Development of low-vibration laboratories; a solid foundation for fundamental research

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In recent years, the development of nanotechnology, bio-nanoscience and biomolecular science has led to a significant growth in the use of high-quality research equipment. Institutes and universities in the Netherlands are leading in these fields. To maintain this leading position several high-quality research buildings have been developed in recent years. The laboratories are designed to provide flexibility and versatility, suitable for the use of current and next generation equipment. This article debates the requirements of these high-quality laboratories, the location of the facility and the design of low-vibration laboratories.

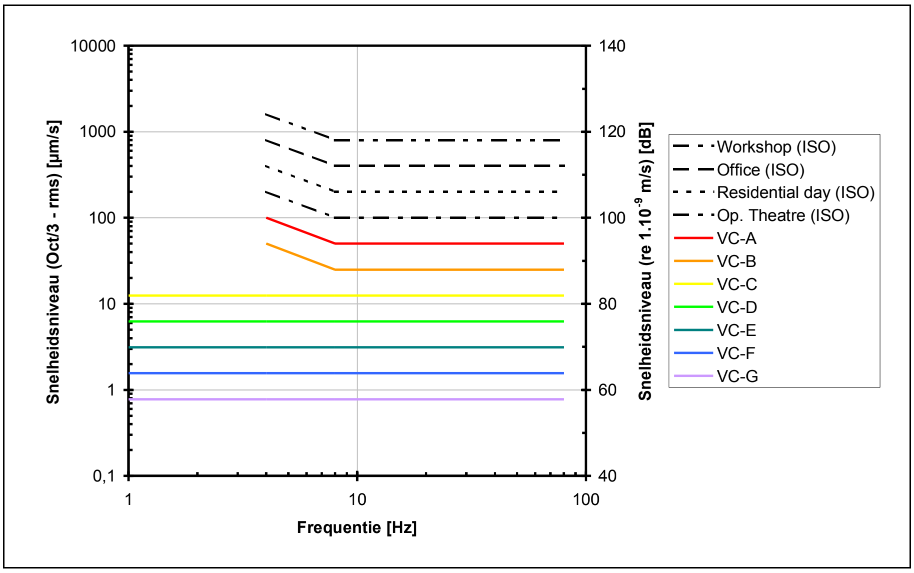
f1.1 Nanolab University of Twente (left), Faculty of Applied Sciences Delft University of Technology (right).

1 Low-vibration laboratories and generic criteria

Low-vibration laboratories are primarily intended to house research institutes which use sensitive equipment. Structure-borne vibrations are the main concern for researchers. In addition, acoustical noise, electromagnetic fields, radiation, air flows, particulates and temperature fluctuations are disturbing phenomena, which lead to strict requirements for the research facilities.

Research institutes demand facilities which are suitable for a wide variety of instruments and equipment. This has led to generic requirements of the floor quality. Implementation of these requirements result in a flexible layout and multifunctional utility of the laboratories. Generic requirements for vibration criteria are used to describe the performance requirements, such as the VC-curves (vibration criteria) [1].

f1.2 Generic performance requirements, VC-curves (vibration criteria) [1]



2 Inventory of vibration sources

Vibration sources are differentiated by influence, by location and by the possibility of adjustment. Vibration sources introduced by the users are for example walking, or the supporting equipment such as vacuum pumps, compressors and process cooling.
Vibrations within the building are caused by pumps, HVAC systems or elevators. The wind induces the natural movement of the building.
With an appropriate design of the construction and an adequate positioning of installations and supporting equipment, the sensitive instruments can be well shielded from vibrations induced within the building.

Roads, railways and industrial complexes are the origin of vibrations which are most difficult to anticipate on. The vibrations propagate through the soil and there are hardly any possibilities to take measures at the source.

Therefore, the quality of the laboratories is often determined by the vibration sources in the nearby area. However, this aspect is hardly ever taken into consideration by choosing a suitable location. Heavy vibration sources such as freight trucks, trains and trams cause relatively high levels of vibration at low frequencies (between 1 and 10 Hz). Even at large distance, these sources cause disturbance to the building foundation, thus effecting the sensitive research equipment.

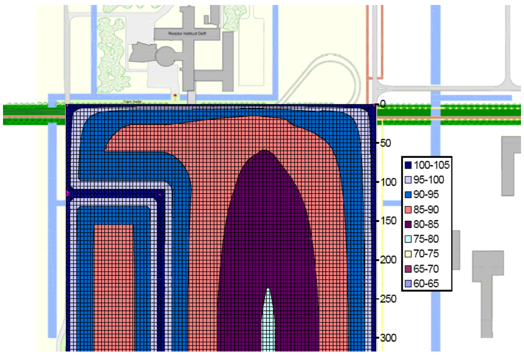
3 Low-vibration science park

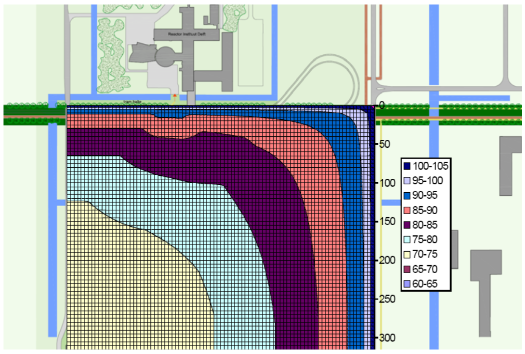
The increasing need for low-vibration laboratories and stricter requirements with regard to acceptable vibration levels lead to an increasing development of low-vibration science parks. The University of Twente (The Netherlands) has banned motorized traffic from the center of the campus, thus avoiding disturbance to nearby the research facilities.

The Delft University of Technology (The Netherlands) reviewed several sites for the new Faculty of Applied Sciences, and has finally chosen the site with the lowest vibration levels. The vibrations induced by traffic, trucks, trams and buses were assessed. With the use of field measurements and calculation models, the traffic plan was optimized by closing several roads and relocating the turning loop of the new railway.

The closure or relocation of roads and a railway lead to a significant reduction of the external source vibrations, which is demonstrated with calculations.

f3.1 Environmental vibrations with the original road plan (left). The closure of roads leads to a significant reduction (right).





With longer distances to roads and railways, the site for the laboratories has been improved significantly by creating an area free of any disturbing traffic.

With regard to future development, it is important that the science park and the nearby area remain free of dominant vibration sources. This requires a structural cooperation between local administration, research institutes and business partners, taking into consideration the common interest in preserving low-vibration facilities [2].

4 Building a vibration-resistant construction

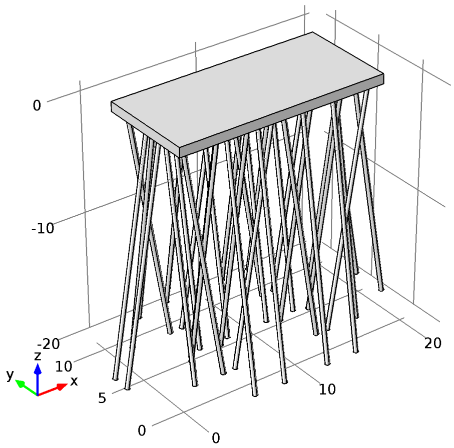
A long distance from an environmental source such as a road or railway is necessary. However, this may not be sufficient to meet the requirements of the laboratory. When the building construction is designed inappropriately, the ground-borne vibrations may induce building vibrations. If the external vibrations coincide with an eigenfrequency of the construction, the vibrations may even increase due to construction resonance.

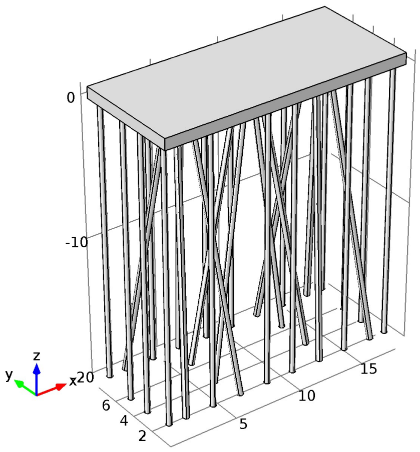
In a well designed building, the building installations such as elevators, pumps, HVAC systems and compressors are positioned at appropriate distance from the laboratories. It may be necessary to position these sources on vibration damping devices. If the requirements are very strict, the possibly disturbing vibration sources are grouped in a dedicated building which is completely separated from the laboratory building. Floors are separated by dilatations to obtain a vibration reduction between the sensitive instruments and the supporting equipment. Internal traffic on laboratory floors is prevented [3].

Taking the dominant vibration sources into account, for each laboratory a floor concept is chosen, appropriate to the vibration requirements. Either rigidly joint to the building, or perfectly disconnected from other constructions, each floor concept has certain advantages.

In river deltas, the soil is often marshy and peaty, unsuitable to bear the construction. In Delft, the new Faculty of Applied Physics is founded on the underground solid layer of sand, on 20 m (65 ft) long concrete piles. The concrete floors of the laboratories are 80 cm thick (30''). To avoid horizontal vibrations of the floors due to external sources, shoring piles are used.

f4.1 Independent floor structures on shoring piles, disconnected from other constructions [4]





5 Calculation and measurement of the vibration transfer function

In combination with the soil composition, the floor structure has a certain vibration transfer from soil to floor. A rough estimate is calculated using the model of a multiple mass spring system. With the model, the effect of the adjustable parameters is assessed, such as floor dimensions and the number of piles [5, 6].

In a further engineering of the structural design, the Finite Element Method (FEM) is used to compile a mathematical model in which the entire floor structure is outlined within in a layered soil model. An external impulse forces the soil model and the floor structure in vibration, and the vibration transfer function from soil to floor is calculated [7, 8].

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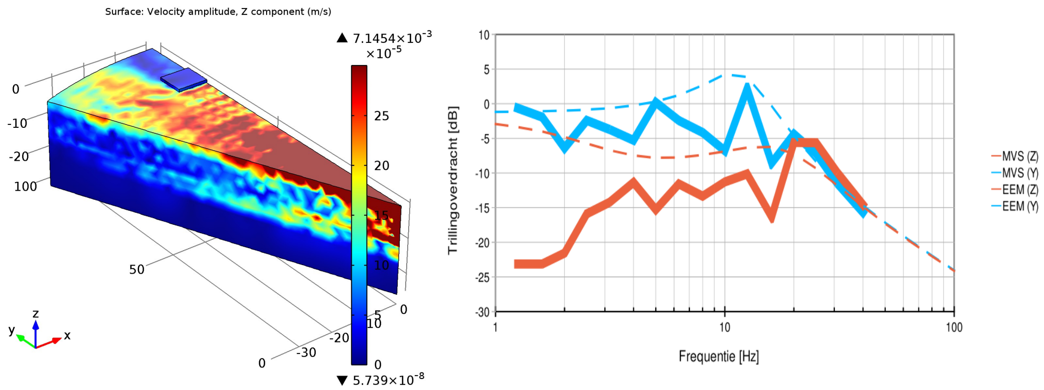
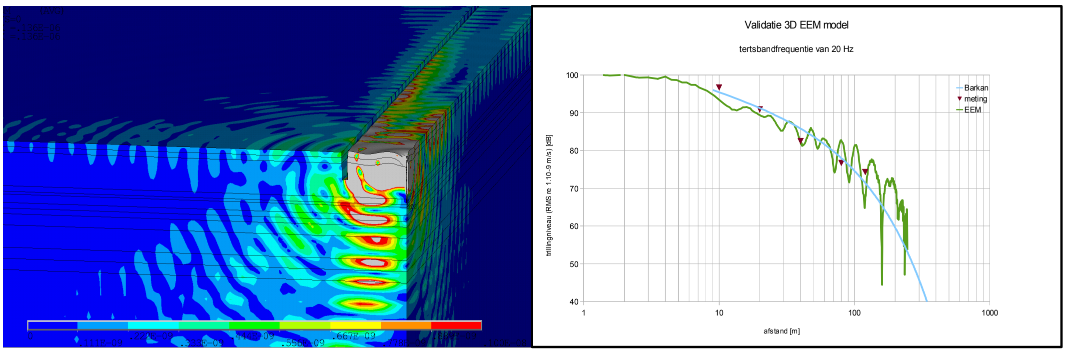
f5.1 Vibration propagation through FEM-model (left), the vibration transfer function from soil to floor (right).



With this complex FEM-model, a more accurate prediction of the vibration transfer function is obtained, taking into account the propagation through the soil, the multiple eigenfrequencies of the construction and the interaction between the construction elements.

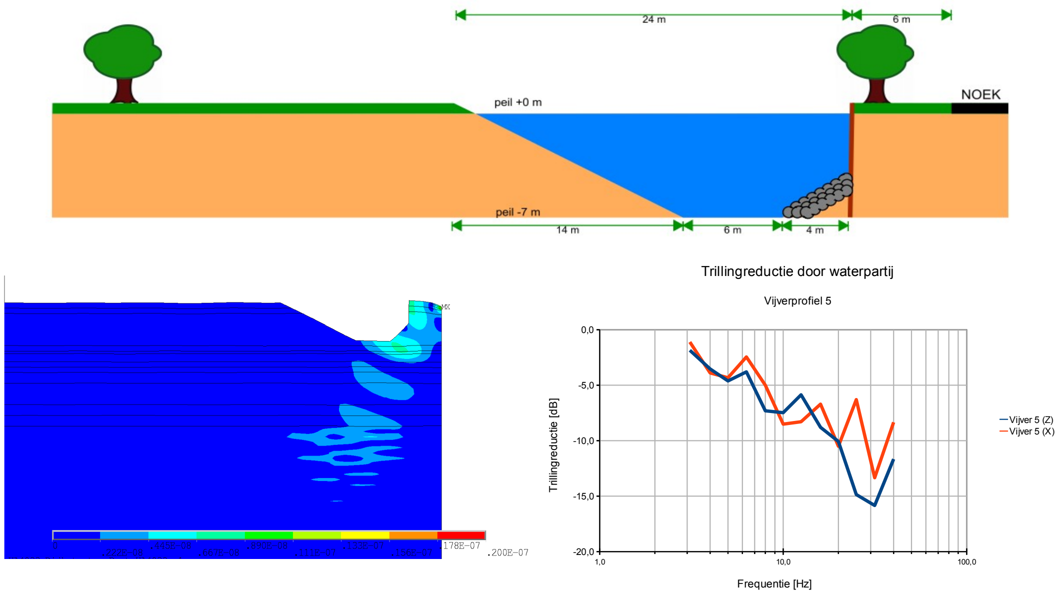
To verify the FEM-model, the actual vibration propagation is measured on site, by forcing an impulse in the soil, thus inducing vibrations. The reduction of the vibration is measured at varying distances for the frequencies of interest.

f5.2 Vibration propagation through FEM-model (left), calculation results compared to field measurements (right).



With a validated FEM-model, alterations in the ground can be studied. Nearby the University of Twente (The Netherlands), a newly planned road may induce ground-borne vibrations. With a pond between the road and the laboratories, the vibrations are reduced, preventing disturbance. Using the FEM-model, the width and depth of the pond were optimized.

f5.3 Water pond parallel to the road (top) is calculated in FEM-model (bottom left) and results in reduction of vibration propagation (bottom right).



6 Under construction: check and review

During the construction of the laboratory several measurements are conducted to ensure the accurate completion of the building. The building is finished when building installations are operational and the research equipment is to be installed. The resulting vibration levels are measured to assure that the research instruments will perform at best, without disturbance of floor vibrations.

7 Conclusion

To accommodate current and future scientific developments, adequate and appropriate research facilities are required, with an increasing demand for low-vibration floors. This requires an inclusive approach of the vibration sources in the building as well as the vibration sources in the vicinity.

Reforming infrastructures such as roads and railways may be necessary to obtain low-vibration science parks. This requires a structural cooperation between local administration, research institutes and business partners, who share a common interest in research facilities. Given the developments in nanotechnology, bio-nanoscience and biomolecular science, the importance of high-quality, low-vibration laboratories will further increase.

With use of on-site measurements, complex FEM calculations and specific design of building constructions, future laboratories will be quieter and better suited for high-sensitive equipment, enabling research institutes to reach another level of accuracy.

8 Resources

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