European guidelines for vibration design have not previously been available. Two European projects investigated the effects of human-induced vibration and guidelines have been drafted from this research.

This project aims to disseminate the knowledge gained in the two European research projects, which both dealt with the human-induced vibration of steel structures. This design problem becomes more relevant as the slenderness of structures increases, due to the increased use of high-strength steels.

The conclusions of the previous research projects (draft guidelines for vibration design of floors and footbridges) have been refurbished and accompanying background documents for vibration design have been elaborated. The resulting guidelines are the first European guidance for the vibration design of structures.

The guideline and background documents have been translated into different languages and published on a project web page (www.stb.rwth-aachen.de/projekte/2007/HIVOSS/download.php) that may be easily found by an Internet search for 'Hivoss'. At this site the guideline and background documents can be downloaded as a free PDF. This download page has received a lot of interest, resulting in 1 900 downloads of the footbridge guideline and 1 000 downloads of the floor guideline up to 30 March 2009.

In addition to the documents, presentations and seminars were arranged to increase the knowledge about vibration and to introduce the guidelines. These seminars were attended by designers, consulting engineers and authorities.

The guidelines have also been presented to the relevant CEN bodies to be considered for implementation in design codes.

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Human-induced vibration of steel structures (Hivoss)

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Table of Contents

1. ABSTRACT

European guidelines for vibration design have not previously been available. Two European projects investigated the effects of human induced vibration and guidelines have been drafted from this research.

This project aims to disseminate the knowledge gained in the two European research projects, which both dealt with the human induced vibration of steel structures. This design problem becomes more relevant as the slenderness of structures increases due to the increased use of high strength steels.

The conclusions of the previous research projects (draft guidelines for vibration design of floors and footbridges) have been refurbished and accompanying background documents for vibration design have been elaborated. The resulting guidelines are the first European guidance for the vibration design of structures.

The Guideline and Background documents have been translated into different languages and published on a project web page that may be easily found by a internet search for "HIVOSS" (or url: www.stb.rwth-aachen.de/projekte/2007/**HIVOSS**/download.php). At this site the guideline and background documents can be downloaded as a free PDF. This download page has received a lot of interest resulting in 1900 downloads of the footbridge guideline and 1000 downloads of the floor guideline up to 30th March 2009.

In addition to the documents, presentations and seminars were arranged to increase the knowledge about vibration and to introduce the guidelines. These seminars were attended by designers, consulting engineers and authorities.

The guidelines have also been presented to the relevant CEN bodies to be considered for implementation in design codes.

2. FINAL SUMMARY

The use of modern high strength steel allows the design of slender and lightweight structures, reflecting the architectural demands. However with increasing slenderness the sensitivity of structures to vibrations rises.

European guidelines for vibration design have not previously been available.

For building construction an international classification of floors with regard to vibration is necessary in order to encourage the use of lightweight structures. For example a lightweight floor based on a steel structure (Quantum floor) cannot be introduced into the international market until the manufacturers can demonstrate unambiguously that their floors will not cause unacceptable vibration levels.

Vibrations are also an issue of increasing importance in current footbridge design practice. More sophisticated bridges (such as cable supported or stress ribbon footbridges) with increasing spans and more effective construction materials result in lightweight structures and a high ratio of live load to dead load. As a result, many footbridges have become more susceptible to vibrations when subjected to dynamic loads. The most common dynamic loads on footbridges, after wind loading, are the pedestrian induced footfall forces due to walking or jogging.

In two research projects the vibration of structures was investigated by considering excitation mechanisms, structural behaviour and human perception of vibration. Both projects resulted in reports in which measuring methods, human perception and criteria were formulated:

- Vibration of floors –VoF (ECSC Project 7210-PR-314) deals with vibrations in office, domestic and industrial building considering different excitation sources
- SYNPEX (RFCS Project: RFS - CR – 03019) deals with vibration of footbridges due to pedestrians passing, including lock-in effects

Although the correct design processes were studied and reported in these projects, the reports cannot be used as such. Manufacturers, suppliers and other parties involved will profit from the knowledge gained in these projects if the key parts of the reports are summarised as guidelines.

Guidelines and accompanying background documents for vibration design were developed from the project reports to make the results suitable for use in design offices.

The English master versions of the guidelines and background documents have been translated into 4 languages: German, Dutch, French and Portuguese. They are now published as a free download on a web page that can easily be found by searching for “HIVOSS” with any internet search engine.

The project HIVOSS and the download page were presented at several conferences and in publications. Additionally the application of the design methods was demonstrated in workshops and seminars to about 450 people who were also informed about the availability of the documents.

Until 30th March 2009 about 3000 downloads were performed from the web page.

3. OBJECTIVES AND INTRODUCTION

The use of modern high strength steel allows the design of slender and lightweight structures. However with increasing slenderness sensitivity of structures to vibrations rises.

European guidelines for vibration design do not exist. An international classification of floors is necessary in order to encourage the use of lightweight structures. For example a lightweight floor based on a steel structure (Quantum floor) cannot be introduced into the international market until the manufacturer can demonstrate unambiguously that their floor will not cause unacceptable vibration levels.

In two research projects the vibration of structures was investigated by considering excitation mechanisms, structural behaviour and human perception of vibration. Both projects resulted in a report in which measuring methods, human perception and criteria were formulated:

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- SYNPEX (RFCS Project: RFS - CR – 03019) deals with vibration of foot bridges due to pedestrians passing, including lock-in effects

Floor Vibrations (VoF)

In building structures, for example offices or domestic buildings, the demand for wide spanning floors has increased to enable the maximum flexibility in the use of the buildings.
Floor structures made of steel or composite structures are designed for ultimate limit states and serviceability limit state criteria:

- Ultimate limit states are those related to strength and stability;
- Serviceability limit states are mainly related to deflections and vibrations and hence are governed by stiffness, masses, damping and the excitation mechanisms.

For slender floor structures, as seen in steel or composite construction, serviceability criteria govern the design, so that the strength of the materials cannot be fully exploited. This shows that serviceability criteria have a big influence on the economy of steel and composite floors.

The aim of the project was to investigate floor vibrations by measurements and numerical methods. The insights in the behaviour of the floors and human perception gained in this project led to a proposal of both design methods and acceptability criteria.

With the proposed design methods and criteria, a designer has a choice between several design routes with which he can unambiguously calculate how to classify his floor. The function of a floor corresponds to a preferred class, for example a floor in an office should be class D.

Footbridge Vibrations (SYNPEX)

The design of footbridges in steel follows the architectural demand for slender and lightweight structures. Experiences with slender bridges have shown that vibrations due to pedestrians passing the bridge may cause vibration problems especially for slender bridges.

Depending on the structure of the bridge a lock-in effect could be observed (e.g. the Millennium Bridge) that causes serious vibrations making it dangerous to use the bridge. Lock-in effect means a synchronisation of the bridge vibration with the step frequency of pedestrians that causes resonance.

No rules for the specification of allowable vibrations of footbridges existed and no unified design methods for the vibration checks of footbridges were available, so during this project a design guide for footbridges was to be developed. The guideline is based on comprehensive numerical studies as well as on measurements on a considerable number of bridges.

The resulting guideline gives guidance to specifiers and clients who can now choose between different acceptance classes and traffic class types to consider the specific boundary conditions of a bridge.

Also the guideline gives engineers guidance to design a bridge that fulfils the specified requirements. The guideline also gives basic information for the layout of dampers, should they be required.

Correlation of the described projects
Both projects, VoF and SYNPEX, dealt with human induced vibrations, numerical and experimental methods for the determination of vibration levels and with the perception criteria of vibrations.
Although the projects dealt with different structures, floors and bridges, the structures are rather similar in their dynamic behaviour. The performance and assessment of measurements, general considerations about the perception of vibrations and general design procedures such as the derivation of natural frequencies, modal mass, etc. have the same background and can thus be efficiently presented in one demonstration project.

Aim of the presented project
The project presented here aims to promote the knowledge gained in the two projects specified above. Both projects already provide drafts of guidelines for their field of application. Within this project the guidelines and accompanying background documentation were revised to meet the following requirements:

1. The guideline should provide a method with which a floor or bridge can be classified.
2. The guideline should be easy to use, unambiguous and should include a number of examples as illustration.

The guideline was promoted by courses and seminars that targeted engineering offices and steel construction companies working in these fields. Bridge owners (e.g. local authorities) were also invited to participate in the courses or seminars.

It was expected that merging both projects would enhance the attractiveness of the seminars because a wide range of vibration problems is covered. Seminars were held in different countries of the EU.
The guidelines assembled in this project are the first European guidelines for the design for human induced vibrations.

The project is divided in 5 work packages.

Work package 1: Write background documents
In this background document the information from the VoF project and the SYNPEX project are presented. The background documents also address the specific problems encountered in either floor or bridge design., and contains information about human induced vibrations, structural dynamics, damping etc. This document can be used to accompany the guidelines.

Workpackage 2: Write a guideline
The guidelines provide methods with which a floor or a bridge can be classified unambiguously based on measurements or a model. The guidelines are dedicated to floor classification and the classification of bridges.

Workpackage 3: Preparation of presentations
In order to promote the new guidelines seminars and courses in different countries will be organised. The presentations to be held on these occasions will be prepared in this workpackage.

Workpackage 4: Seminars and courses
Seminars and courses will be organised in the following countries: UNITED KINDOM, FRANCE, THE NETHERLANDS, BELGIUM and GERMANY

Workpackage 5: Translations
The guidelines, background documents and presentations were translated into the following languages: FRENCH, GERMAN, DUTCH and PORTUGUESE.

4. GUIDELINES AND BACKGROUND DOCUMENTATION

The basis Research projects to be disseminated, VoF[1] and SYNPEX[2], both resulted in draft guidelines for the vibration design of structures that give the technical basis for the guidelines refurbished and presented in this project.

The vibration problems of footbridges and floors have several common effects:

- Vibration is caused by people walking: The footfall forces and walking characteristics have to be identified and specified.
- The tolerance to vibration may be different according to the use of buildings and structures, to the age, health and position of people and to the expectance of vibration. To cover this acceptance classes are needed.
- The techniques to determine structural dynamic properties are similar and follow the same physical rules. Guidance should be given how to determine the relevant dynamic properties.
- The design concept for both construction types building and bridge are the same:
  - 1. Step: Determine design requirement (Acceptance classes)
  - 2. Step: Determine structural properties (Natural frequency, modal mass, damping)
  - 3. Step: Determine design value (velocity or acceleration)
  - 4. Step: Compare design value with design requirement (design check)

Initially the option had to be discussed to write one guideline to cover all questions of human induced vibration for floors in buildings and footbridges.

For the design of floors the VoF-project gave several ways how the design can be performed. A specific method, the OS-RMS-method, was selected to be the focus of the guideline.

On the Continent designers for building structures are usually not very familiar with structural dynamics. In France and Germany, for example, the majority of buildings are built in concrete and structural dynamics is not considered (this will change with the further development of high strength concrete).
These engineers may be put off using steel when the material choice automatically leads to a requirement to consider the dynamic effects.

To overcome this problem the most time effective design procedure (OS-RMS) was chosen to be presented in the guideline. The effectiveness of a design procedure always leads to restrictions in application, so the chosen OS-RMS method should only be applied when normal walking is expected. It cannot be applied for gymnastic rooms or other places with special use. For these occasional occupancies reference is made to the SCI-guide [3].

Table 1 gives an overview of the influence of the different effects on the vibration design of bridges and floors that were initially discussed to be described in one guideline and one background document for both floors and bridges.

The differences between the effects and the fact that many designers do not deal with both types of structures led to the decision to separate the guidelines and background into structure dependant papers.
Another important reason for the separation of the guidelines was the possibility to transpose the guidelines into the relevant codes, which are different for buildings and bridges.

Table 1: Comparison of effects on floor and foot bridge vibration

Effect	Floors	Footbridges
Loading	Load model considers • Single persons walking • Statistical distribution of pace frequency and weight is considered	Load models for • Single persons • Groups of persons • Crowds
Time of excitation (depends on length of structure)	Short due to short relevant walking distances on floors	Long as bridges have a bigger length than floors
Direction of vibration	• Vertical only	• Vertical • Horizontal with danger of lock-in
Influences on the acceptance of vibration	• Receiver has no relation to vibration source • Different positions of persons (laying, sitting) • Activity of persons (sleeping, office works, fabrication work)	• Receiver knows the origin of vibration • One position (standing) only • One activity only (walking, standing)

To have a uniform and project specific layout of reports and presentations a logo was developed, indicating the project HIVOSS as a European vibration project. The logo is presented on the cover pages in Figure 1, which also gives an overview to the amount of pages of the different guidelines and background documents.

These documents include design rules, guidance and recommendation how to apply these rules, technical help for the derivation of dynamic structural properties and application examples.

The examples for floors have been verified with the SCI vibration guide to ensure similar results when applying both methods on the same structural system.

The finalised guidelines and background documents have been translated from English into four languages: German, French, Dutch and Portuguese.

33 pages

55 pages

43 pages

20 pages

Figure 1: English cover pages

5. DISSEMINATION OF KNOWLEDGE

The aim of the dissemination is to reach as many engineers as possible and to make them familiar with the design procedures developed in the project to be disseminated. The intention is that the guidelines may become a common design practice leading, after a period of application, to a draft code.

For the dissemination several ways and means were applied:

- Design procedures were presented at conferences and in conference papers,
- Publication in professional journals,
- Seminars and workshops were performed giving deeper information than it is possible in conference presentations and papers and
- An Internet page providing the free download of guidelines and background documentation, which is very important for the word of mouth marketing.

Conferences are good platforms to present design methods to a big audience. Typically the audience at conferences are experts in their field, so a conference causes technical discussions about the methods that are applied in guidelines and the design procedure becomes known. Within the project the HIVOSS guidelines were presented at the following conferences:

- IABSE Basaar 2007 in Weimar
- DACH Conference 2007 in Vienna
- EUROSTEEL 2008 in Graz
- FOOTBRIDGE 2008 in Porto
- GTL Congres Geluid, Trillingen en Luchtkwaliteite 2008

Publications in journals or books reach a lot of practicing engineers and will also be found in the future. It is an important way to introduce design procedures so that they may become common design practice. The following publications in journals were realised during the project period:

- "Design for floor vibrations" in the Singapore Engineer 09/2008
- "Projet HiVoSS – Vibrations des structures métalliques" in Construction Métallique Informations 2-2007.

Several publications have been prepared which are about to be published. Usually it takes several months from the initial presentation of a paper to the publication. The following publications in journals are about to be published:

- "Dynamische Auslegung von Geschossdecken" (Vibration design of floors) in BAUINGENIEUR, 2009
- Elsa Caetano, Alvaro Cunha, Wasoodev Hoorpah, Joel Raoul (Eds), " Footbridge Vibration Design", ISBN: 978-0-415-49866-1, CRC Press , (expected June 2009)

Workshops and seminars give the most detailed information to engineers. The seminars introduce the theory of dynamics, explain the design procedures and give examples to deepen the understanding of their application.
In total about 450 persons were reached with the seminars. The response to the seminars was very positive and project partners plan to perform additional events. Table 2 gives an overview of the performed seminars.

Table 2: Seminar overview

Announcement	Workshop/Seminar Data
	Seminar in Germany: Duration: 5 hours Date: 12.12.2008 (Aachen) Participants: 40 persons Organisation : RWTH Presentations : RWTH, SBP
	Seminars in United Kingdom: Duration: half day Date: 20.05.2008 (London) Participants: 103 persons Date: 21.05.2008 (Birmingham) Participants: 56 persons Date: 22.05.2008 (Manchester) Participants: 62 persons Date: 17.06.2008 (Dublin) Participants: 46 persons Date: 19.06.2008 (Glasgow) Participants: 27 persons Organisation : SCI Presentations : SCI
	Seminar in the Netherlands: Duration: 5 hours Date: 24.09.2008 (Delft) Participants: 30 persons Organisation : TNO Presentations : TNO, Bouwen met Staal, Cepezed

Announcement	Workshop/Seminar Data
	Seminar in Belgium (in Dutch): Duration: 7 hours Date: 11.11.2008 (Zoetermeer) Participants: 60 persons Organisation : TNO Presentations : ARCELOR, TNO, Bouwen met Staal
Studiedag Hivoss 4 november 2008 te Affligem • Inleiding • Programma • Inschrijvingsformulier • Routebeschrijving *(PS: La version en français se tiendra le mercredi 5 novembre 2008 à Gembloux)* Uitnodiging Het gebruik van het moderne hoge sterktestaal laat toe om slankere lichtgewichtstructuren te ontwerpen. De gevoeligheid van structuren voor trillingen wordt echter groter door deze verhoogde slankheid. Het ongemak dat dit teweegbrengt, wordt vooral waargenomen in vloeren en voetgangersbruggen, structuren die van nature met een licht gewicht en grote overspanningen hebben. Hivoss Het ontwerp van vloeren wordt hoofdzakelijk bepaald door de gebruiksgrenstoestand (doorbuiging en trillingen) van groot belang voor het comfort van de gebruikers. Zowel in vloeren als bij voetgangersbruggen is het vaak de gebruiker die de trillingen veroorzaakt en is dus zelf een belangrijke bron van dynamische excitatie. Door het gebrek aan voorschriften of Europese normen waren aanbevelingen nodig. Hierdoor werden een ECSC-onderzoek over trillingen in vloeren en een RFCS-project over trillingen in voetgangersbruggen ingesteld om na te gaan hoe het trillingsniveau in lichtgewichtstructurente controleren. De resultaten van deze onderzoeken zijn gebundeld in het volgende RFCS-project "HIVOSS" (Human Induced Vibrations of Steel Structures). Op basis van dit Europese onderzoek zijn twee richtlijnen geproduceerd om het trillingsniveau en het comfort van vloeren en voetgangersbruggen te voorspellen, te meten en te beoordelen. Deze ontwerphandleidingen en aanbevelingen zullen aan u worden voorgesteld tijdens dit seminarie. **Partners van het project in samenwerking met het Staalinfocentrum:** • RWTHAACHEN Universtiy • ArcelorMittal • TNO • SCI • CTICM • FEUP • Schlaich Bergermann und Partner	Seminar in Belgium (in Dutch): Duration: 5 hours Date: 04.11.2008 (Afflingen) Participants: 30 persons Organisation : ARCELOR Presentations : ARCELOR, TNO, Staalinfocentrum
 Programme du 5 novembre 2008 09h00 Accueil des invités 09h30 **Mot de bienvenue - Introduction** *Jo Naessens – Centre Information Acier* 09h40 **Présentation technique des produits ArcelorMittal** (ACB, Histar, long spans,...) *Olivier Vassart – ArcelorMittal* 10h00 **Présentation générale sur les vibrations** *Audrey Debackere – Centre Information Acier* 10h30 **Vibrations des planchers - guide de conception + exemples** *Olivier Vassart – ArcelorMittal* 11h00 Pause café 11h30 **Présentation générale sur les passerelles - dynamiques - tests** *Elsa Caetano - FEUP* 12h00 **Vibration des passerelles - guide de conception + exemples** *Mladen Lukic - CTICM* 12h30 **Questions et conclusions** **Mot de clôture** *Jo Naessens – Centre Information Acier* 13h00 Lunch 14h00 Fin du séminaire	Seminar in Belgium (in French): Duration: 5 hours Date: 05.11.2008 (Gembloux) Participants: 20 persons Organisation : ARCELOR Presentations : ARCELOR, FEUP, CTICM Centre Information Acier

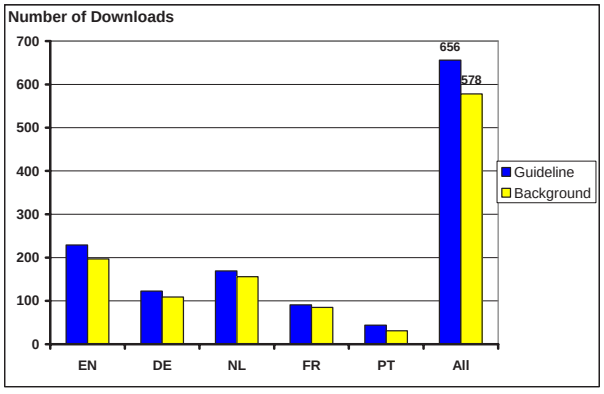
Announcement	Workshop/Seminar Data
	Seminar in France : Duration: 8 hours Date: 09.12.2008 (Paris) Participants: 31 persons Organisation : CTICM Presentations : ARCELOR, CTICM, SETRA Centre Information Acier

The presentation of the project at conferences, in publications and seminars and the information about the free download initiated word of mouth marketing for the new guidelines.
The download page, Figure 2, is marked with several keywords for internet search engines and is thus easy to find by an internet search. Searching for “HIVOSS” the download page is the first hit for all tested internet search engines.
The page provides free download of all guidelines and background documentation in the five project languages.

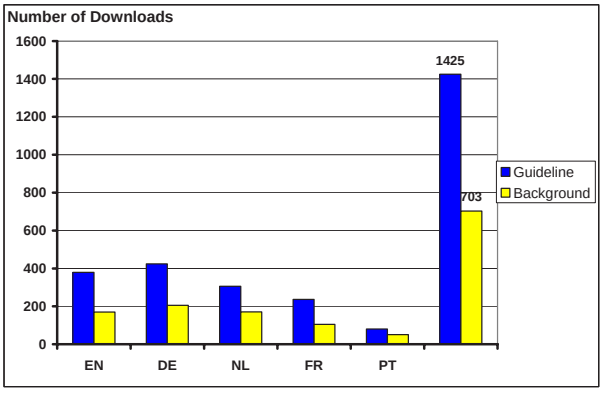
Counters have been installed on the website to record the number of downloads for the difference guidelines and documentation. These show a snowball effect as word of the documents spread.

The number of downloads is illustrated in Figure 3. It can be seen that the interest on the project result is enormous. Until 12th of March about 2000 downloads of the guidelines have been performed, with the majority of these (1400 downloads) downloading the footbridge guideline.

Figure 2: Download page (clicks until 12th of March 2009)



Floors



Footbridges

Figure 3: Visualisation of counter results (12.03.2009)

6. SUMMARY AND CONCLUSION

The use of modern high strength steel allows the design of slender and lightweight structures, reflecting the architectural demands. However with increasing slenderness the sensitivity of structures to vibrations rises.

European guidelines for vibration design have not previously been available.

For building construction an international classification of floors with regard to vibration is necessary in order to encourage the use of lightweight structures. For example, a lightweight floor based on a steel structure (Quantum floor) cannot be introduced into the international market until the manufacturers can demonstrate unambiguously that their floors will not cause unacceptable vibration levels.

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Guidelines and accompanying background documents for vibration design were developed from the project reports to make the results suitable for use in design offices.

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The project HIVOSS and the download page were presented at several conferences and in publications. Additionally the application of the design methods was demonstrated in workshops and seminars to about 450 people who were also informed about the availability of the documents.

Until 12th March 2009 more than 2000 downloads were performed from the web page. The number of downloads is increasing all the time.

The big interest shows the need of guidance for the investigated vibration problems.

After a period of application (which has already started) it should be considered to draft informative annexes to design codes on the basis of the presented guidelines.

7. COMPARISON OF INITALLY PLANNED ACTIVITIES AND OUTPUT

The overall objective of the project was to spread the knowledge gained in the two research projects HIVOSS and SYNPEX by writing a guideline for human induced vibration and presenting it to experts and practicing engineers

After many considerations it was decided by the project team not to write one guideline for the vibration design for floor and bridges but to split it into two, one for floors and one for bridges. Reasons for this decision are described in chapter 4 of this report.

In seminars and workshops about 450 people were reached and conferences and papers were used to inform engineers. By making the guidelines and their background documentation available as free download from an HIVOSS download page the project results spread rapidly.

With 2000 downloads until 12th March 2009 the spread of knowledge is a success.

8. EXPLOITATION AND IMPACT OF RESEARCH RESULTS

8.1 APPLICATION AND POTENTIAL OF USE

The guidelines developed on the basis of former research results give a European solution for the vibration design of footbridges and floors. As these are the only known guidelines that give guidance not only for the design but also for the specification of tolerable vibrations there is good chance that these guidelines may become basis for European tenders for this kind of structures.

On request of CEN/TC 250 JRC –Technical scientific report for footbridges is being prepared that gives the background to the Eurocode tool for traffic action on Bridges and the associated design rules. Partners of the project are members of the old project teams from UK, F, NL, B, D and Italy.

The background document shall not only give the background of existing rules but also give information on new rules that could fill gaps in the Eurocodes.

An important gap is the lack of guidance for the design of footbridges to limit vibrations. To inform the partners the HIVOSS project team has distributed the English draft-version of the document for being considered as reference document for future Eurocode works.

An option would be to publish a guideline as a separate JRC report.

UK - Steve Denton (new chairman horizontal group for bridges)

NL - Dr. Leendertz (Rijkswaterstraat)

I - Prof. Dr. Luka Sanpaolesi (Uni Pisa)
Prof. Dr. Croce (Uni Pisa)

F - Prof. Joël Raoul (CETRA)

D - Mr. Naumann (Ministry of transport and publish and public works)
Dr. Benning (Ministry of transport and publish and public works)
Prof. Krieger (Federal Institute of road technology)

CEN/TC 250: Prof. Dr.-Ing. G. Sedlacek (RWTH Aachen)

8.2 DISSEMINATION

The project period can only be regarded as the initiation of the further spread of the guidelines all over Europe and beyond. The project partners are still very engaged in presenting the outcome of the project at conferences and in papers.

The effect may be observed by anyone as the number of downloads is counted and published on the download page which will remain until codes replace the guidelines.

The guidelines have also been presented to regulatory bodies to be considered when refurbishing the appropriate design codes.

9. LIST OF FIGURES AND TABLES

10. REFERENCES

[1] G. Sedlacek, Ch. Heinemeyer, Ch. Butz, B. Voelling, S. Hicks, P. Devine, P. Waarts, F. van Duin, T. Demarco : "Generalisation of criteria for floor vibrations for industrial, office and public building and gymnastic halls VoF" RFCS Publication, Report EUR 21972EN, 2006, ISBN 92-76-01705-5

[2] C. Butz, M. Feldmann, Ch. Heinemeyer, B. Chabrolin, A. Lemaire, M. Lukic, P.-O. Martin, E. Caetano, Á. Cunha, A. Goldack, A. Keil, M. Schlaich: „Advanced load models for synchronous pedestrian excitation and optimised design guidelines for steel footbridges – SYNPEX", European Commission - Directorate-General for Research; EUR 23318; 2008; ISBN 978-92-79-08303-7, ISSN 1018-5593

[3] A. Smith, S. Hicks, P. Devine: "Design of Floors for Vibration: A new Approach" SCI Publication P354, ISBN 10:1-85942-176-8, ISBN 13:978-1-85942-176-5, 2007

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