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Autor: Plum, Carsten Munk / Svensson, Eilif

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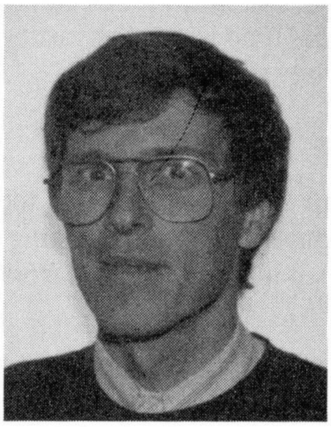
Dynamic Response of a Composite Slab in an Office Building

Comportement dynamique d'une dalle composite d'un bâtiment commercial

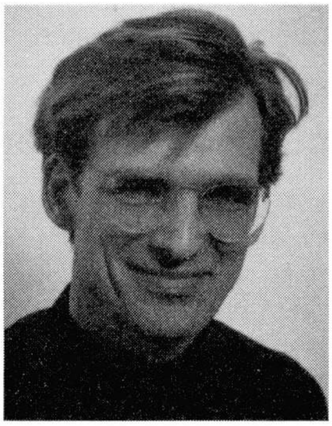
Dynamische Reaktion einer Verbunddecke in einem Verwaltungsgebäude

Carsten Munk PLUM
Chief Engineer
ES-Consult
Vedbaek, Denmark



Carsten Munk Plum, born 1948, obtained his MSc degree from the Technical University of Denmark. He has been working in civil and structural engineering since his graduation as a consulting engineer and has contributed with several papers on theoretical topics related to structural stability.

Eilif SVENSSON
Chief Engineer
ES-Consult
Vedbaek, Denmark



Eilif Svensson, born 1945, obtained his MSc and PhD degree at the Technical University of Denmark. Since he has been working in civil and structural engineering as a consulting engineer with particular emphasis on stability and dynamic in relation to larger steel structures and has written several papers on these issues.

SUMMARY

The structural dynamics serviceability of a composite floor of an office building is investigated using an FEM modal analysis. The results presented show that the structure behaves well when exposed to people walking and running, and acceptably when exposed to many people dancing.

RESUME

L'aptitude au service, pour des cas de charge dynamiques, d'une dalle composite d'un bâtiment commercial est examinée avec une analyse modale par éléments finis. Les résultats présentés montrent que la structure se comporte très bien pour les cas de personnes marchant ou courant. Le comportement structurel est acceptable pour le cas de personnes dansant.

ZUSAMMENFASSUNG

Das dynamische Verhalten einer Verbunddecke in einem Verwaltungsgebäude wurde mittels einer modalen Finite-Element-Berechnung untersucht. Wie die Resultate zeigen, eignet sich diese Bauweise sehr gut für gehende oder laufende Personen und ist noch annehmbar unter Tanzbelastung.

1. INTRODUCTION

During the last decades it has been a tradition to use precast concrete elements for all kinds of buildings in Denmark. We are now successfully introducing a solution based on a combination of concrete elements and steel beams (see fig. 1 & 2). Mixing materials this way we utilize the best properties of each material with regard to economy, bearing capacity, deformations and fire protection. One remaining problem to be clarified is the dynamic response of the structure exposed to human activities, such as walking, running, jumping and dancing.

In the ISO codes (ISO 2631) [1] and related national codes [2] serviceability limits for accelerations (comfort criteria) are introduced for various types of buildings and other structures.

A major challenge for the present lighter structure (see fig. 1 & 2) was the verification of its ability to meet the above mentioned serviceability requirements. To clarify this we examined the structure with simplified calculations and with a more accurate finite element (FEM) modal analysis using the PC based program ALGOR.

2. HUMAN ACTIONS ON THE FLOOR STRUCTURE

Various investigations have been carried out [3] with the goal to set up loading criteria for the dynamic human actions on structures. As a result some simplified formulas for people walking, running, jumping, dancing etc. have been established [2],[3]. An example of the dynamic load from one walking person with a relative weight 1 is shown in fig. 3.

3. SIMPLIFIED CALCULATIONS OF EIGENFREQUENCIES

The floor structure (see fig. 1) can as a first assumption be analyzed as two independent structural systems - a one-way slab and a continuous beam with 2 interior supports.

For the simply supported one way spanning slab we determine the lowest eigenfrequency using well known formulas. The higher eigenfrequencies will be influenced by the integration with the steel edge beams, loading from facades and the elastic support of the cross steel beams. Using the total dead loadings and one third of the live load we have calculated the lowest eigenfrequency to 5.17 Hz in the example shown. This is identical to the result for a traditional fully precast structure. In [3] the recommended lower limit for the eigenfrequency is to 8.0 Hz. This means that we might encounter problems using a completely traditional precast hollow core slab structure.

For the continuous cross beam we assume that the bending stiffness corresponds to the steel section and that the mass corresponds to the loadings on the beam from the slab. Using this the lowest eigenfrequency can be calculated to 3.8 Hz. If we had been using a traditionally simply supported precast T-beam, the eigenfrequency would have been 5.0 Hz. It seems clear that the flexural stiffness of the steel beam will be greater than our assumption due to the interaction with the concrete slab and that the vibrating mass will be lower than the assumed due to the flexibility of the slab. This means that the eigenfrequency will be greater than 3.8 Hz in the real structure.

From the above remarks it seems clear that a more detailed investigation of the integrated floor structure is required.

4. FEM ANALYSIS

For the further investigations we establish a FEM model of the integrated slab / beam structure supported on the stiff columns. The horizontal movements are disregarded.

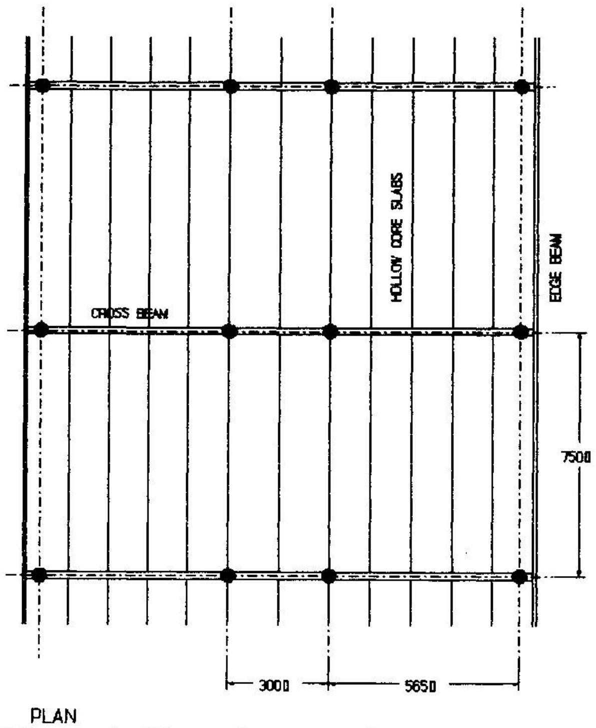


Figure 1. Plan of a part of the floor in the office building

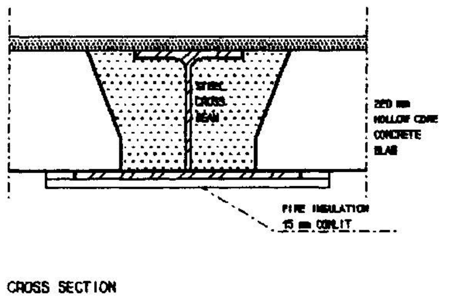


Figure 2. Section in the cross beam.

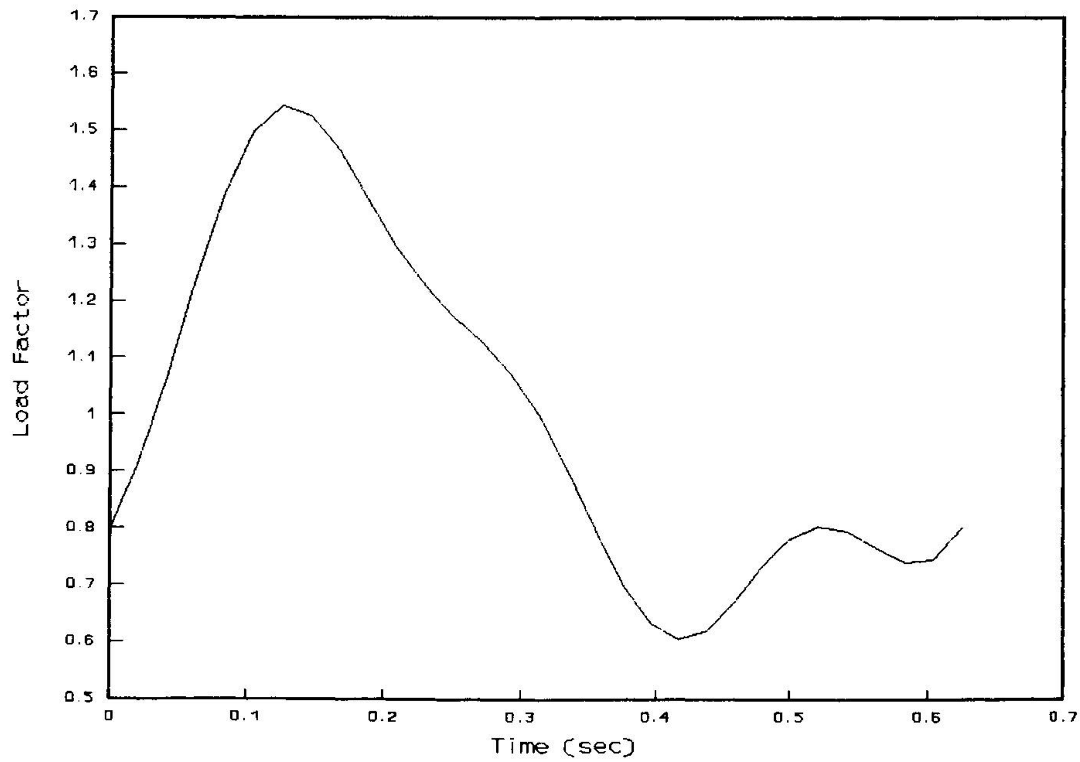


Figure 3. Load Factor versus time for a walking person [3].

The cross and edge beam elements are modelled very simply with their own properties and with nodes mainly identical with the nodes of the plate elements. Above the facade columns we have created extra nodes for the beam elements.

The hollow core slab elements are modelled as isotropic plate elements with 4 nodes each. Between the elements in the longitudinally direction (of the building) we model a pure shear connection to account for the shear lock between the precast elements. This means that it is not necessary to take into account the orthotropic behaviour of the hollow core slab.

The main dimensions of the plate elements are 1.25 m in the longitudinally direction of the building and in the transverse direction 1.2 m, which is identical to the standard precast elements normally used in Denmark. The dynamic mass of the structure is assumed to be dead load and one third of the live load.

The modal analysis of the FEM model gives the results shown in table 1 and partly in fig. 4 for the eigenfrequencies.

Mode	Eigenfrequencies [Hz]	Mode	Eigenfrequencies [Hz]
1	4.80	6	7.33
2	5.47	7	7.79
3	5.74	8	8.70
4	6.24	9	9.63
5	6.96	10	10.04

Table 1. Eigenfrequencies of the floor structure.

It is obvious that mode 1 is very close to the simply supported one-way slab and therefore the first eigenfrequency 4.80 Hz is comparable to the previously calculated 5.17 Hz. The small difference is satisfactory and could mainly be explained by the fact, that the FEM model takes into account the small deformations of the cross beam and the vibration of the edge beam, which acting alone would have had a lowest eigenfrequency of 3.2 Hz. We can then conclude, that the FEM model is sufficiently exact.

Knowing the first 10 eigenfrequencies and the corresponding modes we are able from modal analysis to calculate the response of the floor structure being exposed to a forced dynamical load. For the structure in our example we have chosen to determine the response from people walking, running and jumping (dancing, gymnastic etc) as shown in table 2.

For the two load cases with one person moving it is assumed, that the movement takes place longitudinally crossing the mid span of the floor between two rows of columns near one of the facades. Jumping people are also assumed to act at the mid span. The area between the two interior rows of columns is in this building occupied by installations. The structure is conservatively assumed to have a critical damping ratio 0.01 for all modes.

Some of the results of the response calculations are shown in fig. 5 and 6.

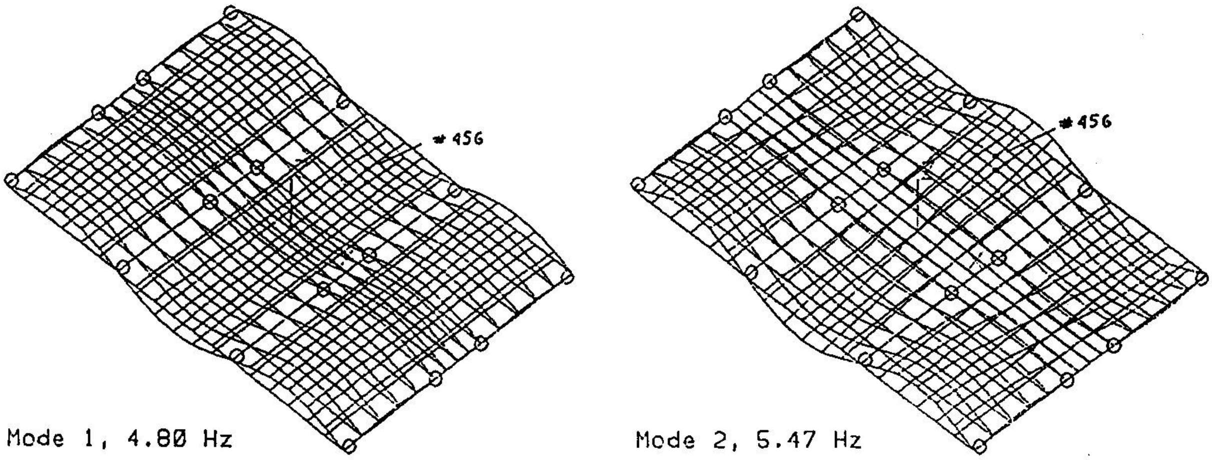


Figure 4. Vibration modes for the first 2 eigenfrequencies.

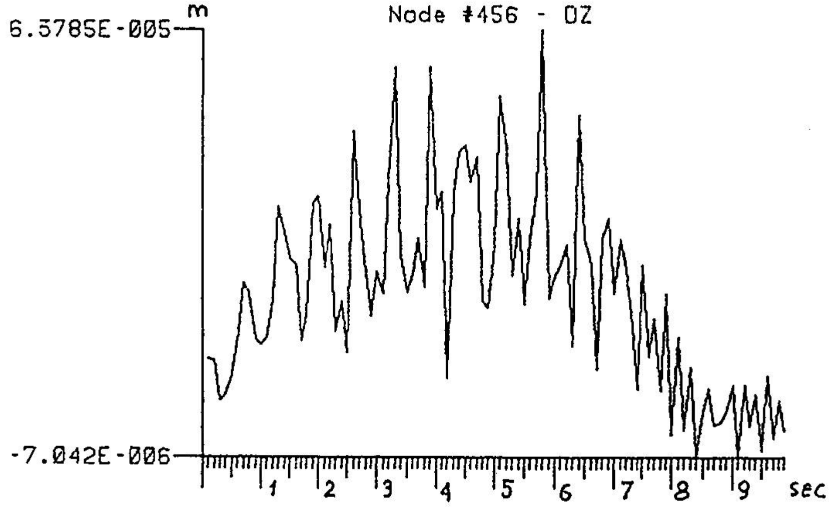


Figure 5. Vertical deformation (in m) of the mid span node (#456) versus time (in sec) during passing of a walking person.

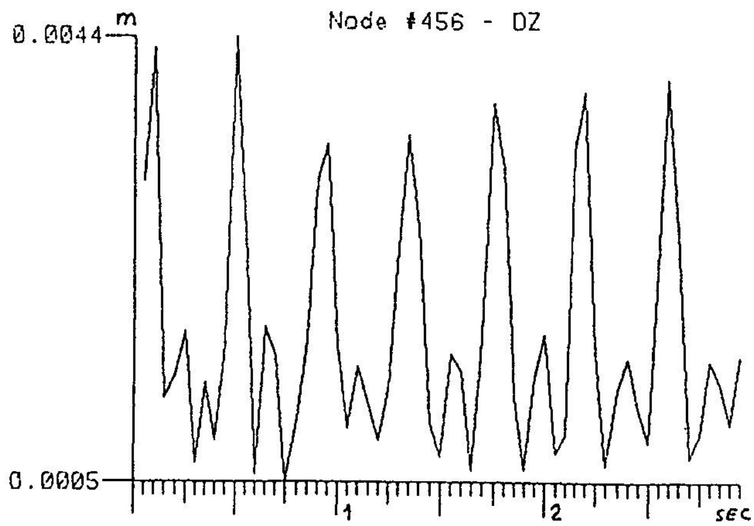


Figure 6. Vertical deformation (in m) of the mid span node (#456) versus time (in sec) during a dancing session (base frequence 2.4 Hz).

Dynamic load	Frequency [Hz]	Velocity [m/sec]	Static load
One person walking	1.6	1.0	800 N
One person running	2.4	2.9	800 N
People jumping (dancing)	1.6 2.4	0 0	1600 N/m² 1600 N/m²

Table 2. Dynamic loadings from human activities on the floor structure.

5. EVALUATION OF THE RESULTS

The response from one person walking across one slab is shown in fig. 5. The vertical deflection of the mid span node is max. 0.064 mm and the corresponding acceleration is max. 0.02 m/sec². The floor behaves very well to the walking person. For a running person we obtain a max. acceleration of 0.03 m/sec². When more than one person are walking the above acceleration will increase. An estimate of the increase factor is 6 [3], which means that the max. acceleration reaches 0.12 m/sec². All the results are below the acceptance level 0.2 m/sec² [3].

The response from people dancing or jumping with a frequency of 2.4 Hz is shown in fig. 6, where the deflection of the mid span node is shown. The max. acceleration of the slab at the dancing persons is 0.8 m/sec² which is acceptable (< 1 m/sec²). The slab situated in the next span is vibrating with a dominant frequency of 4.8 Hz and the max. acceleration is 1.0 m/sec², which is considered acceptable for people participating in the event.

6. CONCLUSION

We conclude, that the floor structure behaves very well to normal and acceptable to abnormal induced vibrations from human activities. It can also be concluded, that the dynamic behaviour of a floor structure cannot be predicted alone by regarding it as composed by independent plate and beam units.

REFERENCES

1. ISO 2631/1 & /2. Evaluation of human exposure to whole-body vibration. Part 1 & 2, 1985 & 1989.

2. DS/INF 77. Bases for design of structures - serviceability of buildings against vibrations, 1992.

3. Bachmann H. & Ammann W., Vibrations in structures induced by Man and Machines. IABSE-AIPC-IVBH, Switzerland, 1987.