

CIR-DAGEN 2022 - HÖGHASTIGHETSJÄRNVÄG

DYNAMIK: FRAMSTEG & UTMANINGAR

Mahir Ülker-Kaustell, Tyréns AB



KORT OM MIG

- KTH, Väg- och vatten, 2001-2006
- Forskarstudent inom strukturdynamik KTH/Brobyggnad, 2006-2013
 - Dynamisk jordstrukturinteraktion
 - Lagerfriktion
- Tyréns heltid 2013-
 - Utredningar av olika slag
 - Kompetensutveckling
 - Programmering
 - Metodik
 - Förvaltningsdata

INNEHÅLL

- Bro
- Bank
- Gränssnittet bro/bank



BRO

- Projektering av nya järnvägsbroar
 - Dynamisk jord-strukturinteraktion
- Utvärdering av befintliga broar
 - Klassningsberäkning - kontroll av tillåten tågfart
 - Uppgradering till högre tågfart och axellaster
 - Övervakning
- Åtgärder för att minska vibrationer hos befintliga järnvägsbroar
 - Viskösa dämpare
 - TMD
- Kunskap om järnvägsbroarnas mekaniska egenskaper
 - Mätningar med kända laster
 - Långtidsmätningar
 - Lagerfriktion

DYNAMISK JORD-STRUKTURINTERAKTION

2010

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Simplified analysis of the dynamic soil–structure interaction of a portal frame railway bridge

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ABSTRACT

A qualitative analysis of the dynamic soil–structure interaction (SSI) of a portal frame railway bridge based on the linear theory of elasticity is presented. The influence of SSI on the dynamic properties of the structure and its response due to the high-speed train model (HSTM) of the Eurocode is analysed by simple concepts from the linear element theory. The dynamic behaviour of the foundation of the structure is simulated by means of dynamic influence functions, describing the stiffness and damping of the foundation–soil interface. These frequency dependent functions are used as boundary conditions in a two-dimensional finite element model of the structure. The equations of motion are solved in the frequency domain and the time domain solution is obtained by the fast Fourier transform algorithm. It is shown that the variation and material damping of the foundation–soil interface may give a substantial contribution to the modal damping ratio of the structure. A comparison of the dynamic response of the structure, subjected to the HSTM, assuming different SSI models shows that using the vertical degree of freedom may grossly underestimate the vertical acceleration in the bridge deck.

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1. Introduction

Traditionally, the analysis of dynamic effects in design calculations for railway bridges have been based on quasi-static analyses in which the dynamic effects are considered by means of dynamic amplification factors [204]. These CDF were determined by experimental studies on the dynamical behaviour of rail structures [1]. However, the increasing train speed and the dynamic effects especially at resonance, have led to a paradigm shift in that today, the design calculations are often based on dynamic analysis [2,3]. According to the European design code (Eurocode [1]), a dynamic analysis may be needed if the maximum allowable train speed on the bridge exceeds 200 km/h. This analysis is based on the so-called high-speed load model (HSTM) which consists of a number of train configurations in which each axle of the train is modelled as a moving point load.

Even under the assumption of linear elasticity, the dynamic behaviour of structural systems is known to be much less intuitive than the corresponding static behaviour: as the inertia and damping terms make the governing mathematical models somewhat more complicated. For example, the distribution of bending moments may differ significantly between the two design methods (see Fig. 1). Are there more important effects related to the acceleration

of the bridge deck. The acceleration values must be limited to ensure a certain level of safety against train derailment which may occur if the vertical bridge deck acceleration approaches the constant of gravity. The Eurocode specifies a maximum vertical bridge deck acceleration of 5 m/s² for subballasted tracks and 3.5 m/s² for ballasted tracks. The limit for ballasted tracks is somewhat lower since in this case, the stability of the track superstructure must also be guaranteed. When bridge deck accelerations are considered, the Eurocode allows a cut-off frequency of 30 Hz, but for other design criteria, consequences of the computed quantity in terms of the required number of modes of vibration) limits the cut-off frequency.

The geometry and limitations in material parameter values yields a design problem which is quite difficult if the limits on the bridge deck accelerations cannot be met. The redistribution of tension forces or stresses can often quite easily be accounted for simply by choosing another steel thickness or adding a few extra reinforcement bars in a concrete section. However, if the dynamical criteria cannot be met, it may be very difficult to adjust the main and/or stiffeners of the structure in such a way that the train-bridge resonance speeds are moved outside the range of train speeds at hand. Especially the choice of boundary conditions for dynamic analyses, appears to constitute a group of very sensitive parameters, which have a considerable influence on the dynamic behaviour of certain bridge types. In this paper, the authors demonstrate how these parameters may influence the behaviour of a portal frame bridge. Furthermore, the introduction

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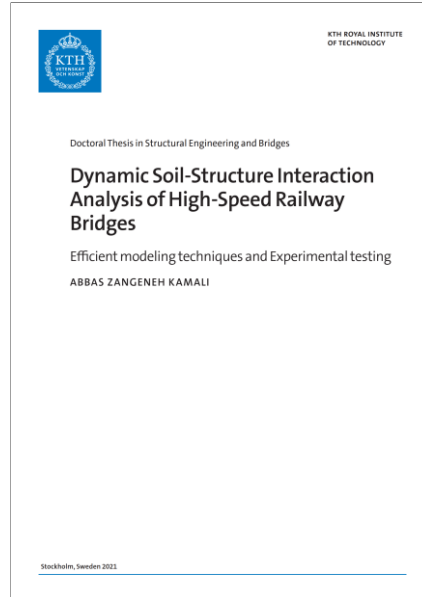
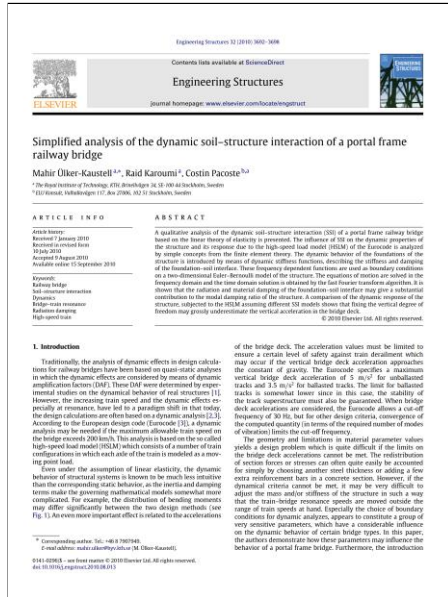
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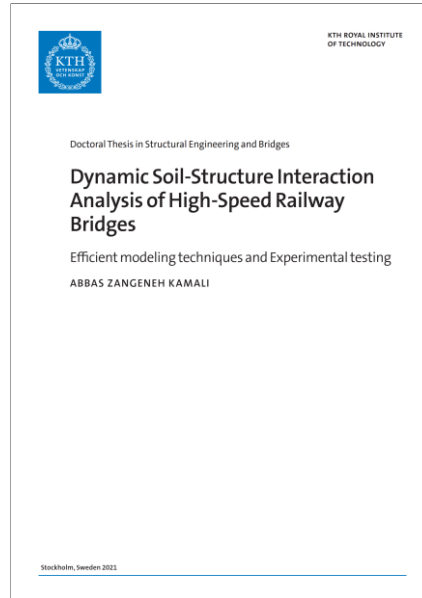
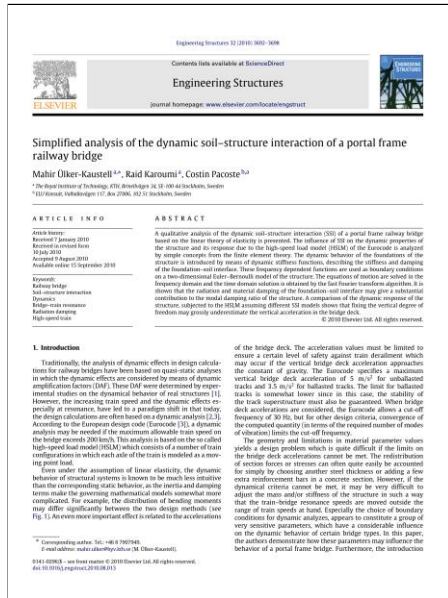
DYNAMISK JORD-STRUKTURINTERAKTION

2010 → 2021



DYNAMISK JORD-STRUKTURINTERAKTION

2010 → 2021



Ny kunskap

11 år för att nå en metod som är tillämplig

Några delar återstår dock:

- Årstidsvariation
- Parameterval
- Osäkerhetsanalys

LAGERFRIKTION

2013

International Journal of Rail Transportation, 2013
Vol. 1, No. 4, 237–257, <http://dx.doi.org/10.1080/23248378.2013.835129>



Influence of rate-independent hysteresis on the dynamic response of a railway bridge

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(Received 18 June 2013; final version received 24 July 2013)

It is well known that the dynamic properties of civil engineering structures have a more or less pronounced amplitude dependency. However, it is rather difficult to quantify this both experimentally and theoretically. This paper describes an attempt to identify the sources of the amplitude dependent variation of the natural frequency and the modal damping ratio of the first vertical bending mode of a simply supported, balanced steel-concrete composite railway bridge. It is proposed that the most likely sources to the non-linear properties of this mode of vibration are the ballast track, the foundations and the roller bearings used mainly to relieve constraint forces due to changes in temperature. The non-linear influence of the suggested sources were modelled in a 2D finite element model using the classical Bouc-Wen model which was implemented as a user-defined element in ABAQUS. The results suggest that the roller bearings alone can give account for the variation in the dynamic properties observed in experimental data from the bridge and that the combination with a simple model of the track superstructure gives the most realistic result. A noticeable increase in the dissipation of energy was found as the amplitude of vibration was increased beyond that available in the experimental data, thus motivating further research within this field.

Keywords: railway bridges; non-linear dynamics; soil-structure interaction; ballast; roller bearing; Bouc-Wen models

1. Introduction

In a previous publication [1], the authors have shown that the dynamic properties, i.e. the natural frequency and the modal damping ratio of a particular simply supported steel-concrete composite bridge have a certain amplitude dependency. The natural frequencies of the first vertical bending and the first torsional mode were found to decrease with increasing amplitude of vibration, while the corresponding damping ratios were found to increase. These results were obtained by analyzing the free vibrations of the bridge after a train passage by means of the continuous wavelet transform (CWT). Clearly, the reduction of the eigenfrequency may lead to non-conservative conclusions in terms of critical train speeds for high-speed railway bridges. However, the increasing damping ratio may very well compensate for this effect.

A simplified analysis based on a single degree-of-freedom system of the bridge was later performed [2] which confirmed the above stated suggestions. However, the nature of these non-linear effects is still unknown, although it was suggested that they may originate in soil-structure interaction since it is a well-established fact that soil materials have a similar qualitative behaviour. Other sources are also possible, such as the hysteretic

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LAGERFRIKTION

2013

→ 2021

→ 2024?

International Journal of Rail Transportation, 2013
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1. Introduction

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TSK10 Bro 14M - Fördjupad dynamisk analys

Mahir Ulker-Kanaltel
18 december 2021

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1 Bakgrund

Projekterad gång- och cykelbro 14M ingår i projekt Tyvfrånstads Södertörn och ska ersätta befintlig gång- och cykelbro och kör 2.0x2.2 över väg E4/E20 i Fittja. Figur 1 visar en skiss av broens statiska system. Den föreslagna broen är en massbänkbro i ett spann om 32 meter. Broen ska byggas på övergångsskivan. Under broen går väg E4/E20 och det finns planer för att utvidga vägen till fyra riktningar, men av produktionsmässiga skäl (ombyggnad av trafik) vill man bygga broen i ett spann. Ett naturligt val för denna bro är att bygga den med fundamentala tekniken för broar vertikala lagringssystem med enstaka stödder som är utformade proportionellt mot L^2 där L är broens längd.

För att kunna bygga broen utan att behöva en stödder i mitten av broen, så har man valt att använda en TMD (Tuned Mass Damper) för att minska vibrationerna. Detta är en massa som är fäst i broen och som kan röra sig i relation till broen. Den ska vara fäst i broen och ha en massa som är proportionellt till broens massa. Den ska också ha en dämpning som är proportionellt till broens dämpning. Detta är en massa som är fäst i broen och som kan röra sig i relation till broen. Den ska vara fäst i broen och ha en massa som är proportionellt till broens massa. Den ska också ha en dämpning som är proportionellt till broens dämpning.

*Tuned Mass Damper, en typ av dämpningsanordning.



Figure 1: Bridge static system

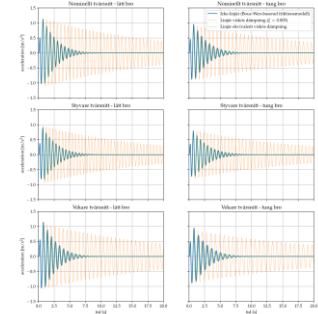


Figure 6: Jämförelse av vertikal acceleration vid broens stöd för de olika antagandena rörande broens mass och styvhets.

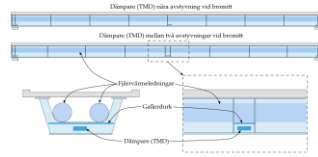
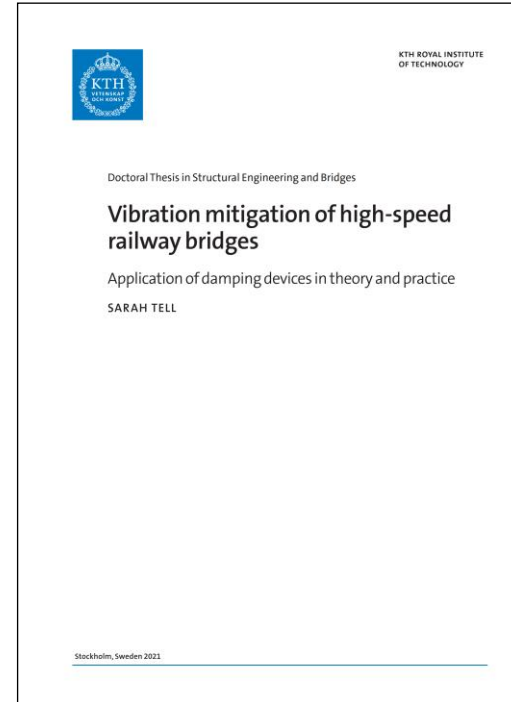


Figure 7: Skisser beräknade olika potentiella placeringar av dämparen.

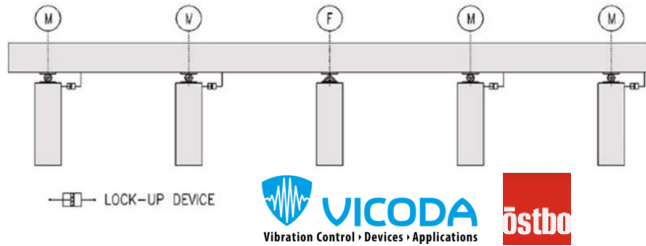
VISKÖSA DÄMPARE

- Viskösa dämpare används ofta som lastfördelande och stabiliserande element vid seismisk dimensionering. Det handlar då primärt om att undvika kollaps
- En liknande lösning skulle kunna användas för att minska vibrationerna hos järnvägsbroar i bruksgränstillståndet
- Viskösa dämpare är oberoende av frekvens vilket ger ökad robusthet jämfört med en TMD
- Funktionen hos viskösa dämpare måste övervakas och underhållas



VISKÖSA DÄMPARE

Typical application of a STUs in bridge design



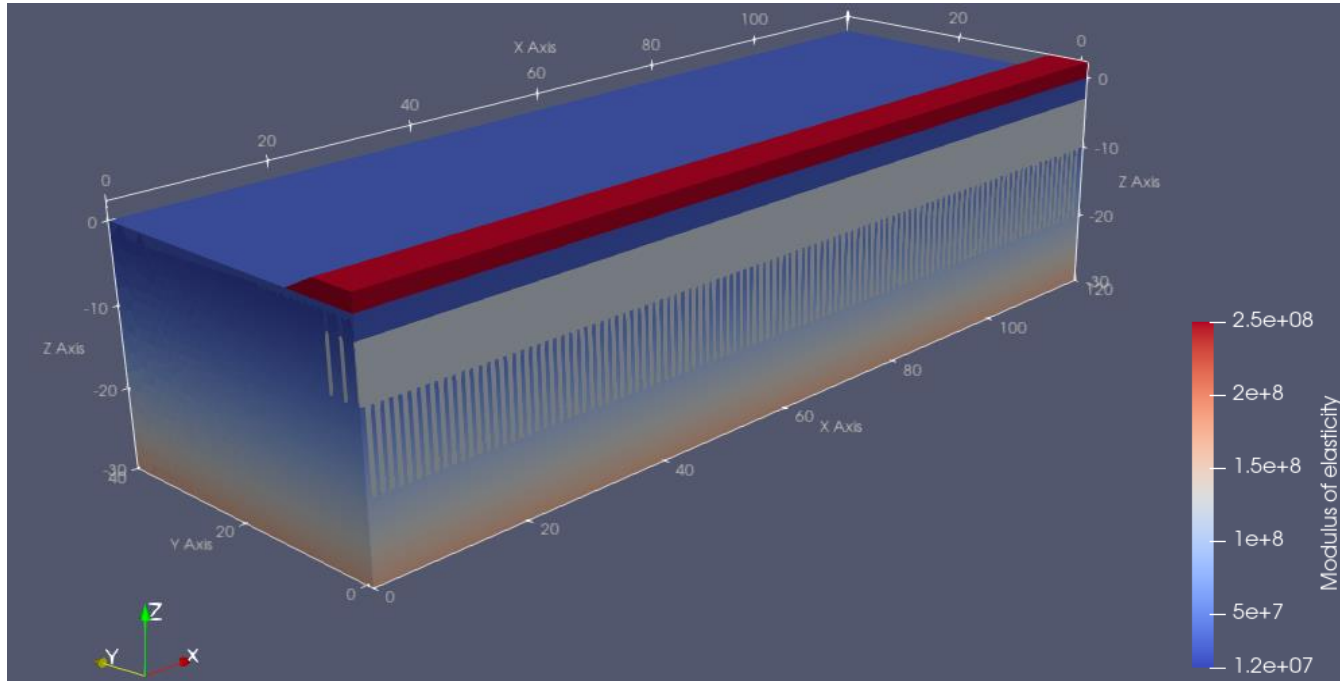
Det verkar lovande att använda viskösa dämpare för att sprida belastningen av longitudinella krafter hos längre järnvägsbroar.

Man har testat i Finland.

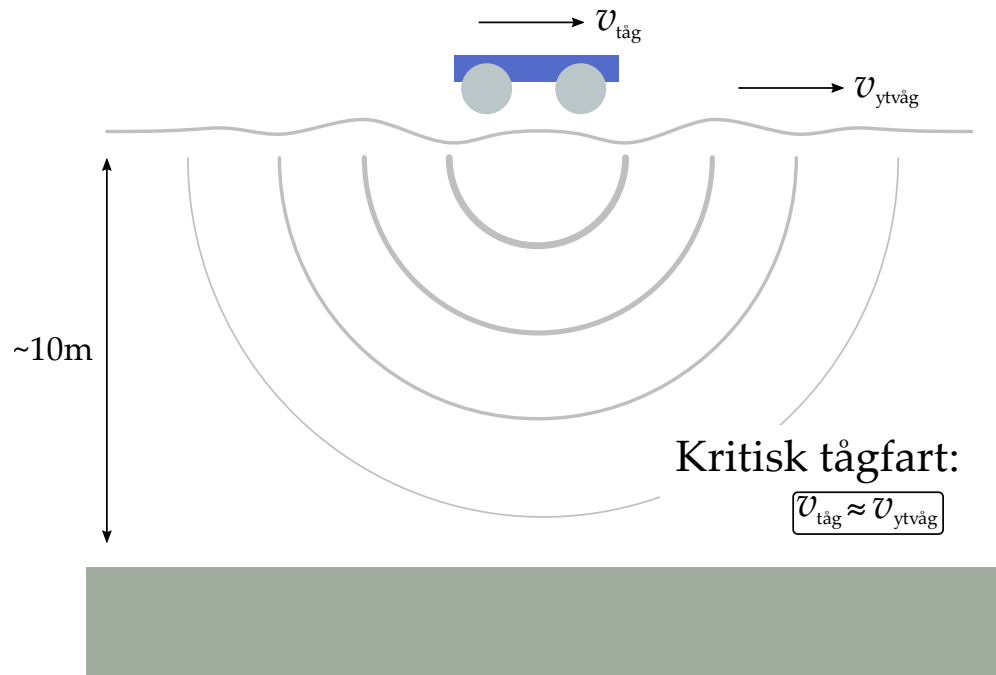
Detta kräver dock kontinuerlig övervakning av dämparnas funktion.



BANKAR FÖR HÖGHASTIGHETSJÄRNVÄG



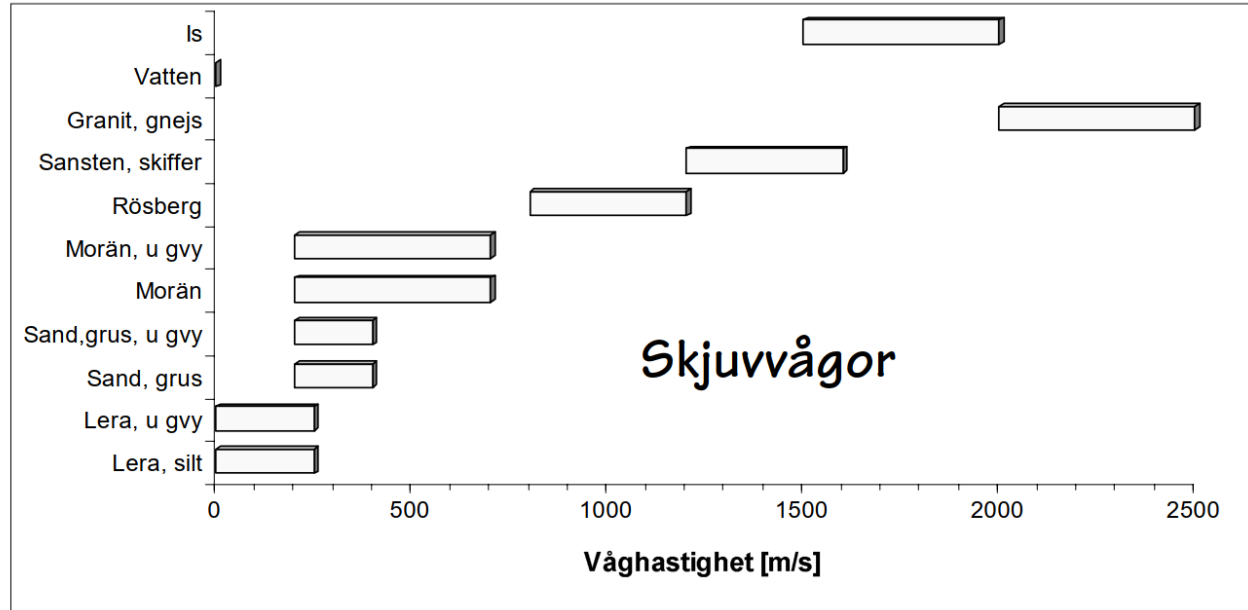
KRITISK TÅGFART



KRITISK TÅGFART

Figur 6.2
Skjuvvågornas utbred-
ningshastighet i olika
jord- och bergmaterial.

Efter IVA Meddelande 225
(1979), Triumf (1992)



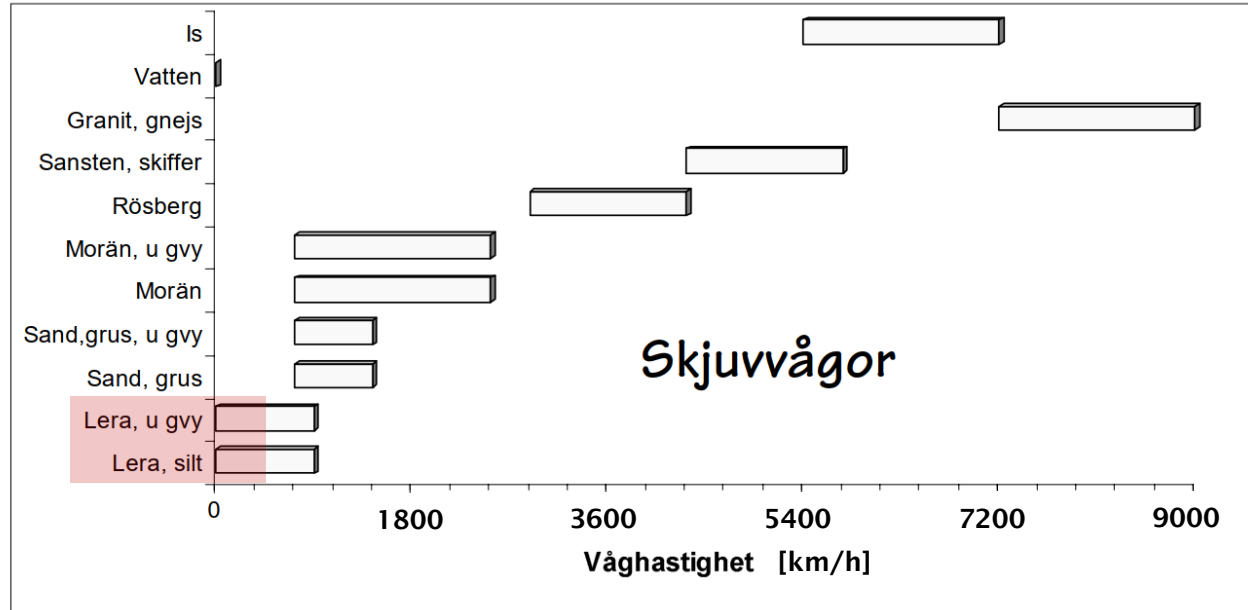
KRITISK TÅGFART

- Ytvågen kallas "Rayleighvåg"
- Rayleighvågens fart beror av bankens geometri och material samt på jordlagerföljdens material
- Rayleighvågen verkar ner till ett djup i storleksordningen 10 meter
- I en homogen, elastisk halvrymd är Rayleighvågffarten proportionell mot materialets skjuvvågsfart
- $c_{\text{Rayleigh}} \approx 0.9c_s$

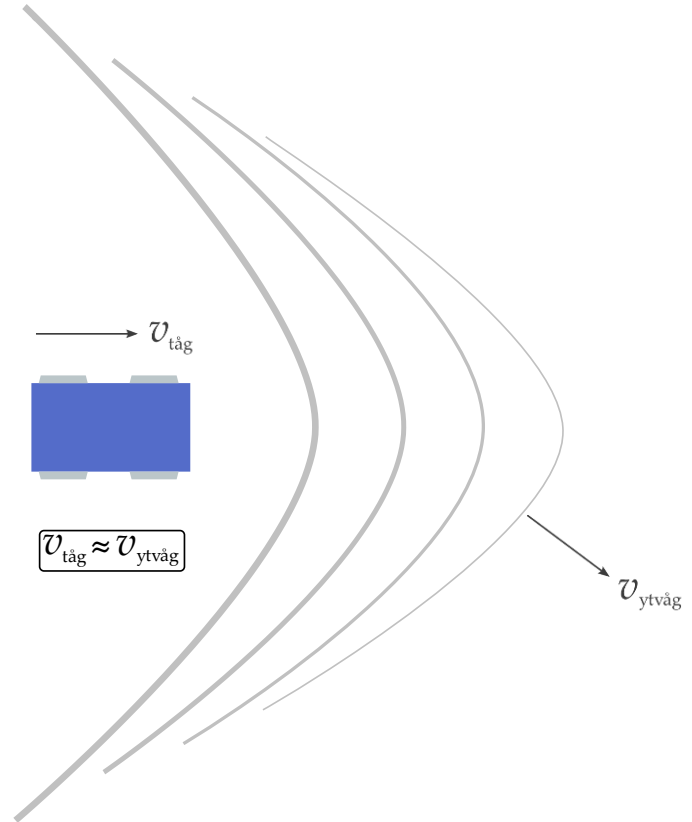
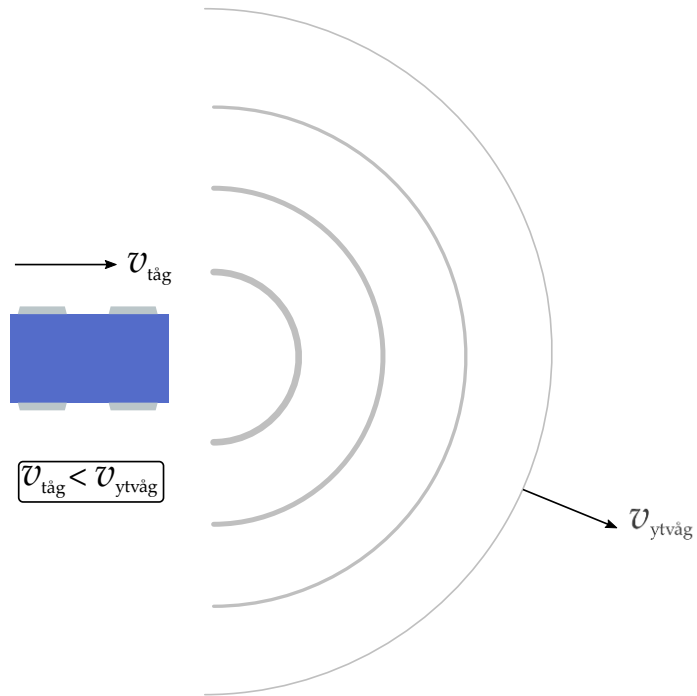
KRITISK TÅGFART

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Skjuvvågornas utbred-
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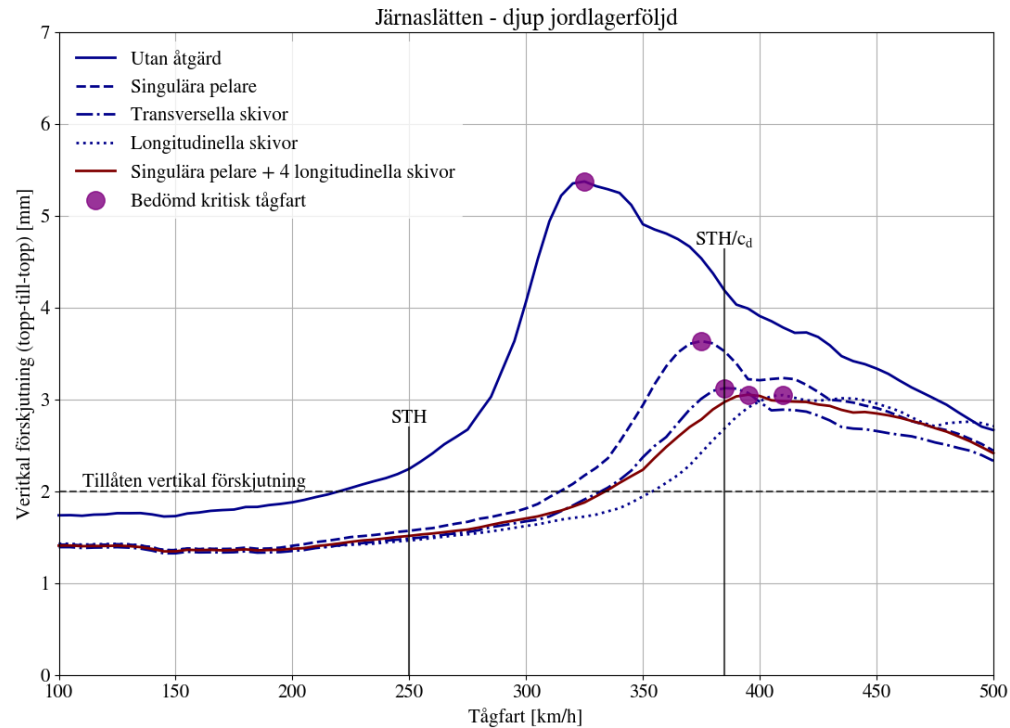
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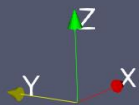
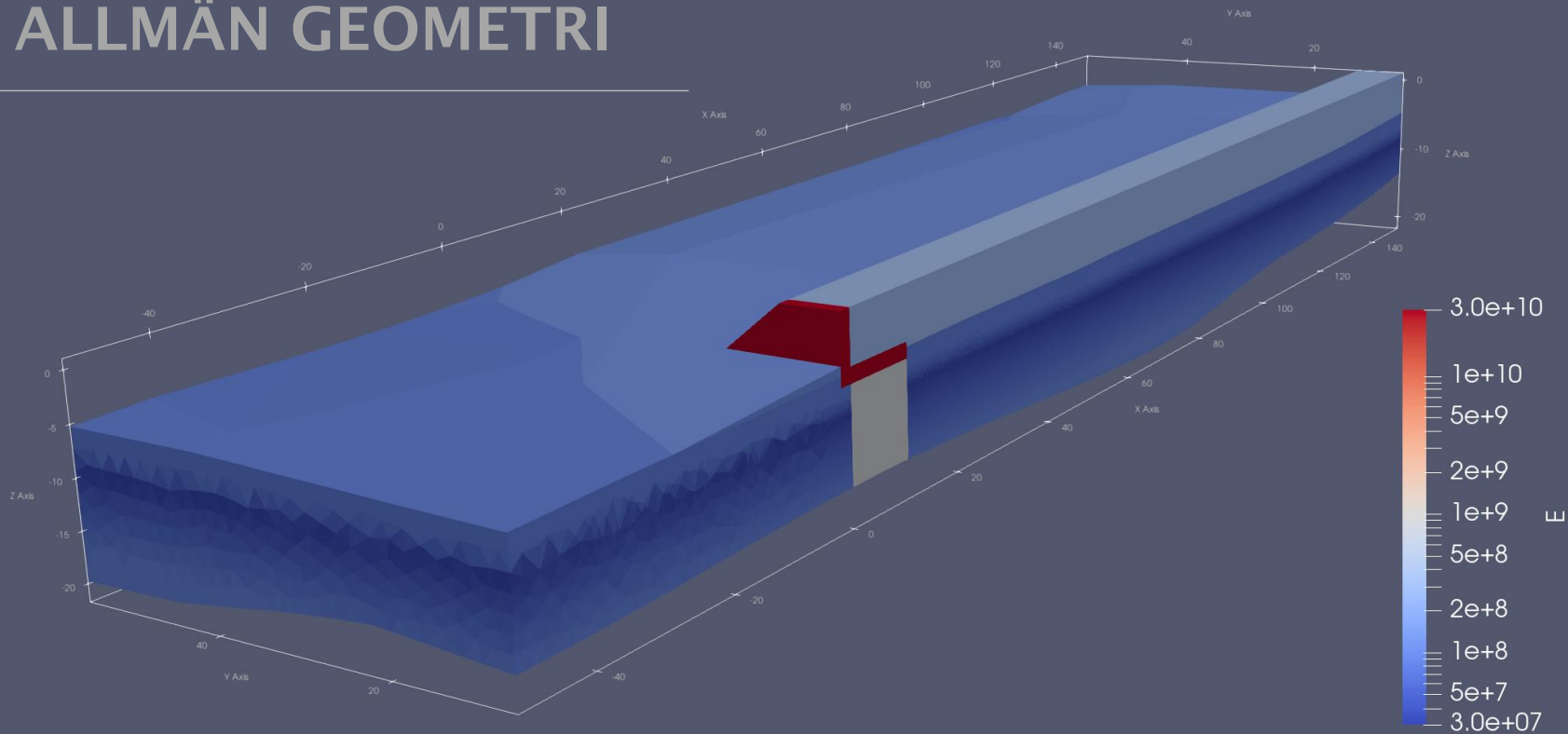
KRITISK TÅGFART



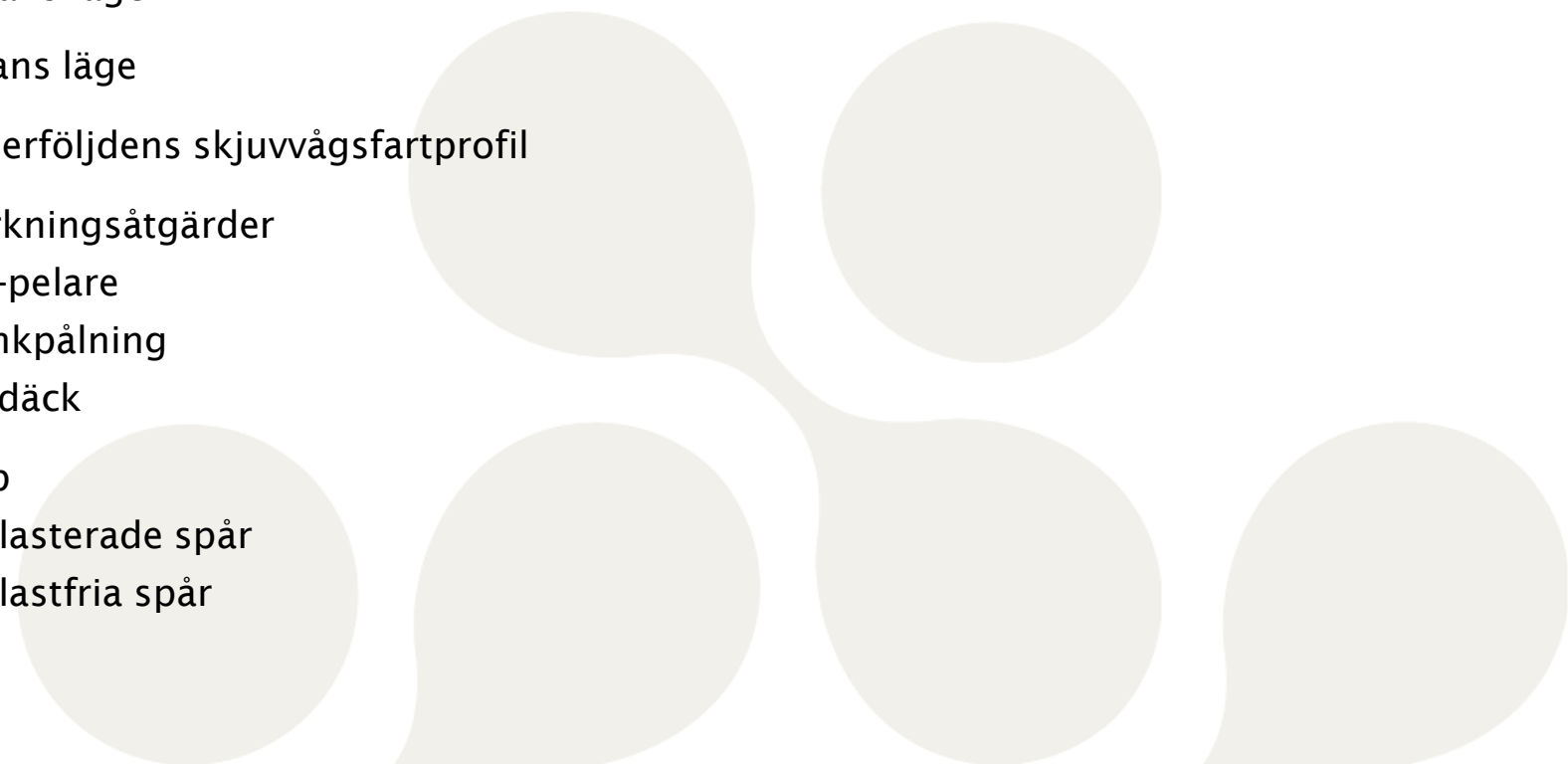
KRITISK TÅGFART



ALLMÄN GEOMETRI



KRITISK TÅGFART

- Markytans läge
 - Bergytans läge
 - Jordlagerföljdens skjuvvågsfartprofil
 - Förstärkningsåtgärder
 - KC-pelare
 - Bankpålning
 - Påldäck
 - Spårtyp
 - Ballasterade spår
 - Ballastfria spår
- 

KRITISK TÅGFART

- Markytans läge
- Bergytans läge
- Jordlagerföljdens skjuvvågsfartprofil
- Förstärkningsåtgärder
 - KC-pelare
 - Bankpålning
 - Påldäck
- Spårtyp
 - Ballasterade spår
 - Ballastfria spår
- Kriterier avseende jordmaterialens töjningsberoende
 - Man vill vara i det linjärelastiska området vid dimensionering. Både beräknings- och beständighetsmässigt.
- Konstitutiva modeller och parametrar
- Hydrologi
- Tjäle
- Valideringsdata

FLERA PÅGÅENDE PROJEKT

- Ostlänken
- Mälardalen
- Norrbotten
- Göteborg-Borås



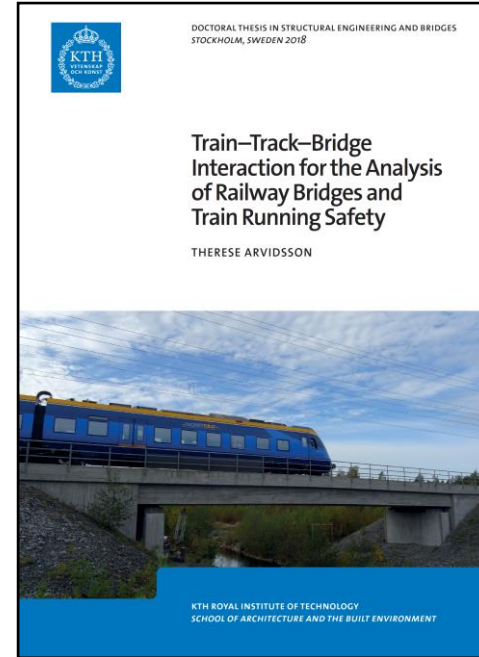
BULLER & VIBRATIONER

- Omgivningspåverkan
- Högre frekvenser
- Tåg-spårinteraktion



QTMS, Quiet Track Monitoring System, provides you with high quality data to start your digitalization journey and to explore the world of possibilities with Internet of Things, Machine Learning and AI. In order to increase your track maintenance efficiency.

QTMS Quiet Track Monitoring
System - Quality assured data



BULLER & VIBRATIONER

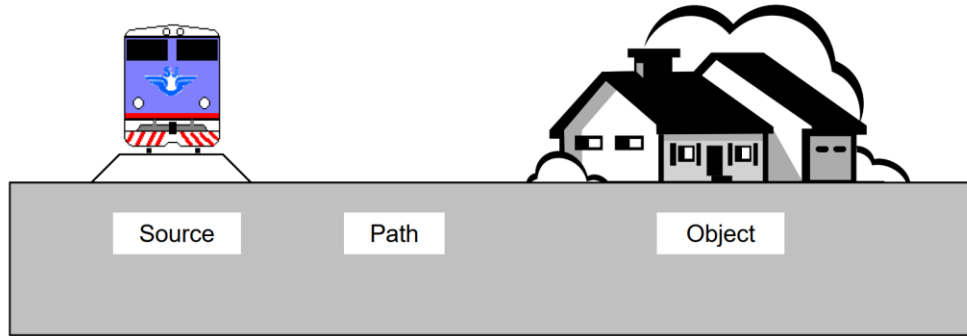


Fig. 1. Schematised source-path-object

- Mäta vid och omkring bandelar med
 - Oförstärkt mark
 - Bankpålning
 - Påldäck
 - KC-pelarförstärkning



KTH Architecture and
the Built Environment

**Train-Induced Vibrations on Embankments
and in Buildings – Prediction and Validation
of Some Models**

Christoffer With

Doctoral Thesis

Division of Soil and Rock Mechanics
Department of Civil and Architectural Engineering
Royal Institute of Technology

Stockholm 2008

BULLER & VIBRATIONER

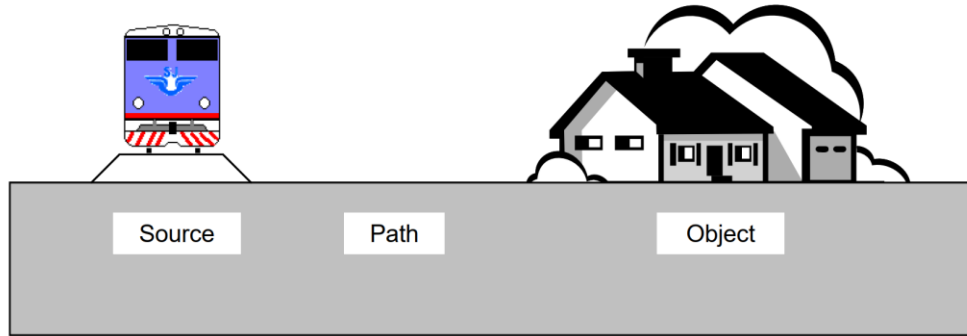


Fig. 1. Schematised source-path-object

- Utveckla bättre beräkningsmetoder
 - Större frekvensband (0, 200) Hz
 - Snabbare lösningar vid fördjupad utredning och jord-strukturinteraktion



KTH Architecture and
the Built Environment

**Train-Induced Vibrations on Embankments
and in Buildings – Prediction and Validation
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Christoffer With

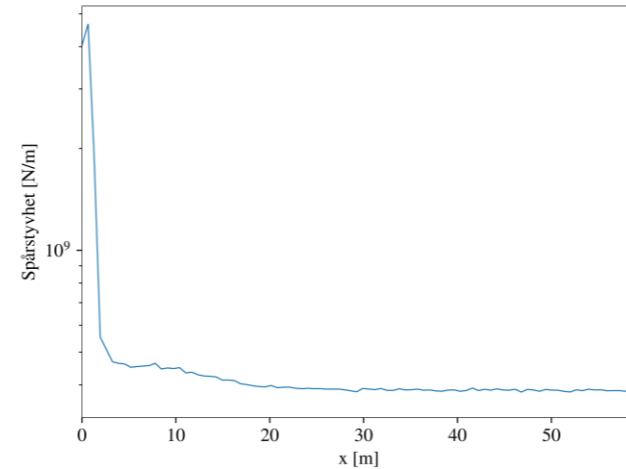
Doctoral Thesis

Division of Soil and Rock Mechanics
Department of Civil and Architectural Engineering
Royal Institute of Technology

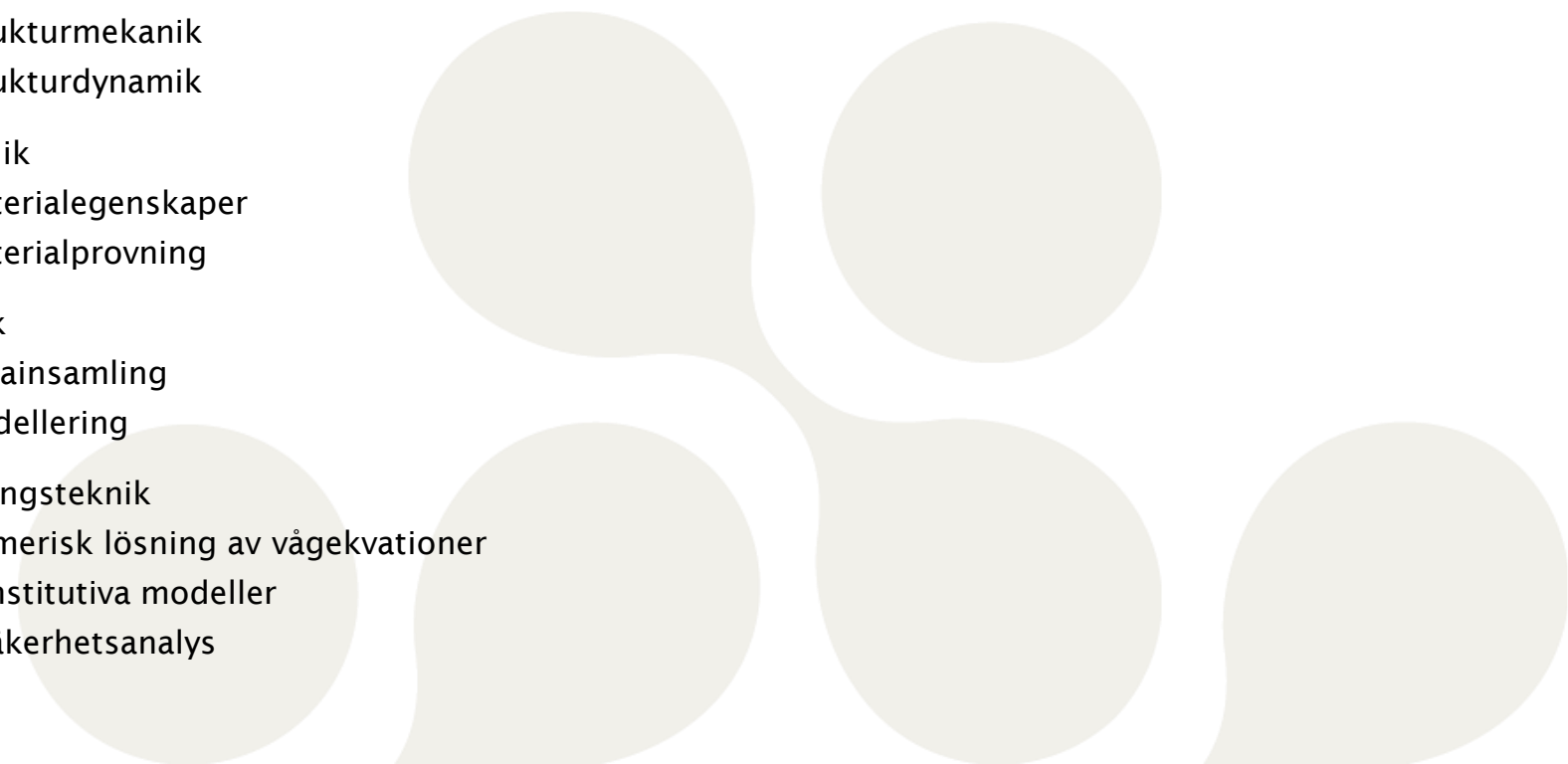
Stockholm 2008

GRÄNSSNITTET BRO/BANK

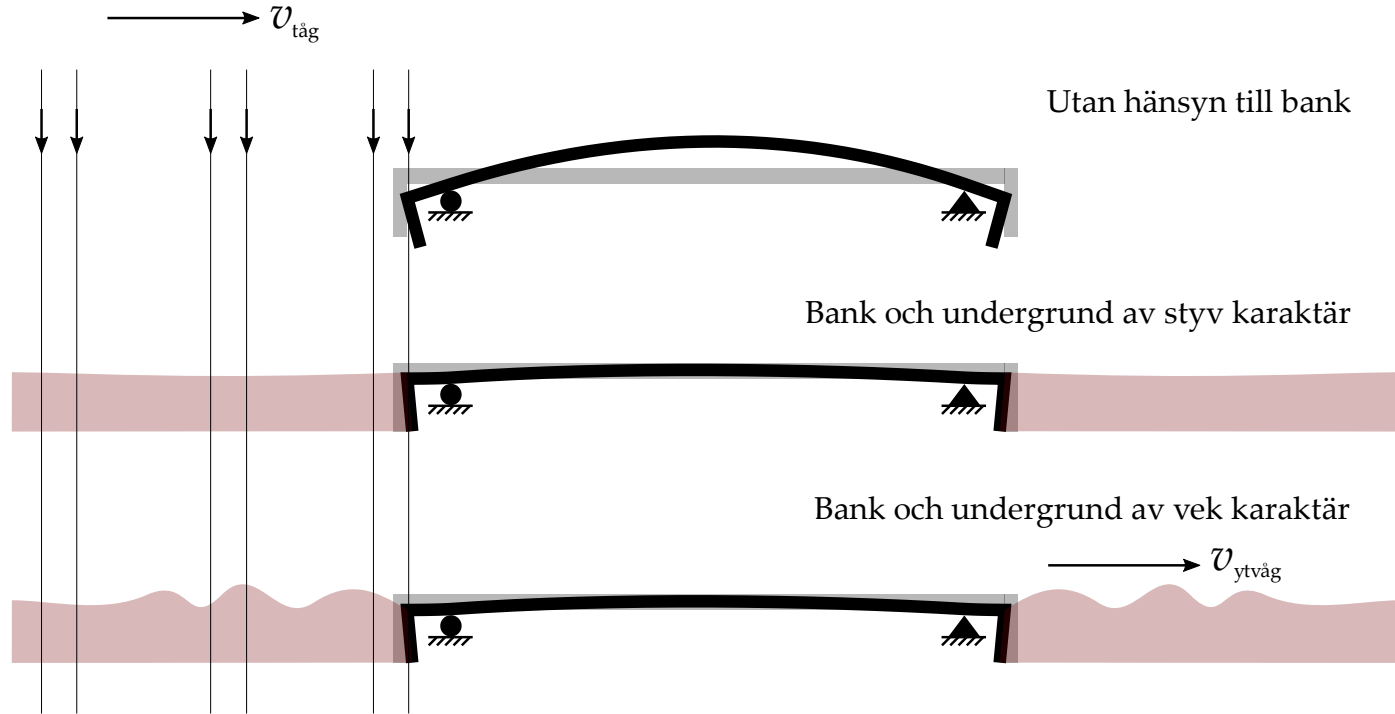
- Sättningar vid övergångszoner
- Ändskärmsbroar
- Årstidernas inverkan på gränssnittet mellan bro och bank
- Dynamisk jord-strukturinteraktion i tjälsatt mark



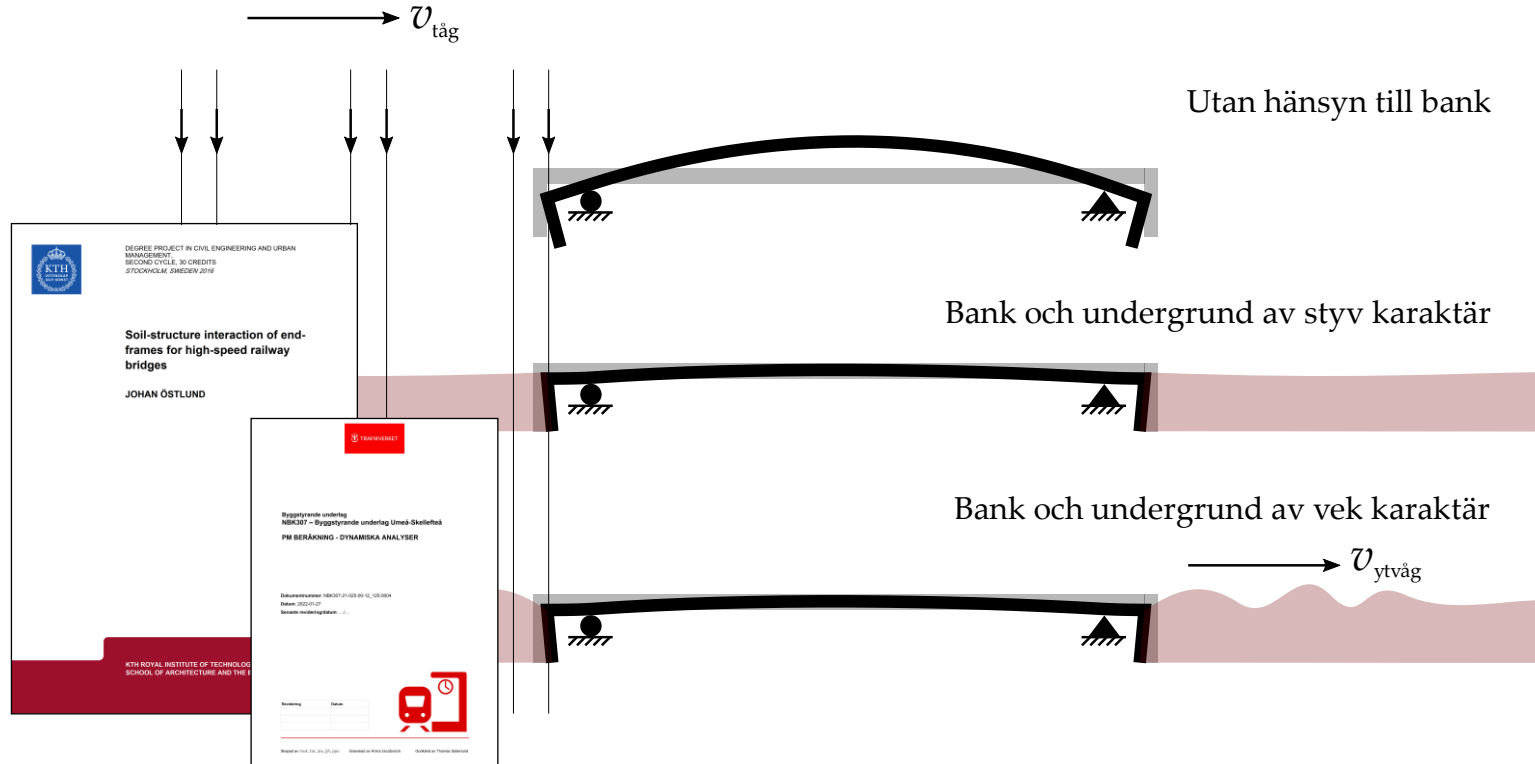
GRÄNSSNITTET BRO/BANK

- Broteknik
 - Strukturmekanik
 - Strukturdynamik
 - Geoteknik
 - Materialegenskaper
 - Materialprovning
 - Geofysik
 - Datainsamling
 - Modellering
 - Simuleringsteknik
 - Numerisk lösning av vågekvationer
 - Konstitutiva modeller
 - Osäkerhetsanalys
- 

ÄNDSKÄRMSBROAR

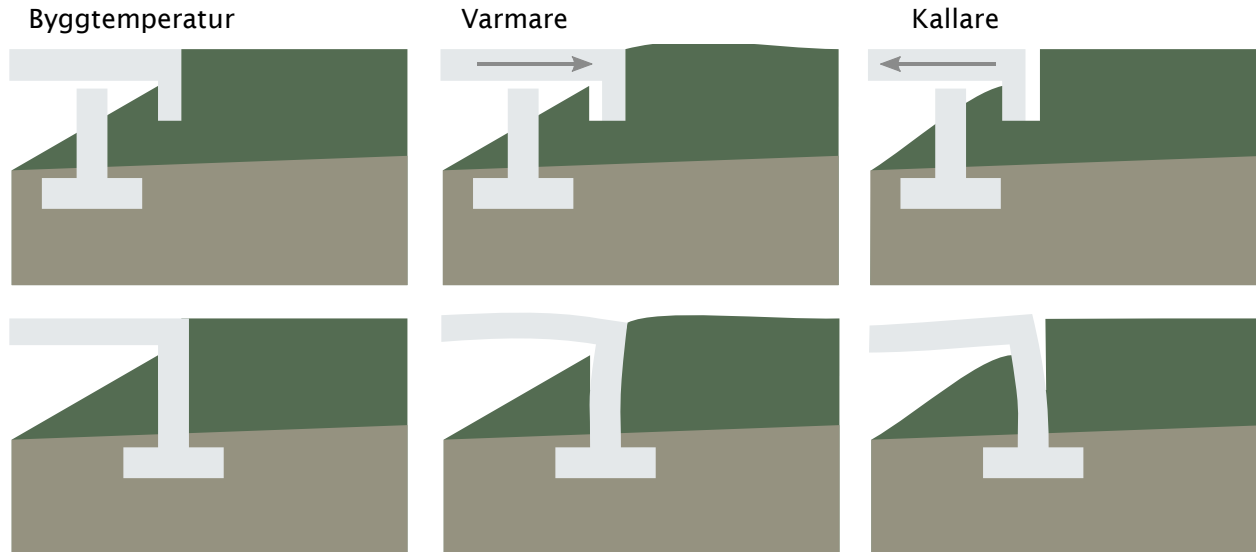


ÄNDSKÄRMSBROAR

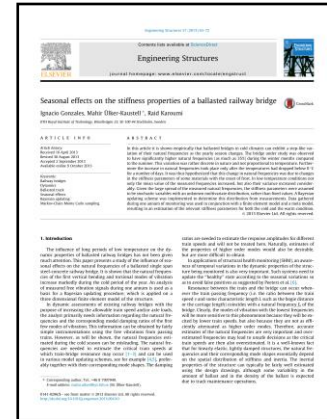
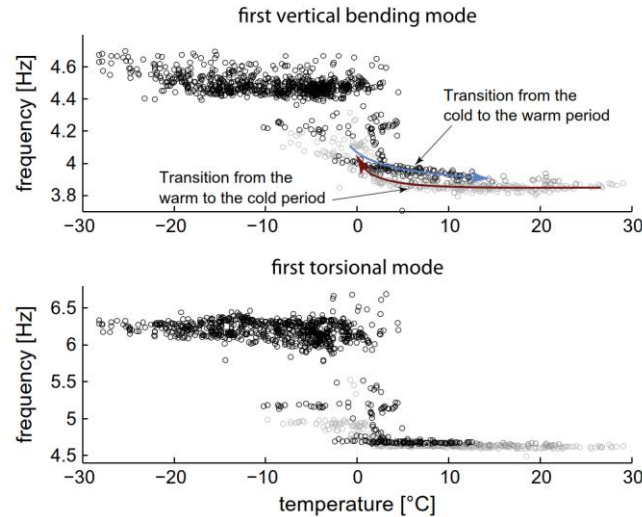


GRÄNSSNITTET BRO/BANK

- Inverkan av temperaturförändringar på
 - Kontaktförhållanden
 - Aktivt/passivt jordtryck



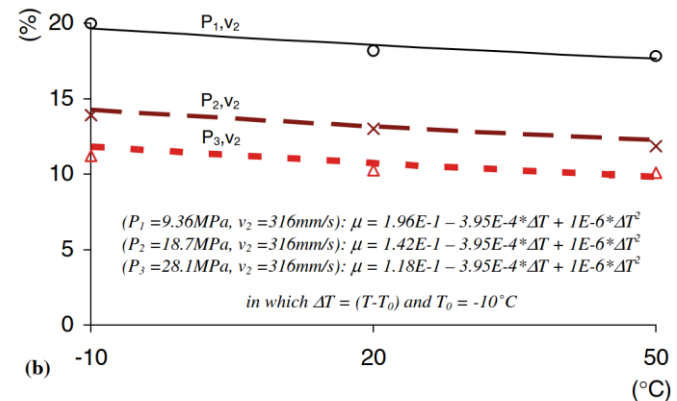
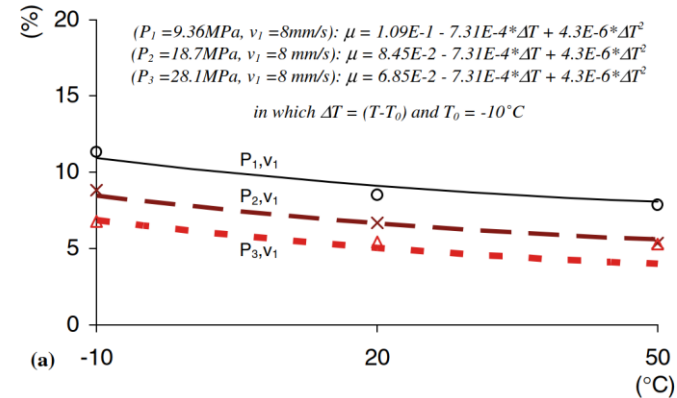
TEMPERATUR KAN HA STOR INVERKAN PÅ EGENFREKVENSER OCH MODER



TEMPERATUR KAN HA STOR INVERKAN PÅ EGENFREKVENSER OCH MODER

Potentiella förklaringsmodeller:

- Frusen ballast/tjäle
- Lagerfriktionens temperaturberoende



GRÄNSSNITTET BRO/BANK

- Broteknik
 - Strukturmekanik
 - Strukturdynamik
- Geoteknik
 - Materialegenskaper
 - Materialprovning
- Geofysik
 - Datainsamling
 - Modellering
- Simuleringsteknik
 - Numerisk lösning av vågekvationer
 - Osäkerhetsanalys
- Dagens tekniska lösningar
- Orsakssamband
- Gränssnittets egenskaper under olika årstider
 - Idag antas ett idealiserat gränssnitt
 - Tjäle och termiska deformationer
- Gränssnittets egenskaper i ett livslängdsperspektiv
 - Utformning/investeringskostnad
 - Underhåll
- Mätningar

AVSLUTANDE KOMMENTARER

- Långtidsmätningar på ett antal olika järnvägsbroar
 - Utredda inverkan av temperatur och tjäle
 - Utredda inverkan av lagerfriktion
 - Utredda lämpliga konstruktionslösningar för gränssnittet mellan bro och bank
- Tvärvetenskapligt angreppssätt
 - Strukturmekanik
 - Geoteknik
 - Geofysik
 - Akustik
- Tvärfunktionella teams
- Anpassning till marknad eller marknadsanpassning?
- En nyckel till bra forskning, innovation och teknikutveckling är övervakning
- Övervakning ger mycket data
- Data måste bearbetas
- Data måste förvaltas
- Kombinera FoU med drift och övervakning
- Hur vi ser på data
- Konsultens nya roll som dataproducent
- Yrkesrollens förändring

**TACK FÖR ER
UPPMÄRKSAMHET!**

