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Serviceability floor loads

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ABSTRACT

Serviceability of structures has to be verified for a lower load level than the design load used for safety considerations. Representative values of actions used in serviceability load combinations are often defined in a way that the fraction of time spent above a given load level should be limited to a certain value. To determine these load levels more information on the stochastic nature of the loading process is needed than to estimate the design load.

A convenient way in structural design codes is to express representative values (rare, frequent and quasi-permanent) as a fraction of the characteristic value by using load reduction factors. However, the characteristic value is usually defined in a different way i.e. with a certain probability of not being exceeded (in a chosen period of time).

The current paper estimates representative values of floor live loads by numerical simulation using stochastic live load models with a special focus on serviceability. The results are compared to values given in existing standards (Eurocode on first place). Improvements are suggested concerning the load reduction factors, the definitions of the representative values and the stochastic load parameters.

1. Introduction

1.1. Background

Structural design codes are optimized to achieve a relatively consistent level of safety in different design situations. This is done in terms of failure probabilities or equivalently reliability indices. The same situation, i.e. consistency, is desired for structural serviceability.

The problem with serviceability is twofold. Firstly, the criteria for serviceability limit states are often not easy to define or are subjective. A good example is the limit for visually disturbing deflections of a beam, where the human perception could be influenced by various aspects e.g. the observeŕs personal factors, the type of materials used, the surrounding environment etc.

Secondly, in many cases not only the maximum of the loads – in a certain time period – are of interest. It could be important how often and how long a given load is exceeded. This kind of information on loads is not always easy to determine. For example the occurrence rate and the duration of intermittent loads on floors are quite uncertain, as it is more difficult to collect data on them, than to test e.g. material strength in a laboratory. The same applies for deflection limits.

It is essential when developing design codes that the design criteria should relate to the loads considered. If it is not clear for the designer, which load should be applied to a given design criterion, then the whole calculation is pointless. For instance using the total load for checking a deflection limit, which is originally intended to be related to variable loads, will lead to an unnecessary stiff element.

1.2. Representative values of variable actions

International Standard ISO 2394 [1] defines representative values of actions i.e. values used for the verification of limit states. Since Eurocodes (EN) apply the principle of limit state design, definitions from [1] are adopted in EN1990 [2] such as in the current study. The most fundamental representative value of a variable action is the characteristic value Q_k, defined as the 98% fractile of the annual maxima i.e. the intended probability of the action not being exceeded is 98% in a reference period of 1 year. This is equivalent to the say that the return period of the Q_k is equal to 50 years, thus the average of the 50-year extremes (maximum during the lifetime of a building) is also equal to Q_k (given that yearly maxima are independent).

The combination value of a variable action $\psi_0 Q_k$ takes into account that it is not likely that two independent variable actions have their maximum in the reference period (50 years) exactly at the same time. Furthermore the combination value ψ_0 also takes

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into account that for two independent random loads the standard deviation of the sum is less than the sum of the standard deviations. The value of ψ_0 is chosen so that the probability of the action effect being exceeded in the reference period due to the combination of actions is approximately the same as when only an individual action is considered (i.e. the characteristic value). This can be done in several ways depending on the level of approximation, as described in [1,3]. For serviceability the combination value is used to reduce non-dominant actions when considering irreversible serviceability limit states.

The frequent value $\psi_1 Q_k$ is associated with reversible limit states to reduce the dominant action, implying that the action effect might be exceeded more than once or for a longer time interval within the reference period. In principle the frequent value might be determined in two different ways: (1) the total time within a chosen period of time, during which it is exceeded, is only a small given part of the chosen period of time or (2) the frequency of its exceedance is limited to a given value. According to [2] the small part of the time being exceeded is 0.01 for imposed actions. However in some background documents of the code [4] 0.05 is recommended.

The quasi-permanent value $\psi_2 Q_k$ is used for calculation of long-term effects (regarding serviceability). It is determined in such a way that the total period of time for which it is exceeded is a large fraction of the chosen period of time. For building floors the recommended fraction is 0.5. Alternatively the time-average of the action can be used to estimate the quasi-permanent value.

2. Model and analysis

2.1. Live load model

The live load model used in this study is based on the model proposed by JCSS [5]. The load is modeled as a stochastic process, which consists of two parts: the sustained and the intermittent live loading. The sustained live load Q_{LS} (Fig. 1a) takes into account ordinary loading situations (e.g. furniture, machinery, stored objects, average usage by people etc.), while the intermittent live load Q_{LE} (Fig. 1b) describes short, extraordinary load peaks (e.g. clustering of people at special events, emergency situations, remodeling, etc.) caused by abnormal events. The total live load Q_L is the sum of Q_{LS} and Q_{LE} (see Fig. 1c). It is evident that the maximum of the total load $Q_{L,max}$ does not necessarily coincide with the maximum sustained load $Q_{LS,max}$ or the maximum intermittent load $Q_{LE,max}$.

According to [5] the arbitrary-point-in-time magnitude of the sustained load can be assumed gamma distributed with expected value μ_s and standard deviation:

$$\sigma_s = \sqrt{\sigma_{v,s}^2 + \sigma_{u,s}^2 \kappa \frac{A_0}{A}} \tag{1}$$

where A_0 is the correlation area, A is the influence area (for beams 2 times the tributary area A_T) and the κ is the peak factor taking into account the structural configuration and the investigated effect. It is usually between 1.0 and 3.0 [6]. In this study $\kappa = 2.0$ was chosen for the sake of simplicity. $\sigma_{v,s}$ denotes the standard deviation of a zero mean normal distributed variable representing the variation of the particular floor; $\sigma_{u,s}$ is the standard deviation of a zero mean random field, which represents the spatial variation of the sustained load [5].

The magnitude of the intermittent load is also assumed gamma distributed with expected value μ_e and standard deviation:

$$\sigma_e = \sqrt{\sigma_{u,e}^2 \kappa \frac{A_0}{A}} \tag{2}$$

where $\sigma_{u,e}$ is the standard deviation of a zero mean random field representing the spatial variation of the intermittent load

Both loads – the sustained and the intermittent – are modeled using Poisson processes. The sustained load is a square wave process, assumed to be constant between occupancy changes. The number of load changes is Poisson distributed with an occurrence rate λ. The intermittent load is considered as a renewal process with an occurrence rate v and a deterministic load duration d_p. The parameters used for the simulation are given in Table 1.

2.2. Analysis

The above described model was used for Monte Carlo simulation. Realizations of the sustained and the intermittent floor loads for the design lifetime (50 years) were generated according to the stochastic model. The total live load for each day of the 50 years period was calculated as the sum of the sustained and intermittent load. This was repeated 10,000 times and the results were evaluated according to the EN definitions of the representative values.

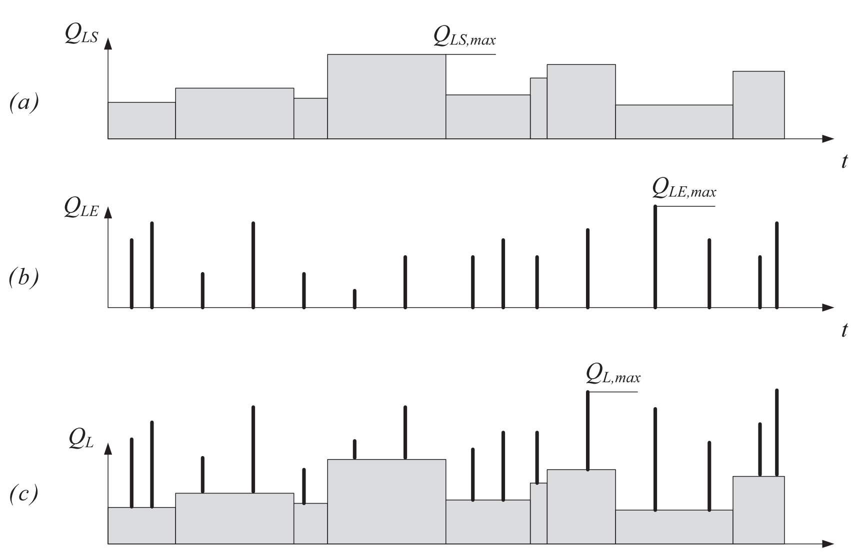

Fig. 1. Sustained (a), intermittent (b) and the total live load (c).