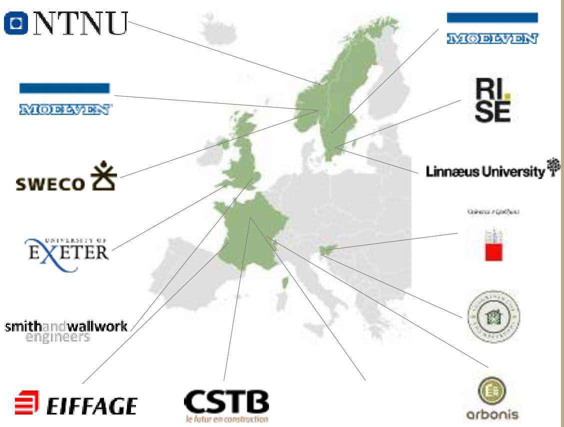
DynaTTB : Dyna mic Response of Tall Timber Buildings under Service Load

26th Japan-France Building Colloquium

5th june 2023 – Manuel MANTHEY, Olivier FLAMAND



DynaTTB is a project bringing together industrial and academic partners from 5 European countries (Slovenia, United Kingdom, Norway, Sweden and France).

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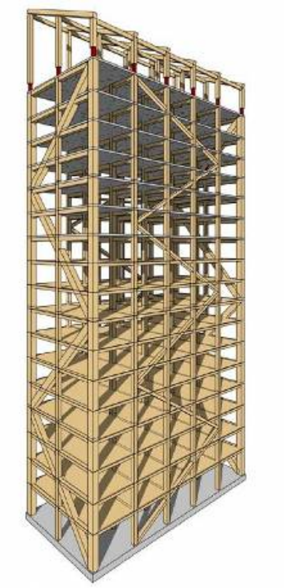
Starting point of the DynaTTB project

Dynamic Response of **T**all **T**imber **B**uildings under Service Load (Dyna-TTB)

Starting point :

- The world's tallest wooden tower (Norway, Mjøstårnet, 85m) has been "weighted down" to meet comfort requirements.
- The top 7 floors have a 30cm thick concrete floor. The top floor exceeds the chosen comfort criteria. It is sold by specifying it to the buyer.
- Most all-wood buildings can meet this requirement (even for "small" heights of 4-5 floors).



In-situ measurements: 9 buildings have been shaken !

2 buildings in France, hybrid structure (timber-concrete)

THE HYPÉRION TOWER – 56 M

- Located in Bordeaux
- 17 floors (R+16)
- Construction from March 2019 to June 2021
- Residential use
- Highest hybrid wood/concrete tower in France
- Large balconies

THE « TREED IT » TOWER – 36 M

- In Champs sur Marne
- 12 floors (R+11)
- Construction from mas 2018 to December 2020
- Student residence : Many interior partitions (rooms)

Hybrid / multi-material structures

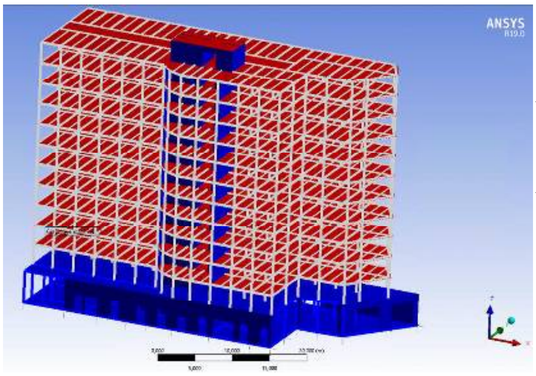
1st Treed-It campaign

Philosophy :

- The right material in the right place.
- Lighter structures.
- Optimization of material quantities (frugality).
- Favors the use of bio-sourced materials.
- Reduction of the carbon footprint of buildings.

Geometry and Materials

What is special about these two towers is their hybrid character. The concrete cores, for reasons of fire protection in particular, are made of reinforced concrete. With this structural system, it is to be expected that the concrete core will mainly guide the lateral stiffness of the tower. Tests conducted at various times during construction have shown that this is not so simple.



Concrete core all along the tower

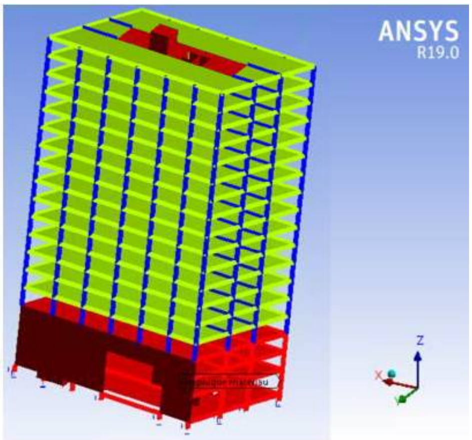
Timber-concrete floors | *CLT floors*

Timber columns | *Steel columns*

Timber beams

1st levels in concrete

Piles for foundations



Treed-It FEM — *Hyperion FEM*

How to get rid of the weather for testing ?
The mass shaker

With a heavy shaker input force is such that the amplitude of noise becomes negligible.

Two levels of amplitude, two levels of moving mass.

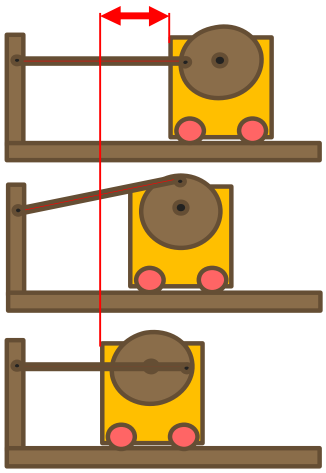
Lever arm can be set to 158mm or 248mm

Moving mass is 400kg; 150kg addition is possible

The applied force increases according to the frequency²

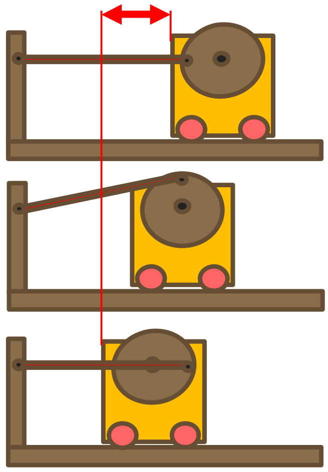
=> $F = M.(2.\pi.f)^2 . A$

When the force of the shaker exceeds the frictional resistance, the exciter slides on the floor.



The mass shaker in action at Hyperion

Ballast per bag of sand



Acceleration and relative displacement measurements

Location of sensors: 3 accelerometers on 3 different floors

Four different kinds of tests have been achieved, each having a particular purpose

- The measurement of vibrations under **ambient excitation**, by turbulent wind, nearby traffic or works inside the building, gives way to long lasting records (10 to 60 minutes) with the aim to identify modal frequencies. It provides a good insight of modal frequencies.

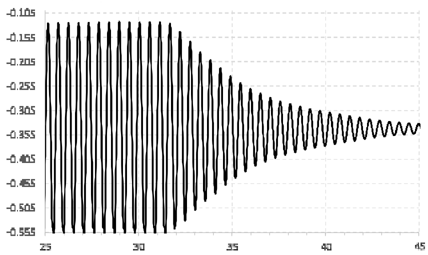
- An artificial excitation by a **mass shaker** delivering a **horizontal sinusoidal force**, with a **continuous and slow variation of the frequency** of which, called **swept sine** test. Because input force is controlled, the dynamic response of the building, i.e. accelerations measured at various locations, shows the frequencies of increased amplitude, pointing out the modal frequencies.

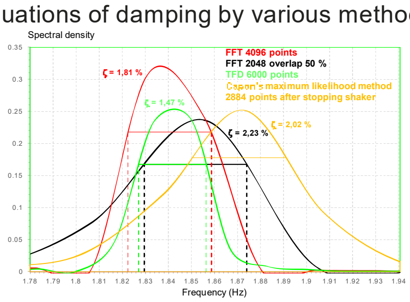
- An artificial excitation by a **mass shaker** delivering a **continuous horizontal sinusoidal force** at a **fixed frequency**. This **constant excitation** test must be brief to avoid beating, due to the unavoidable small difference between the frequency of the applied force and the modal frequency of the building which is excited. It was lasting 60s in this series of tests limiting data processing to time domain approach only.

- An **interrupted excitation** by the **mass shaker**, called a **shutdown test**, is used to **measure modal damping**. The initial excitation frequency is the one of a selected mode, then amplitude decreasing after the excitation has been stopped gives a good approach of modal damping.

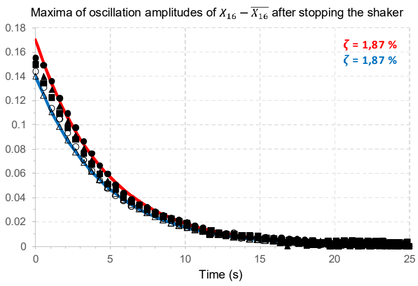
ADAPTED METHODS FOR THE MEASUREMENT OF STRUCTURAL DAMPING

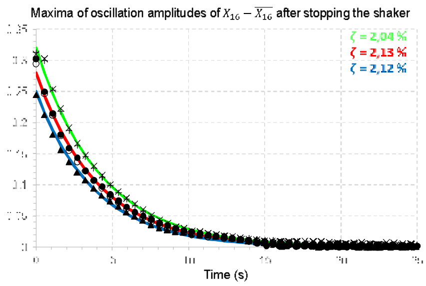
Example of shutdown test record for bending mode and the evaluations of damping by various methods.





Examples of damping evaluation from repeated shutdown test records for bending mode with shaker located in the south corner of the building and with small amplitude (left) and on the east side with large amplitude (right)





increase of damping with amplitude on bending mode

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How does this relate to numerical simulations?

"GOOD PRACTICE" MODELS HELP PREPARE FOR IN-SITU TRIALS

> The model gives an estimate of the natural frequencies and modal deformations (choice and settings of the exciter, location of the sensors).

> The model helps to convince the client before the tests: via a temporal simulation of the excitation by the machine and the demonstration that the amplitude of the deformation remains very limited (deformation verified by LVDT during tests).

IMPROVEMENT OF THE MODEL BY COMPARISON WITH TRIALS

> The measured frequencies and modal shapes are compared with the numerical results and an optimisation process is started.

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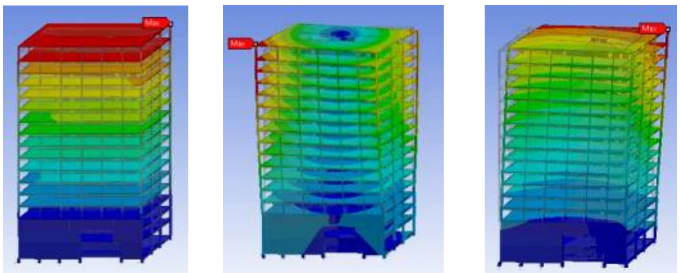
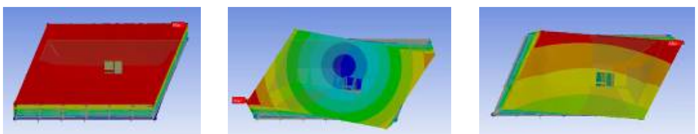
Analysis of the simulations

INITIAL FINITE ELEMENT MODEL



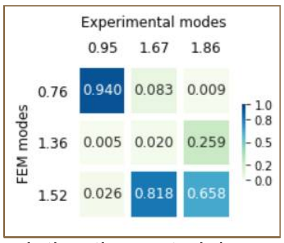
Bending 1 | Torsion | Bending 2 + Torsion



The measured frequencies are directly compared with the numerical results

	f1	f2	f3
Experimental [Hz]	0.95	1.67	1.86
Initial [Hz]	0.76	1.52	1.37
Error [%]	**-20.14**	**-9.21**	**-26.62**

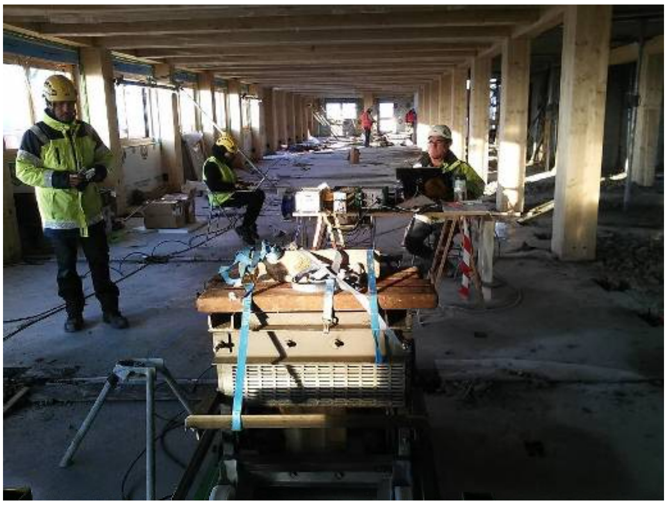
The modal shapes are compared with the numerical results (Modal Assurance Criterion)



An optimisation process can be started parameter by parameter. In addition to updating the material parameters used, or the connections between elements, it has sometimes been necessary to add components that were initially neglected.

CSTB le futur en construction / What role for non-structural elements?

In simulation, lightweight partitions were initially considered more as a distributed mass than as a discrete element bringing a gain in rigidity to the structure.



1st round of testing

2nd round of testing

CSTB le futur en construction / What role for non-structural elements?

On-site measurements were made twice for each of the two towers :

1/ With all the structural elements implemented (walls, floors, beams, etc.)

2/ After the addition of non-structural elements (light partitions, facade, balconies, etc.)

Treed-It	Mode 1 – bending X	Mode 2 – bending Y	Mode 3 - torsion
1st round of testing (mass shaker)	1.37	1.54	1.69
2nd round of testing (mass shaker)	1.39	1.49	1.62

Numerous partitions (student residence)

Mass +43%

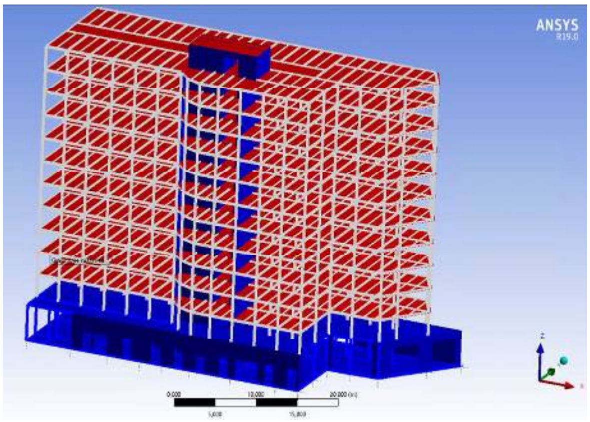
Frequencies - 21% ???

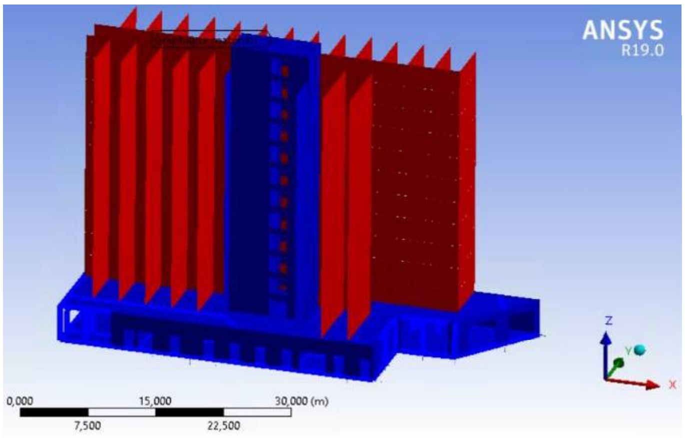
Hyperion	Mode 1 – bending X	Mode 2 – torsion	Mode 3 – bending Y
1st round of testing (mass shaker)	0.95	1.67	1.88
2nd round of testing (ambient)	0.95	1.50	1.81

! Balcony weight (+700t)

Consideration of internal partitions in the simulations

Ex ample on the Treed-It tower adding shell elements for the partitions





Initial model

View of the interior partitions

Conclusions

Timber buildings (and hybrid building) are lightweight and subject to wind excitation, which poses a serious problem for occupant comfort ---▶ DynaTTB project.

In-situ tests of towers with a timber or hybrid structure were performerd => providing modal frequencies and modal shapes that were compared with numerical simulations.

Damping was found to be amplitude dependent: a large amplitude excitation is needed to capture it, the FE model is of great help to prepare these tests.

The FE models need to be improved by :

- Optimising the parameters (initial values can be poorly estimated).
- Taking into account the stiffness of so-called "non-structural" elements as partitions or screeds, whose relative stiffness may have a role here in the overall stiffness of the structure

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