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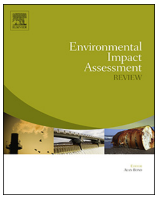

Social life cycle assessment of concrete bridge decks exposed to aggressive environments

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ABSTRACT

Sustainable design of structures includes environmental and economic aspects; social aspects throughout the life cycle of the structure, however, are not always adequately assessed. This study evaluates the social contribution of a concrete bridge deck. The social performance of the different design alternatives is estimated taking into account the impacts derived from both the construction and the maintenance phases of the infrastructure under conditions of uncertainty. Uncertain inputs related to social context are treated through Beta-PERT distributions. Maintenance needs for the different materials are estimated by means of a reliability based durability evaluation. Results show that social impacts resulting from the service life of bridges are not to be neglected in sustainability assessments of such structures. Designs that minimize maintenance operations throughout the service life, such as using stainless steel rebars or silica fume containing concretes, are socially preferable to conventional designs. The results can complement economic and environmental sustainability assessments of bridge structures.

1. Introduction

The World Commission on Environment and Development (WCED) defined in 1987 sustainable development as “meeting the needs of the present without compromising the ability of future generations to meet their needs” (WCED, 1987). Since then, sustainability has attracted an increasing attention in many sectors of the society as a response to the negative side effects of the predominant focus put on economic expansion. Sustainability has to be understood as maximizing the benefits, or minimizing the burdens, for the society, not only in the short but in the long term as well (Sierra et al., 2018). Therefore, sustainable design of a specific product should be based on the economic, social and environmental implications of its production and use over time. According to the definition of sustainable design, long lasting products are very prone to interfere in sustainable development, as their impacts will be long lasting as well, thus affecting future generations. This is the reason why essential structures, such as dams or bridges, which are designed to last for over 100 years in most of the cases, are in the spotlight of many researchers. In particular, bridges are critical elements of the transport system of a region, due to the economic and social consequences that may derive from their failure. In recent years, research has been conducted on both the environmental (Du et al., 2014; Pang et al., 2015) and the economic impacts of concrete bridges (Safi et al., 2015; Yepes et al., 2017; Navarro et al., 2018). Additionally, the simultaneous impacts in the environmental and economic field derived from the design have also been analyzed (Yepes et al., 2015; García-Segura and Yepes, 2016; Martí et al., 2016). However, to the best of our knowledge, very little has been published regarding the social assessment of bridge structures throughout their life cycle (Gervásio and da Silva, 2013; Lounis and Daigle, 2010).

This is a natural consequence of the maturity level of the different methodologies existing for the assessment of the environmental, economic and social impacts under a life cycle framework. The environmental life cycle assessment (E-LCA) has become highly standardized both methodologically and in terms of implementation (ISO, 2006a; ISO, 2006b). The methodology existing for the assessment from an economic perspective, namely the life cycle costing (LCC), also shows a relatively mature state (Hunkeler et al., 2008), although an ISO standard does not yet exist. However, social life cycle assessment (SLCA) is a quite new technique for estimating social impacts throughout a product's life cycle. Considerable efforts have been made in SLCA for developing a strong and coherent methodology, resulting in 2009 in the ‘Guidelines for social life cycle assessment of products’ (UNEP/SETAC, 2009), referred herein simply as the “Guidelines”. Nonetheless, according to Jørgensen (2013), the SLCA still requires to show its validity before it can be considered to be out of its infancy. Even the Guidelines state that ‘there is an urgent need for the application of SLCA’ by means of case studies that help to further develop this recently arisen methodology.

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Since the publication of the Guidelines, several studies have been carried out under the life cycle framework focusing on different types of products, such as electronics (Umair et al., 2015; Wilhelm et al., 2015), food industry (De Luca et al., 2015; Bouzid and Padilla, 2014) or fertilizers (Martínez-Blanco et al., 2014). Regarding the construction sector, social impacts related to different building materials (Hosseinijou et al., 2014; Hossain et al., 2017), to concrete recycling (Hu et al., 2013) and to building construction (Dong and Ng, 2015) has been assessed so far. These latter studies exclude the maintenance and use stage from the analysis, due to the complexity of the evaluation required for this phase. This analysis perspective may lead to erroneous conclusions, as the maintenance stage is a main source of impacts throughout the life cycle of a structure. Consequently, the comparison of different building materials under a life cycle perspective should not only take into account their different maintenance needs, but it should integrate them as well in an assessment, which considers every relevant life cycle phase of the product.

Considering the above, the application of SLCA to concrete structures taking into consideration the different life cycle stages cannot be found. In particular, no SLCA has been performed to date on bridge structures, thus evidencing a lack of information towards the sustainable design of such infrastructures. To overcome the above-mentioned limitations, this study aims to apply the methodological framework proposed in the Guidelines to assess the social performance associated to different construction materials applied to a reinforced concrete bridge deck.

2. Social performance evaluation of deck designs

Deterioration and maintenance of reinforced concrete structures are some of the most demanding challenges that the construction industry is confronted with. In particular, concrete structures are subjected to particularly aggressive degradation processes when exposed to marine environments. Although there are several mechanisms that may degrade concrete in such environments, experience demonstrates that the most critical threat in concrete structures in marine environments is chloride-induced corrosion in the reinforcing steel. Different alternatives have been developed throughout the last years to prevent reinforcing steel from being corroded. The present research focuses on specific prevention strategies applied to a real concrete bridge deck exposed to a marine environment. The bridge of Illa de Arosa, in Galicia - Spain is analyzed. Fig. 1 shows a cross section of the bridge deck. The input data regarding both the geometry and the durability characterization of this structure has been obtained from the literature (León et al., 2013; Pérez-Fadón, 1985; Pérez-Fadón, 1986). Located 9.6 m over the high tide sea water level, the deck has a width of 13 m and a section depth of 2.3 m. The original concrete mix of the bridge deck has a cement content of 485 kg/m^3, and a water/cement ratio w/c = 0.45. According to Pérez-Fadón (1985), the reinforcing steel amount is 100 kg/m^3 of concrete, with a concrete cover of 30 mm. This quantity does not include the steel of the prestressing tendons. It is worth noting that according to the Spanish regulations for marine environments, the deck is designed for no cracking of concrete, i.e. the concrete remains uncracked.

This study evaluates the social performance of alternative deck designs for the case study considered based on prevention strategies that are usually assumed when designing structures in marine environment. On one hand, the original concrete cover is increased to 35 mm, 45 mm and to 50 mm (measures CC35, CC45 and CC50 respectively henceforth). On the other hand, the original concrete mix is modified by adding fly ash, silica fume and polymers. Specifically, additions of 10% and 20% of fly ash (measures FA10 and FA20), 5% and 10% of silica fume (measures SF5 and SF10) and 10% and 20% of polymers (measures PMC10 and PMC20) are assumed. The mentioned percentages are expressed as a percentage of the cement content of the reference concrete mix design. The polymer assumed in the present study in the definition of PMC alternatives is styrene-butadiene rubber (SBR) latex, which has been widely used for such purposes (Yang et al., 2009). Both polymers, silica fume and fly ash, improve concrete durability by densification of concrete, thus hindering chloride diffusion. Another way to reduce concrete porosity is by reducing the water/cement ratio. In this study, a decrement in the water/cement ratio to w/c = 0.40 and to w/c = 0.35 (measures W/C40 and W/C35) has been considered. The concrete mixes corresponding to the design alternatives presented above are shown in Table 1. Additionally, it has been considered to treat the exposed deck surface with hydrophobic (measure HYDRO) and with sealant (measure SEAL) surface treatments. The replacement of the existing ordinary steel with galvanized steel (measure GALV) and with stainless steel (measure INOX) has also been considered. In summary, 15 preventive designs are evaluated as alternatives to the design of the existing bridge deck. This study compares the social performance of each of the presented preventive designs, taking into consideration the social impacts derived from the different stages of the life cycle for the described deck.

3. Social life cycle assessment

The framework for SLCA presented in the Guidelines relies on the standardized *E*-LCA methodology as presented in ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). Therefore, the SLCA involves four steps, namely the goal and scope definition, inventory analysis, impact assessment, and interpretation.

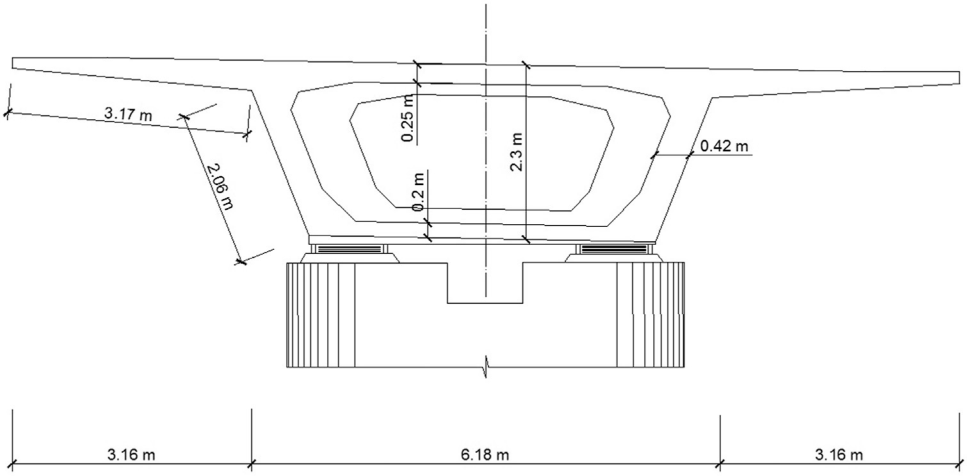

Fig. 1. Cross section of the Arosa's concrete bridge deck.

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