Numerical Analysis of Highly Nonlinear Effects in Bridge Dynamics

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Summary

Structural engineering typically tries to linearise physical processes in order to simplify their analysis. Whilst this is often permissible without a substantial reduction in accuracy, numerous phenomena are in fact highly nonlinear and cannot be linearised without sacrificing accuracy and, in a structural design context, structural safety. Many of the most complex such phenomena occur in bridge dynamics and this paper outlines some work in relation to nonlinear numerical analyses of dynamic interactions. Examples discussed are the process of lifting a bridge segment from a floating barge and that of nonlinear cable oscillations.

Keywords: Bridge Dynamics, Nonlinear Analysis, Long-Span-Bridges, Stay-Cables, Finite Element Analysis

1. Introduction

Ever more powerful computational resources allow more and more sophisticated numerical analyses to be performed. Some of the most demanding simulations in structural engineering are found in the field of nonlinear structural dynamics.

Whilst in structural design the phenomena are usually linearised in order to simplify their analysis, numerous phenomena are of a high order of nonlinearity and cannot reasonably be linearised. Nonlinear dynamic processes require a sophisticated analysis where care is exercised to check for convergence and often resolution on the spatial and temporal scale need to be higher than for linear problems. The issue of computational demand is not the subject of this paper, however it is important to note that many of the very complex nonlinear problems can nowadays be simulated on standard office computing hardware within reasonable amounts of time. There is hence less and less of an excuse not to perform nonlinear computations and clients ought to be aware of this. More importantly for the engineer, it is often more efficient to invest in the more costly nonlinear simulations, when otherwise in linearised simulations the error needs to be carefully estimated as an essential part of the result interpretation.

Many of complex nonlinear phenomena can be found in bridge dynamics. This paper presents two examples of highly nonlinear dynamic problems in bridge engineering that were analysed numerically. The paper will outline the modelling techniques used and present some results.

There are several possible causes of nonlinear effects in structural dynamics, but this paper will focus on nonlinearity of the system stiffness. Often in structural dynamics the system nonlinearity arises from static effects and damage. If then the dynamic effects are relatively small compared to the static effects, a linearization can be performed and a more efficient linear dynamic analysis be executed. This also allows for the utilisation of modal superposition techniques. If however strong nonlinearity arises from the dynamic effects, nonlinear analyses must be performed and generally time stepping schemes are employed. Two examples for such problems will be discussed in the paper (1) Segment lifting dynamics and (2) Stay-cable vibrations induced by anchorage excitation.

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2. Nonlinear Dynamics

2.1 Segment lifting dynamics

When cable-stayed bridges with steel girders are erection in free cantilevering over water, segments are typically hoisted from a barge using a lifting gantry positioned on the superstructure. The segment is delivered from a barge which is subject to wave excitation. Nonlinearity arises from the successive load transfer from the barge to the bridge cantilever and eventual separation. A re-impacting of the segment onto the barge trestles may occur, leading to an impact effect.

Fig. 1: Stonecutters Bridge segment lifting setup

Here, the lifting of segments during the construction of Stonecutters Bridge [3, 4] is studied. Figure 1 shows the tip of the cantilever with the gantry and the segment positioned on the barge ready to be lifted using strand bundles.

Figures 2 and 3 show the system response during the lifting from initial shortening (cable force free) until after lift-off of the segment from the barge. It can be seen how the force in the cable increases, leading to a coupling of the cantilever with the barge motion. When the segment becomes free, it re-impacts several times onto the barge. This leads to a strong dynamic magnification, whereby the peak cable force and thus peak load on the cantilever is well beyond the static weight of the segment. For the case without jack retraction the dynamic magnification factor (DMF) is 1,45. In the second case a jack retraction of 200 mm in 5 seconds applied when the segment first lifts off. This increases the gap and reduces the re-impacting, thus reducing the DMF to 1,35.

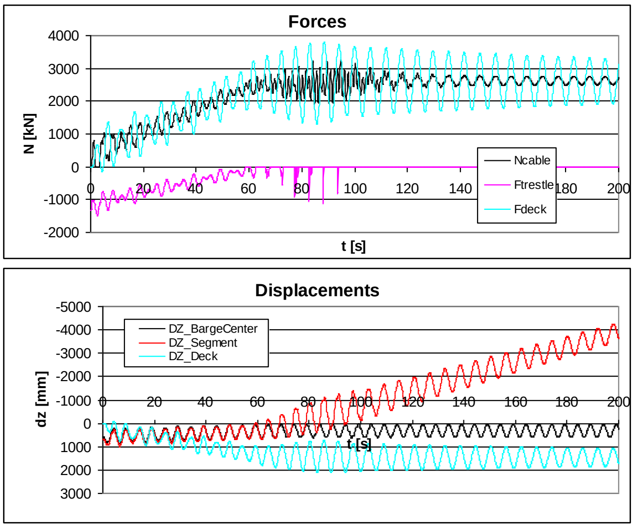

Fig. 2: Segment lifting response without jack retraction

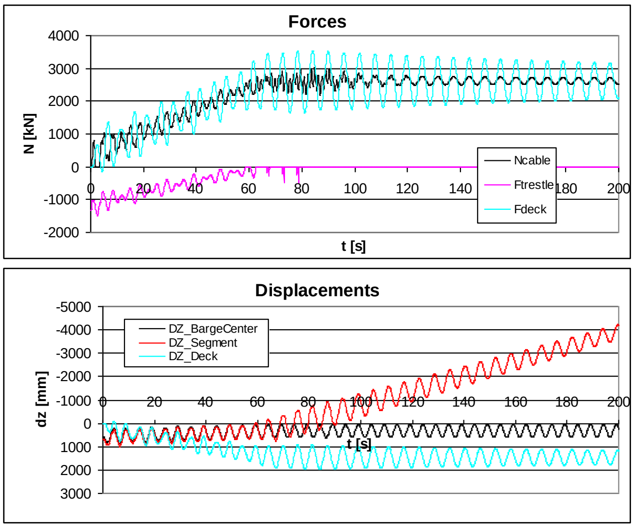

Fig. 3: Segment lifting response with 200mm jack retraction

3. Summary, Conclusions and Outlook

This paper outlined the complexity of some nonlinear dynamic problems and shown how powerful modern numerical algorithms and computing platforms have become. In the future engineers will have to seriously consider whether linearisation is the best answer to dealing with nonlinear problems. On the other hand, nonlinear simulations are considerably more difficult to validate and are described by more parameters that may be subject to uncertainty. The development of methods for evaluating the quality of such solutions is hence an important challenge. This directly relates to estimating the risk that the underlying phenomena pose to the structure. Such risk can only be determined by analysing the quality of the model, the uncertainty in the parameters and the vulnerability of the structure and/or its components. Robust design is often a better answer than an ever more complicated analysis.