OVERVIEW OF THE STRUCTURAL DYNAMICS COURSE AT EPFL

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SUMMARY *In the context of several trends toward higher strength materials, increased slenderness of elements and more generally, lighter-weight construction compared with traditional structures - as well as an increased awareness of earthquake risk - EPFL offers a comprehensive teaching program in the area of structural dynamics. This paper describes the first of three courses that are offered to Masters students. Following descriptions of the context of the course within the civil engineering curriculum, course objectives are described in terms of academic and practical goals. The technical content of the course includes fundamental aspects that are present in all such courses and additional topics such as an introduction to wind engineering, tuned-mass dampers and Fourier transforms for signal analysis. Teaching is enhanced by class demonstrations using physical models, case studies of structures, computer exercises and standard problem sets. Student evaluations have been very favourable and participation in the two subsequent optional courses on dynamics has been strong.*

KEYWORDS: Fundamental structural dynamics, natural frequencies, dynamic movements, distributed mass systems, multiple degrees of freedom, modal analysis, tuned-mass dampers, Fourier transforms, case studies

1. INTRODUCTION

The importance of structural dynamics is increasing. While traditional design and construction methods often resulted in structures that have rarely been sensitive to dynamic excitation, trends over the past decades are changing this situation. Use of high strength steels and high performance concrete is increasing, especially for “signature” structures. Modern architecture and modern bridge design trends encourage high slenderness ratios. The number of movable structures is also increasing. A consequence of these trends is an increased sensitivity to dynamic effects on structures.

With the increase in urban concentration over the past decades and more concentration predicted in the future, trains, subways and trams are becoming located closer and closer to buildings that may be sensitive to vibrations through foundations. Furthermore, an emphasis on public transport means that buildings such as conference centres and theatres are located close to public transportation hubs. These trends are also increasing the exposure of structures on which the effects of dynamic excitation need to be minimized.

Although ignored in many countries until recently, the importance of earthquake excitation is now recognised in medium-hazard countries such as Switzerland. New buildings are currently designed using updated code requirements (SIA 2003) and many existing buildings require strengthening, especially when they are expected to provide emergency services such as medical support and fire protection in case of a severe seismic event.

In recognition of these trends, EPFL offers three courses at the Masters level that treat structural dynamics. The first course, Dynamic Analysis of Structures, is an introduction to the field and is compulsory for all civil engineers. The other two courses are optional and they deal with numerical methods and earthquake engineering. This paper describes the first course. The next section provides more detail related to the academic context of the course and presents the course objectives. Subsequent sections summarize the course content, documentation, special features, and finally, evaluations by, and of, the students.

2. CONTEXT AND COURSE OBJECTIVES

Before taking the course, Dynamic Analysis of Structures, students follow Bachelor level courses in physics, mathematics, materials science, statics and structural mechanics. In physics, they have already been exposed to concepts of vibration and resonance. From mathematics, they have knowledge of matrix algebra, solving partial differential equations and trigonometry. From materials science, they know the difference between elastic and plastic behaviour and details such as values for Young's Modulus for construction materials. Their knowledge of structural mechanics is presumed to include statically indeterminate structures so that they are (supposedly) able to determine frame and multi-span-beam stiffness coefficients.

As published in the EPFL Course Catalogue, the objectives of this course are to "Develop capabilities to determine natural frequencies of vibrating structures as well as resultant stresses and movements". Less formal objectives are to gain an intuitive understanding of dynamic behaviour, to explore sensitivity trends (with respect to parameters such as material properties, stiffness, damping levels and geometries), to recognise the inherent inaccuracies of behaviour models and finally, to understand through cases that sometimes, small changes on site can be more effective than complex time-consuming numerical studies of dubious value. A further objective is to expose students to challenges that may arise during project design stages so that they are able to decide whether or not a particular aspect requires expert input. Engineers need to know what they do not know.

This course is intended to prepare the students for later optional courses in numerical methods and earthquake engineering. Many times during the course both of these themes are mentioned. The numerical methods course treats non-linear numerical analysis of structures and since the scope of the course, Dynamic Analysis of Structures, is limited to linear-elastic behaviour, subject divisions are clear. While a short introduction to earthquake engineering is provided in discussions of acceleration and response spectra, treatment is cursory and explicit references are given regarding the availability of the optional course, Earthquake Engineering.

3. COURSE CONTENT

The course covers the following subjects:

- Introduction, review of structural stiffness coefficients, parallel and series stiffness
- One-degree-of-freedom systems
    - Free vibration (review)
    - Damped vibration
    - Forced vibration (partial review)
    - Transmittance
    - Foundation movements
    - Non harmonic forces (Sudden forces, explosion, impact with significant mass)
- Distributed mass systems
    - Rigid bodies

    - Flexible bodies
- Systems with mutiple degrees of freedom
    - Free vibration including modal analysis using the orthogonality principle
    - Damped vibration
    - Forced vibration
    - Tuned-mass dampers
- Responses and Spectra
- Introduction to wind engineering
- Practical indications (Approximations for conceptual design, construction phase sensitivity, transformations of response-time readings to frequency domain)

A typical lecture would begin with a demonstration in order to show visually the phenomenon in question and to counteract other intuitive understandings that may be present from other subjects, such as static analysis. For example in static analysis, one-storey structural frames move in the direction of the forces applied to them, whereas in dynamic analysis, at a forcing frequency above resonant frequency, structural movement is out of phase with applied forces. Demonstrations are followed by mathematical developments, typically involving the resolution of differential equations and graphs showing the effects of key parameters. Results of this resolution are then compared with further demonstrations to confirm with the student that the mathematical development matches the reality that they observe.

Once the first part of the course is presented (first four subsections of one-degree-of-freedom systems), a continuing theme in the course is that further complications, such as distributed masses and more degrees of freedom, are dealt with through transforming the more complex systems to one or more equivalent one-degree-of-freedom systems. Once the transformation is completed through determination of equivalent values for parameters such as mass, stiffness, damping and force, all that is established for these simpler systems becomes applicable to the more complex system.

While the transformation is easily explained for equivalent frame forces in cases of foundation movements under one-storey frames, learning is more difficult for distributed mass systems and modal analysis. Distributed mass systems are analysed using the principles of virtual work and important aspects of this part of the course are explained inductively through several worked examples. For modal analysis, a mixture of worked examples and theoretical development, along with laboratory demonstrations are employed.

4. SPECIAL FEATURES

In order to increase understanding and accounting for the high academic level of EPFL Master students when compared with students in other countries, it was decided to enrich the standard curriculum related to this topic with special features. The special features of this course can be divided into two categories, pedagogical methods and special topics in structural dynamics. These are described in the following paragraphs.

Pedagogical methods include case studies, demonstrations and Matlab exercises. Case studies are presented with copies of papers containing details and at the end of most two-hour sessions, 15 minutes is devoted to a case. Cases include “Missed opportunities” for the

Tacoma Narrows Bridge, Millennium Bridge vibration and retrofit, Los Angeles City Hall base isolation, Eiffel Tower measurements, amusement park structures and in Switzerland, damping of pedestrian bridges and diving platforms. Demonstrations are given using scale models of flexible one and two-storey frames, a specially made device that modifies damping and a simple mass on a vertical spring to show the effect of a step load (in this case, gravity). Matlab exercises are used to facilitate problem sets related to numerical evaluation of arbitrary loading and response signal analysis, thereby avoiding long and repetitive calculations.

The special topics in structural dynamics are wind engineering, tuned mass dampers and fast Fourier transforms. Two hours of lectures on wind engineering are given by Dr. Jacques Hertig, a wind specialist who provides basic notions of boundary layer wind properties and how they are translated into code provisions, including those situations that are not covered by current codes. The part on tuned-mass dampers is largely supported by a practical paper written by Bachmann and Weber [1] since it describes design principles and methods that are understandable to Masters level students. Fast Fourier transforms are treated in the last class of the course through linking theory to a practical worked example. Since Masters students at EPFL are already knowledgeable in the area of computational complexity (O Notation), it is demonstrated that changes in the algorithm increase efficiency and the ability to manage large data sets.

4. DOCUMENTATION

For this course, there are documents containing course notes and copies of slides that can be purchased internally at EPFL. These documents are based on references [1-5] plus initial notes written twenty years ago by Prof. Leopold Pflug. In addition to this, students have access to one-page resumes of each week of courses on the web, plus exercises and their solution sheets which are made available one week after the availability of the relevant exercise. Since clarity can always be improved, it is a yearly summer task to revise all documents in collaboration with students who have recently followed the course.

5. EVALUATIONS

There are two types of evaluations; evaluations of the students (grades) and of the teacher and assistants by the students. Students are evaluated principally through an oral exam which takes place two to three weeks after classes finish. They are given 30 minutes at a desk to prepare the answer to a question they receive upon entering the room on transparencies. After this, they have 15 minutes where they present their solution and answer questions. The topics of questions range from details of their reply to general themes treated in the course. Both theoretical and practical aspects are covered.

Secondary evaluations are carried out through a written mid-term test and through reports from the assistants who guide them through exercises. These evaluations are used to “save” people who, because of nervousness, bad luck and misunderstanding, respond badly during the oral exam. Occasionally, good secondary evaluations are used to increase the grade by half a point out of six even though the student is not near a failing grade.

Teacher-assistant evaluations are carried out each term for each course at EPFL. The basic evaluation involves just one rating about the quality of the course (one to six, one being the worst) and the opportunity to make written comments. If a course receives an average of less than four, a detailed evaluation of approximately twenty questions is carried out. The most recent evaluation was 5.1 with no rating below four. This was mostly attributed to the quality of the assistants. Further indication of the success of this course is that approximately three quarters of the class continue their studies of structural dynamics through taking the optional course in earthquake engineering. This proportion is greater than the proportion of civil engineering students who specialise in structures.

6. CONCLUSIONS

The first of three courses in structural dynamics fulfils objectives to build upon knowledge of the topic of dynamics in basic physics to teach fundamentals of structural dynamics. Intuitive understanding of important phenomena is gained through demonstrations, case studies and exercises. Case studies also help show that complex numerical development is sometimes not needed to achieve practical engineering objectives. Finally, students become prepared to continue with the more advanced topics that are treated in later optional courses.

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References

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