Safety Science 91 (2017) 168–180

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Holistic approach for treatment of accidental hazards during conceptual design of bridges – A case study in Sweden

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ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 12 July 2016
Accepted 13 August 2016

Keywords:
Bridges
Conceptual design
Accidental hazards
Holistic approaches
Risk

ABSTRACT

The control of risks in engineering design is, for most conventional construction projects, achieved through the use of design codes. However, relying on design based on code-compliance can lead to situations where risks are overlooked or inadequately treated; a complementary approach is needed. In this paper, a holistic risk-informed approach for the treatment of accidental hazards during the conceptual design of bridges is considered and a framework for such an approach is provided. The treatment of these design situations is incompatible with current codified approaches. Although risk assessments are commonly used in the design of large scale infrastructure projects, such approaches are rarely used for more common bridge designs. The assessment procedure, applicable for more conventional bridge projects, is described and some background information is provided that is useful for applying the proposed approach in practice. To illustrate the application of the proposed approach in practice, a case study of a bridge construction project in the west of Sweden is considered in which the approach is applied.

1. Introduction

Engineering design requires that the risk of failure is adequately controlled to ensure tolerable safety levels as well as serviceability in the resulting structure. In modern day design, the control of these risks is achieved through the use of design codes (Bulleit et al., 2014). A previous paper (Björnsson, 2015a) investigated the inadequacies of design codes as instruments for controlling risk in engineering design. These limitations were discussed considering three separate aspects of codified design: (1) the role of design codes as instruments of regulation; (2) the balance between the two different types of design provisions provided in design codes (i.e. prescriptive or objective based); (3) the safety formats in the codes. Each aspect was investigated on its own, citing various sources (see, e.g., Shapiro, 1997; Elms and Tukstra, 1992; Sexsmith, 1999; Coeckelbergh, 2006; Davis, 2012; Bulleit, 2012), and risks were identified for which the design codes are inadequate in treating. It was concluded that a complementary approach is necessary for addressing these risks more appropriately; a holistic approach, based on risk assessment procedures, was advocated. The requirements of such an approach as well as some practical considerations relating to its implementation in practice were also discussed. This paper builds upon the conclusions from Björnsson (2015a) by outlining in more detail an approach which aims at better controlling risks not adequately treated in the design code. The focus is on the treatment of accidental hazards during the conceptual design phase for bridge structures; a design situation which is currently not well addressed using codified design approaches (Björnsson, 2015a).

The approach advocated in this paper has three main advantages:

1. It serves as a complement to codified approach.
2. It broadens scope of assessment (accounts for system & non-structural aspects).
3. It is also applicable for conceptual design of bridges.

To start, the approach is intended to be a complement to the design codes and as such is intended for controlling risks not adequately addressed or outside the scope of the codes. In this way the treatment of risks in engineering design is more complete. The second advantage is that it provides a broader interpretation of the design process as it's not confined to the design and verification of individual structural components. Instead, the resolution of the system is broadened to not only include technical design of the entire structural system, but also the interrelation of the structure with extra-structural aspects of the system (e.g. the transportation network and its users). Finally, the proposed approach can be applied at the early stages of the design phase (i.e. conceptual design) and helps provide additional information valuable for informed decision making and specifically for comparing proposed

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http://dx.doi.org/10.1016/j.ssci.2016.08.009
0925-7535/

technical solutions as well as identifying critical scenarios that may require more investigation at later design stages (i.e. risk screening). The first two advantages have been discussed in more detail in Björnsson (2015a) while the third requires some more elaboration (see Section 1.1).

To help illustrate the value of the proposed approach, it was applied to a construction project in Sweden as a case study. The project entails the construction of two new road connections to help bypass heavily utilized roads. Based on a feasibility study conducted by the Swedish Transportation Authority (STA), three technical solutions are investigated using the proposed approach. The aim of these investigations is to assess the influence of conceptual design decisions (in terms of different choices of the overall technical systems) on the risks related to extreme or accidental events. Furthermore, the results of such assessments should help determine which of risks are critical (for each of the solutions) and evaluate which design strategies could be implements for treating these risks during later stages of the design and construction.

1.1. Risk considerations during conceptual design

During the initial conceptual design phase, multiple technical solutions, or design alternatives, may be proposed based on the initial design constraints and specifications for the construction project; see Fig. 1. The solutions themselves will not be very detailed and may only include brief descriptions regarding the overall structural concept for the bridge structure; e.g., a cable-stayed or a suspension bridge. The transition to the detailed design phase entails deciding which of the design alternative is preferable (the process of making this decision is discussed in later sections). Once a preferred alternative has been chosen, there will likely be additional design constraints specified as requirements for the detailed design phase, e.g., concerning preferable/required design activities/verifications. For example, it may be decided that a bridge is preferable to a tunnel solution for crossing a navigational waterway and a requirement is specified that the bridge piers are protected against or designed to withstand vessel collision; something that would not have been an issue if the tunnel option were chosen. Once the detailed design phase is completed, a finalized design is specified and the construction can commence.

In the subsequent sections, a description is provided for a supplementary design procedure that focuses on the treatment of risks that are not adequately addressed using design based on code-compliance. Special attention will be placed on its application during the conceptual phase for the design of bridge structures. To help illustrate its application in practice, a case study of an infrastructure project in Sweden is presented for which the methodology was applied.

2. Assessment procedure

The risk assessment procedure is meant to be generic and possible to apply during the conceptual design of conventional bridge structures with the aim of better controlling the risks that are not adequately treated in the design codes. In this paper, focus will be on the investigation of accidental or extreme hazards relevant for the design of bridges; see Table 1.

The basic steps for the procedure are to identify and deductively assess each hazard and determine relevant risk scenarios while attempting to screen non-critical scenarios based on qualitative assessments. This screening process is conducted by considering the chain of events describing each scenario and determining appropriate strategies for mitigating the risks they represent; see Fig. 2. In total, four separate design strategies are possible: (1) the risk is considered insignificant (or out of scope) and the scenario is neglected, (2) resources are allocated for preventing the initiation of the scenario, (3) the element directly affected by the hazard is strengthened such that damage cannot progress further or (4) resources are allocated for limiting the consequences associated with further progression of damage.

With regards to design situations that are provided in the code, it could be said that the prominent strategy is one of controlling local resistances. In other words, for some action specified in the codes (e.g. traffic loads) the strategy is to control the local resistance such that minimum reliability levels for the structural components are attained; i.e. the *withstand damage* strategy in Fig. 2 is adopted. However, there may be cases that the provisions in the code are limited in their application (or even un-conservative) and as such, additional measures need to be taken. It is important that the designer considers whether or not all the provisions apply specifically for the design case being investigated. An example was brought up in a previous paper (Björnsson, 2015a) regarding the risk of microbiologically induced corrosion (MIC) for a bridge constructed in Sweden; in that case, it was wrongfully assumed that the provisions in the code regarding more conventional forms of

Table 1
Examples of accidental hazards for bridges (Björnsson, 2015a).

Initiating hazards	Source of hazard
Collision to supports	Trucks, trains, ships, airplanes
Collision to bridge deck	Trucks, ships
Overloading of deck	Inadequate strength, abnormal loading
Explosion	Vehicles, nearby structures
Fire	Vehicles, nearby structures
Hydraulic action	Scour, debris flooding
Other natural events	Storm (wind), earthquakes, landslides, settlements
Malevolence	Terrorism, vandalism

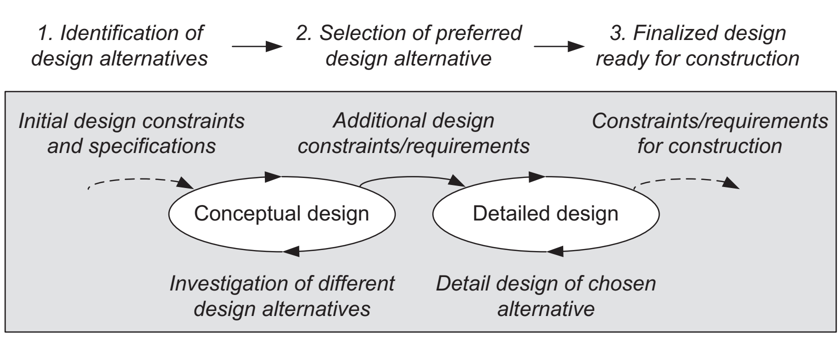

Fig. 1. Investigation of risks during conceptual and detailed design phase.