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Monte Carlo simulation for seismic analysis of a long span suspension bridge

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A B S T R A C T

The seismic analysis of long-span cable suspended bridges is undoubtedly a problem in structural analysis that involves a high number of uncertain parameters. In this work, through a probabilistic approach (Monte Carlo simulation) seismic analysis is carried out able to take into account the variability of certain factors relating to the seismic input. Displacement time histories, necessary to define seismic scenarios, are built artificially based on the response spectrum of the site. The analysis is carried out using a 3D numerical model built using one-dimensional finite elements using ADINA software code. This model has been developed in conjunction with a purpose-built program in FORTRAN language to conduct the Monte Carlo simulations. The results expressed in terms of displacements and stresses are described by their average value and their variance.

1. Introduction

The seismic analysis of complex structures is generally a problem affected by uncertainty. Some of the most important uncertain parameters are: the location of the epicenter, the seismic intensity and the attenuation law, the velocity of seismic waves through the soil, the frequency content of the seismic waves, the local effects of the site, etc. Aside from these uncertainties, typical of the seismic analysis of any structure, there are also the uncertainties and non-linearities of behaviour typical of the complex structures such as long-span suspension bridges [1,2]. Many uncertainties are related to the composition of the soil, some are related to the structural behaviour, i.e. the real distribution of masses and rigidity, and others to the numerical models used to describe it.

For a so an extensive structure such as a long-span suspension bridge, complete knowledge of the soil besides being extremely expensive for such an extensive structure, does not introduce the seismic analysis into the well-structured problems defined by Simon [3] since a certain amount of uncertainty would remain within the problem. Remaining with seismic matters, it seems in fact impossible to predict with precision the real location of the epicentre or the prevailing direction of seismic waves.

From a general point of view, the uncertainties can be divided into three fundamental types: *aleatory uncertainties* (arising from the unpredictable nature of the size, the direction or the variability of environmental action, the parameters estimation), *epistemic uncertainties* (deriving from insufficient information as well as from measurement errors or inadequate modelling) and *model uncertainties* (deriving from the approximations present in numerical models). The characterization of uncertainties in engineering and their treatment within structural problems is an extremely wide theme; Der Kiureghian and Ditlevsen [4] provide an interesting overview of this topic. In general, random or aleatory uncertainties can be addressed using a reliable procedure to estimate the parameters involved in the problem [5–8]. Epistemic uncertainty can be reduced by improving the surveys aimed at characterization of the phenomena studied and using fuzzy approaches [9–11]. Finally, one possible way to reduce model uncertainties is the use of several FEM models with different levels of detail and the proper planning of numerical simulations [12,13].

In this context, it is evident that a classic deterministic approach is inadequate for an appropriate assessment of the behaviour of a long-span suspension bridge under seismic action. More reliable approaches can be found in methods to handle uncertainties in structural problems, such as using probabilistic formulations or fuzzy theories.

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2. Structure description

The structure analysed in this article shows geometric and mechanical characteristics based on the design of the bridge over the Strait of Messina Bridge in 1992 [14]. Although the structure was not built, the project and the analyses are of great interest due to the importance of the construction and the problems involved in the definition of structural behaviour. The project of 1992 provides that the Strait is crossed with a suspended bridge with a main span of 3300 m in length (Fig. 1). The total length of the bridge deck, including the side spans, is 3666 m, with a width of 52 m. The bridge deck is constituted by three box sections (Fig. 2), the external ones with the task of carrying roadways and the central one the railway system. Every 30 m the three box sections are joined by a transverse beam. The shape of the box sections and the distance that separates them were designed to reduce the effect of wind on the structure. The longitudinal profile of the bridge deck is slightly arched, starting from an altitude of 52 m on the side of Sicily, rising to 77 m in the middle of the bridge and then dropping to 62 m on the side of Calabria. This trend is to ensure a minimum clearance of 60 m with a width of 600 m, which is necessary for navigation.

The two towers (Fig. 3) of the suspension bridge (made entirely of steel) are two multilevel portal frames and reach an altitude of 381 m. The legs are not perfectly vertical but have a transversal inclination of approximately 2° so that the distance between the axes of the legs change from approximately 78 m at the base to 52 m at the top. The leg sections are octagonal and can be fitted within a rectangle of 16 × 12 m. The two legs are connected by 4 transverse beams that mount the structure, approximately 17 m high and 4 m wide. The structure has four main cables, arranged in pairs on the vertical side of the ends of the transverse beams of the bridge deck, and thus at a distance of 52 m. The axle spacing between the cables of each pair is 1.75 m and each cable has a diameter of approximately 1.24 m. The effective development of the cables is approximately 5240 m and includes 3370 m of cable length in the central span and 1020 m and 850 m on the two side spans. The two cables of each pair are connected to each other every 30 m by steel rings from which hangers extend to connect and support the bridge deck to the main cables.

The main cables supporting the floor transmit their axial action in part along the vertical parts of the towers, and in part directly to the ground, anchored in two large structures (on the side of Sicily and Calabria), in massive reinforced concrete. The anchor blocks are different, since the nature of the deposit on which they rest is diverse. In Sicily, the land is made up of slightly cemented gravels while in Calabria there is a more consistent rock. For this reason the anchoring in Sicily is composed of a block of approximately 328,000 m^3 while that in Calabria is approximately 237,000 m^3. Table 1 shows the main mechanical characteristics of the structure.

The main structure of the bridge (except for the anchoring blocks) is designed in steel. The characteristics of strength and deformability are shown in Table 2.

3. Definition of seismic input

3.1. Signal generation

For the analysis of structures resistant to seismic action, a dynamic analysis of response (using a response spectrum or a time history) is often required by the technical rules. This analysis is required for all structures that have high non-linearities of behaviour, when structures to be analysed have irregularities in plan or in elevation, or when certain temporal information in the response of the structure itself must be known [15]. In some cases the most appropriate dynamic analysis is the step-by-step integration of the equations of motion characterizing the seismic event. However, the use of dynamic analysis is linked to the need to have an accelerogram representative of the seismicity of the area, data that is not always present. Besides, a non-deterministic approach would

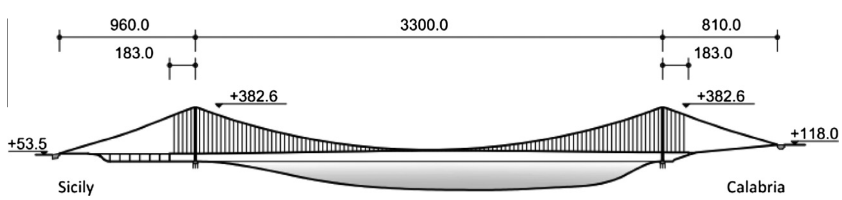

Fig. 1. Geometrical dimensions of the Messina Strait Bridge (m).

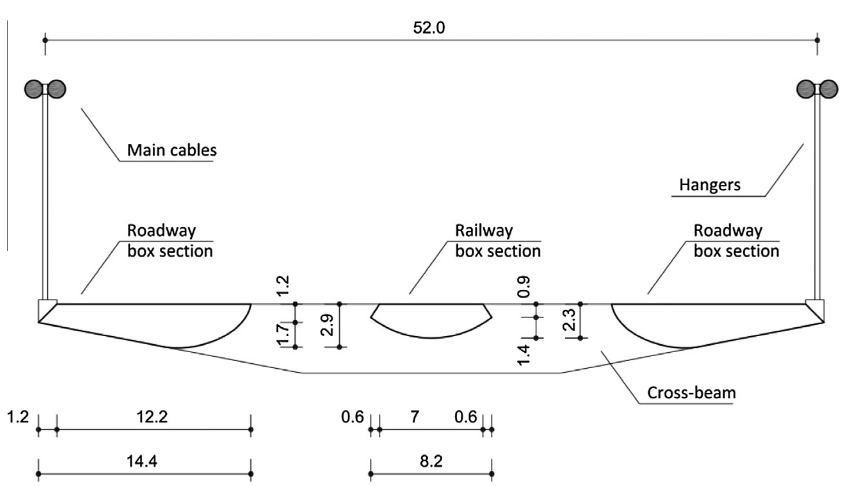

Fig. 2. Geometrical dimensions of the bridge-deck section (m).