PERFORMANCE-BASED DESIGN
AS A DECISION STRATEGY FOR RISK REDUCTION

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1. INTRODUCTION

It is now generally accepted that several types of "risks" can be recognized for built facilities and environments: they are not limited to collapses and heavy damages but involve comfort and way of life (cf. e.g. Augusti *et al.*, 2003).
The most rational way of tackling such risks and their reduction is Performance-based Design PBD (or, better, Performance-based Engineering).
This lecture will present and discuss briefly the general approach to PBD, and illustrate some examples of application.

2. PERFORMANCE BASED DESIGN: GENERALITIES

By definition, "Performance-Based Design" (PBD) requires the satisfaction of the relevant performance requirements with a sufficiently high probability throughout the lifetime of an engineering system.
Indeed, design is always addressed to fulfil one or more performance objectives, but while up to a few years ago this aim was pursued on the basis of engineering experience and practice, PBD is a design philosophy specifically constructed in order to reach rationally and with a given reliability the chosen objectives.
In this context, the "risk" is usually expressed in terms of the mean annual frequencies of exceeding relevant limit states (LS). These mean annual frequencies can be calculated by combining the site-specific hazard (in turn, measured by the mean annual frequency that the "action" exceeds a given intensity level) with information on the "exposure" (i.e. the probability that the action finds facilities to damage) and the "fragility" of the facility (the conditional probability of exceeding a limit state for a given intensity of the action).
Such "complete" approach to risk evaluation (and consequent reduction) is however very complicated: on the one side the possible combined effects of several actions (earthquakes, wind, voluntary and/or accidental human actions...) should be considered, with an enormous increase of statistics and mathematics; on the other side a number of non-technical questions rise, including comparisons and choices between incommensurable quantities such as casualties, economic losses, quality of life...
These questions will be hinted in the lecture, but the main part will follow the most usual "technical" approach, i.e. focus on one facility subject to a specific action, and calculate its risk neglecting the question of "exposure"; two examples, dealing with to two different types of actions, will be presented.

3. PERFORMANCE BASED DESIGN: APPLICATIONS

Under the above limitations the risk of a structure, identified with the mean annual frequency $\lambda(LS)$ of exceeding a specified limit state, can be assessed by a convolution of two variables: the damage measure *(DM)*, an appropriate measure of the structural damage; and intensity measure

(IM), representing the characteristics of the action at the site, and is usually expressed by a measure of the ground motion intensity.
The total probability theorem allows to evaluate $\lambda(LS)$ by the double integral, Eq.(1):

$$\lambda(LS) = \iint G[LS \mid DM] \cdot dG[DM \mid IM] \cdot d\lambda(IM)$$

where: $G[LS|DM]$ is the conditional probability of exceeding the *LS* given *DM* (describing the failure or loss); $G[DM|IM]$ is the conditional probability of exceeding *DM* given *IM* (derived by structural analysis, and describing the demand prediction for a given *IM*); $\lambda(IM)$, also known as the hazard curve, is the mean annual frequency of occurrence of the action with an intensity higher than *IM* at the specific site (given by the hazard analysis).
The choice of *IM* in Eq.(1) must be based on the requirements of sufficiency, efficiency, and hazard computability (Giovenale *et al.*, 2003).
A sufficient *IM* yields *DM* conditionally independent, given *IM*, on other quantities that may affect the action; thus, it (i) permits an unbiased evaluation of $\lambda(LS)$ by Eq.(1), (ii) simplifies the choice of the records to be used in nonlinear dynamic analyses (to take into account the record-to-record variability), (iii) legitimizes the operation of scaling the action input diagrams,, and (iv) allows decoupling hazard and structural analysis.
An *IM* is (relatively) "more efficient" if it results in a "smaller" variability in the structural response for any given intensity. The variability is expressed by the dispersion in *DM* for any given value of *IM*. Since $G[DM|IM]$ in Eq.(1) can be estimated by running nonlinear dynamic analyses, using a "more efficient" *IM* reduce the number of runs that are needed to estimate $\lambda(LS)$ with the same confidence level. The dispersion in the structural response given *IM* will be assumed as a quantitative measure of the efficiency of that *IM*.
Hazard computability of an *IM* is related to the effort required by the assessment of the hazard curve, $\lambda(IM)$.
Anyway, it is evident that sufficiency is an essential property of an *IM*, and non-compliance with it may result in discarding that *IM*. Once the sufficiency of a candidate *IM*'s is established, efficiency and hazard computability are two relative criteria that can be used to favour that candidate *IM* over the others.
This procedure has been followed in great rigour in Augusti & Ciampoli, 2007, to evaluate the seismic risk of composite steel-concrete: particular attention has been devoted to an appropriate choice of the "best" intensity measure among several "candidates". This paper and its results will be illustrated in the lecture and summarized in the final text.
Sibilio and Ciampoli (2007) have tackled another action and another risk: namely, the discomfort of pedestrians on a bridge that oscillates due to wind actions.
The examined footbridge is an actual structure whose aeroelastic characteristics are known. The relevant "limit state" is identified with a threshold value of the wind-induced oscillations, in accord with the ISO 2631 standard, taking into account the suggested user perception and acceptance criteria. The buffeting and vortex shedding effects on the footbridge deck have been investigated through a 3D finite element non linear analysis in time domain, and the reliability has been assessed by two numerical simulation techniques, i.e. Monte Carlo and Subset. Also these results will be illustrated in the lecture and summarized in the final text.

4. CONCLUSIONS

The general discussion and the example presented demonstrate that Performance-Based Engineering (or Performance-Based Design, PBD, as it is more usually called), although still in its infancy, can already be a powerful tool to estimate rationally, and consequently reduce, risk of built facilities.
Much remains to be done in this direction, e.g. to estimate risks of environments under real-world combination of actions. These problems are much too often tackled in an emotional way: a scientific approach and an appropriate modelling can help decision-makers to tackle them in a rational way.

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