardization committees: *What is the reliability level of wind loaded structural members designed according to Eurocodes? Are the current methods ensuring the target reliability level?*

1.3 Contribution of this paper

Arpad[NEM]

1.4 Scope

The scope of the paper is limited to:

- Structural reliability on component level, i.e. structural system effects are not taken into account;
- Local wind loads only, i.e. wind loads on reference areas less than $10\mathrm{m}^2$;
- Dynamically insensitive structural elements, i.e. the natural frequency of the element lies below the natural frequency of the incident winds [];
- Situations where wind loads are assumed to be the dominant loading type and where other loading types (variable or permanent) are assumed to be negliglible;
- Strength-related failure modes (ULS);
- Temperate wind climates (like mid-lattitude depressions) only, i.e. the influence of small-scale weather systems such as hurricanes / thunderstorms is assumed to be negleglible. Maybe not

always rectified SEE PAPERS however generally assumed (Research towards mixed climates. What to do with this: [?] [?])?;

- Situations where the wind flow is not influences by either topography (mountains) or surrounding buildings.

Furthermore throughout the paper it is assumed that the wind climate is stationairy, i.e. the effects climate change have not been taken into account.

1.5 Outline

The outline of this paper is as follows. In section **??** the methodology is describes which will be used for the analysis. In section 4 the details and the results of the case-study are presented. In section 7 the results of the case-study and the potential of the assessment procedure are discussed. In section 9 the conclusions and recommendations are provided.

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2 Review of existing literature

To investigate the effects of these modeling choices much research has been conducted. The research all started with the establishment of the physical wind load model, which is also referred to as the Davenport Wind Loading Chain.

2.1 Davenport Wind Loading Chain

Some history regarding the development of the DWLC may be added here[NEM]

Due to its conceptual ease, the DWLC is the foundation of many wind load models found in current codes of practice [?]. The DWLC provides a conceptual representation of the synthesis of extreme wind loads and is thought of as a 'chain' consisting on a number of 'links' each representing a relevant physical aspect contributing to the wind load.

The first link of the chain, "wind climate", accounts for the characteristics of the large-scale wether systems which depend on the geographical location of the building. The wind climate is represented by a time-averaged wind speed corresponding to a standard exposure, averaging time and reference time.

The second link of the chain, "terrain effects", corrects for the influences of the upwind terrain which cause the increase of mean wind speed with height and the terrain-introduced wind-gustiness. As the upwind terrain differs per incident wind direction, also the "terrain effects" differ per incident wind direction.

The third link of the chain "aerodynamic effects" accounts for the (local) increase in wind speed due to the aerodynamic shape of the building, as well as the wind gusts introduced by local vortex shedding at the edges of the building. Besides, it takes into account the effects of a non-uniform pressure distribution over the reference area, resulting in relatively lower forces at larger tributal areas. Depending on the location on the building and incident wind direction, the aerodynamic effects result in either high compression forces (maxima) or high suctional forces (minima).

The fourth link of the chain "dynamic effects" accounts for the potential wind-induced resonant vibrations, which depend on the damping ratio and natural frequency of the building. In case of dynamic insensitive structures or structural, the wind-induced resonant vibrations are negliglible.

The fifth link of the chain, "criteria", recognizes that clear crtieria must be in place for judging the acceptability of the predicted loads and responses for both ultimate limit states and serviceability limit states.

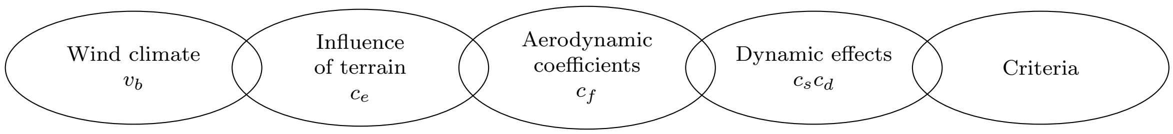

Figure 1: Davenport Wind Loading Chain, based on [**?**]

For a propor representation of the structural reliability, the uncertainties in each of the links in the DWLC as well as the effects of wind-directionality need to be discounted for in the reliability analysis [**?**]. However, both the probabilistic modeling of the individual links in the chain, as well as methods to deal with wind-directionality effects, are still under active debates in the scientific cummunity. Besides, only a limited number of research exists that provides a full-probabilistic assessment of wind-loaded structural elements.

In the following sections, an overview is presented of the most important findings regarding the probabilistic modeling of the individual links in the DWLC(see SECTION), the probabilistic methods for taking into account wind directionality effects (see SECTION) and the published results regarding full-reliability calculations (see SECTION). In section SECTION an overview will be provided of our modeling choices.

2.2 Probabilistic modeling of of DWLC components

The probabilistic modeling

For these factors very little data /literature is available. For this reason generally the recommendations in the PMC are often is used for the probabilistic modeling.

Whilst little attention is directed towards the probabilistic modeling of the 'influence of terrain', or the 'dynamic effects', most of the discussions are related to probabilistic modeling of the 'wind climate' and the 'aerodynamic coefficients'. Both of these links regard the probabilistic modeling of extremes, and the discussions about them therefore have many similarities. The main points of discussion thereby are (1) the extremal analysis method and distribution type to be used for the modeling and (2) the parameter interference techniques to be applied for the distribution fitting.

2.2.1 Extremal analysis method and distribution type

Both the wind climate and the aerodynamic characteristics require the modelling of extremes. Thereby the variables will be modeled based on the principles of extreme value analysis. In the literature a numerous amount of extremal analysis methods and distribution models models have been proposed for the probabilistic modeling of extremes. Roughly, these methods can be distinguished in 'classical methods' such as the block maxima method (BM) and the Peak over Theshold (POT) method and extensions to these classical methods.

BM approach

The BM approach consists of dividing the observation period into nonoverlapping periods of equal size and restricts attention to the maximum observation in each period after which an extreme value distribution is fitted. The underlying assumption of the BM approach are independent identically distributed random variables and convergion of the parent distribution towards some extreme value distirbution.

Within the BM approach the main discussions regard two topics; the minimum block-duration to ensure statistically independent extremes and the distribution type to fit on the extremes.

- In case of the extreme wind speeds, the block-duration is gerenally chosen to be one year. Governing reason for that is to capture seasonal effects, rather than to ensure statistically independency. A more pronounced discussion is related to the choice of the distribution function to be fitted over the extremes.Traditionally the Gumbel distribution is fitted to the annual maxima. The theoretical justification of this distribution lies in the widely accepted assumption that the parent wind speeds are W2 distributed, and the extremes of the W2 disttribution converge towards a Gumbel distribution [**?**, **?**]. However, [**?**] did statistical analysis on 100 US-wind records and found that in 61 cases the Weibull (W2/3?) distribution was the best fit, 36 the Gumbel distribution and in 3 cases the Frechet distribution was the best. Gomez and Vickery state that, in cases of mixed climates, the Fréchet distribution is the best.

- In the case of the extreme pressure coefficients the minimum required block-duration is less of a settled issue. Cook and Mayne [1] based the minimum record-length on the lower limit of the Spectral Gap in the Macrometeorological spectrum. They suggested that one record should have a minimum length of 10 minutes in full scale. Lou and Peterka [4] used signal autocorrelation as a measure of dependency between extremes and found that periods smaller than 1 minute in full scale already resulted in zero autocorrelation. Other studies showed that the sample duration could be shortened to 10 s [**?**]. Comparisons of the effect of different block-durations on the level of the Cook-Maybe fractile may be found in the literature as well [**?**] [**?**] [**?**] [**?**] and found that the results were significant.

  The type of Extreme Value distribution that should be fitted on the sample data is neither a settled issue. In almost all cases the Gumbel distribution is fitted. Kasperski [**?**] discusses the use of the upper-bounded Weibull distribution, for reasons that wind tunnels cannot produce unlimited pressures for a given mean wind speed. Based on a statistical analysis of measurement data, he finds that in most of the cases indeed the W2/3 distribution best fits the data and in some cases the Frechet or Gumbel distribution. Similar findings are made by other researchers [**?**, **?**].

POT method
In the POT, one selects those of the initial observations that exceed a certain high threshold after which the Pareto distribution is fitted [**?**]. Main discussions are related to the height of the threshold value and the methods to ensure statistically independent extremes.

- POT and extreme wind speeds?

- POT and extreme pressure coefficients?

2.2.2 Distribution parameter interference techniques

By arpad[NEM]
Some papers addressing the importance of sampling errors on the design wind speeds:

- Simiu *et. al* [**?**] investigated (among others) the effects of sampling errors on the estimation of design wind speeds from a confindent interval approach and found them to be significant.

- Rojiani and Wen [**?**] also (among others) investigated the effects of sampling uncertainties on the design wind speeds and found that the effects of distribution type and parameter esitmation technique were of larger signifance.

2.3 Wind directionality

Several researchers have investigated the influence of wind-directionality on the design wind loads. Simiu and Filiben [?] show that "cladding loads calculated without taking directional information on extreme wind speeds into account may in certain cases be larger than the actual loads by a factor of two or more."
Isyumov *et. al* [?] state that "the ASCE 7 directional factor of Kd=0.85 is not unreasonable for the structural and cladding loads for buildings located in areas, where extra-tropical winds dominate."
Davenport [?] estimated the differences in the risks in the design of cladding pressures when the influence of wind direction is taken into account and found that "if the peak pressure coefficient aligns with a direction of relatively weak winds, the reduction can easily be a factor two".

2.4 Full probabilistic analysis

As stated before, the focus of the literature is mostly on the in-depth analysis of a single, selected link only. In the literature, a handful of studies may be found that provide a full-probabilistic assessment which accounts for the uncertainties in the entire DWLC.

The ones were Cook and Mayne [?], who developed a method often referred to as 'the Simplified Method'[NEM] to account for the uncertainties in the wind speeds and the pressure coefficients, where the uncertainties in the other links were kept deterministic. Many researchers [?, ?] have used, discussed and refined this method.

Some recent studies did account for the uncertainties in all links jointly.
E.g. for the purpose of partial factor calibration Hansen [?] and Sedlacek provide a full probabilistic design method that takes into account uncertainties in all links. For the probabilistic modeling of each of the parameters choices were made based on literature / sample data. The effects or their modeling choices on the reliability level were however not investigated.

In a super amazing pioneer study just kidding[NEM], Meinen investigated the influence of some modeling choices ont he reliability level of an element. The results showed that.. ? It is actually interesting to look at the influence of modeling choices on beta-level, as it has a large impact.

As a result, only limited knowledge exists on the effects of modeling choices on the structural reliability of wind-loaded structural elements, i.e. uncertainty propagation.

2.5 Our choices with respect to the modeling of extremes

As it it

In this research the block-method combined with the Generalized Extreme Value distribution is adopted [?] [?] [?].