Design of hollow core floors - Dynamic behaviour

Vibrations, fatigue

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Structural and Building Engineering / Concrete Structures

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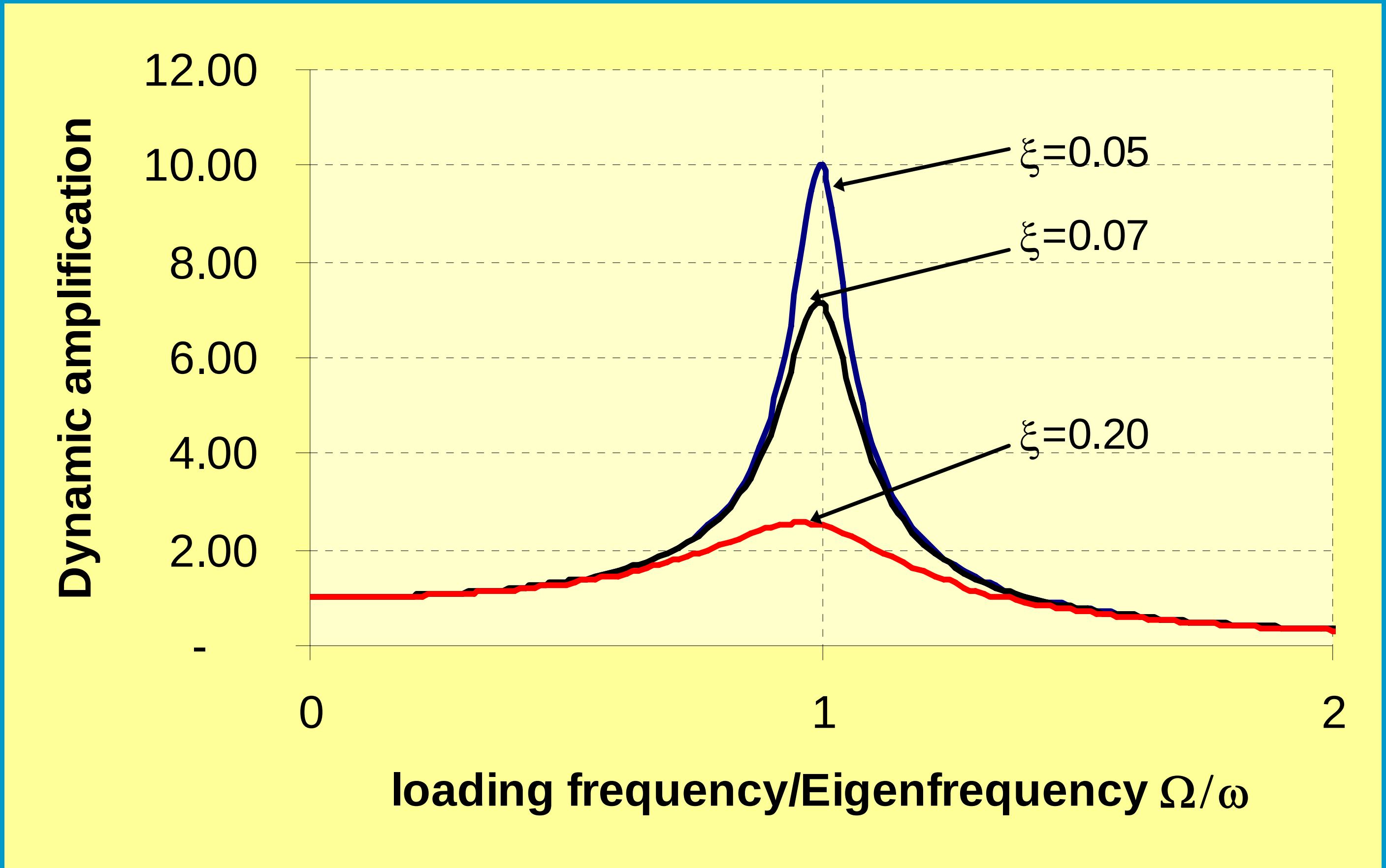
Dynamic actions

- Vibrations
  - Gyms (Sports- and dance halls)
  - *Machine foundations*
  - *Climate related actions (wind)*
- Fatigue
  - Floors subjected to traffic loads (Trucks and forklift-trucks)
  - Park decks
  - *Machine foundations*
  - *Climate related actions (wind)*

Vibrations
Sports and dance halls

Problem: with a standard design in accordance with building codes resonance phenomena can still occur

Resonance



Significant deformation increase!

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Design by frequency tuning

Structure type	Sports halls	Dance halls
Reinforced concret	$f_1 > 7.5$ Hz	$f_1 > 6.5$ Hz
Prestressed concre	$f_1 > 8.0$ Hz	$f_1 > 7.0$ Hz
Composite	$f_1 > 8.5$ Hz	$f_1 > 7.5$ Hz
Steel	$f_1 > 9.0$ Hz	$f_1 > 8.0$ Hz

After: Bachmann u.a. [1995], Vibration Problems in Structures, Practical Guidelines

Many national codes (eg. DIN 1045-1 do **not** have **frequency limitations**!

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Eigenfrequency of hollow core slabs

Simply supported beam:

$$f_1 = \frac{\pi}{2 \cdot l^2} \cdot \sqrt{\frac{E \cdot I}{m}}$$

More accurate determination of frequency possible if requested (dynamic analysis, FEM) – but input data should be determined as accurate as possible!

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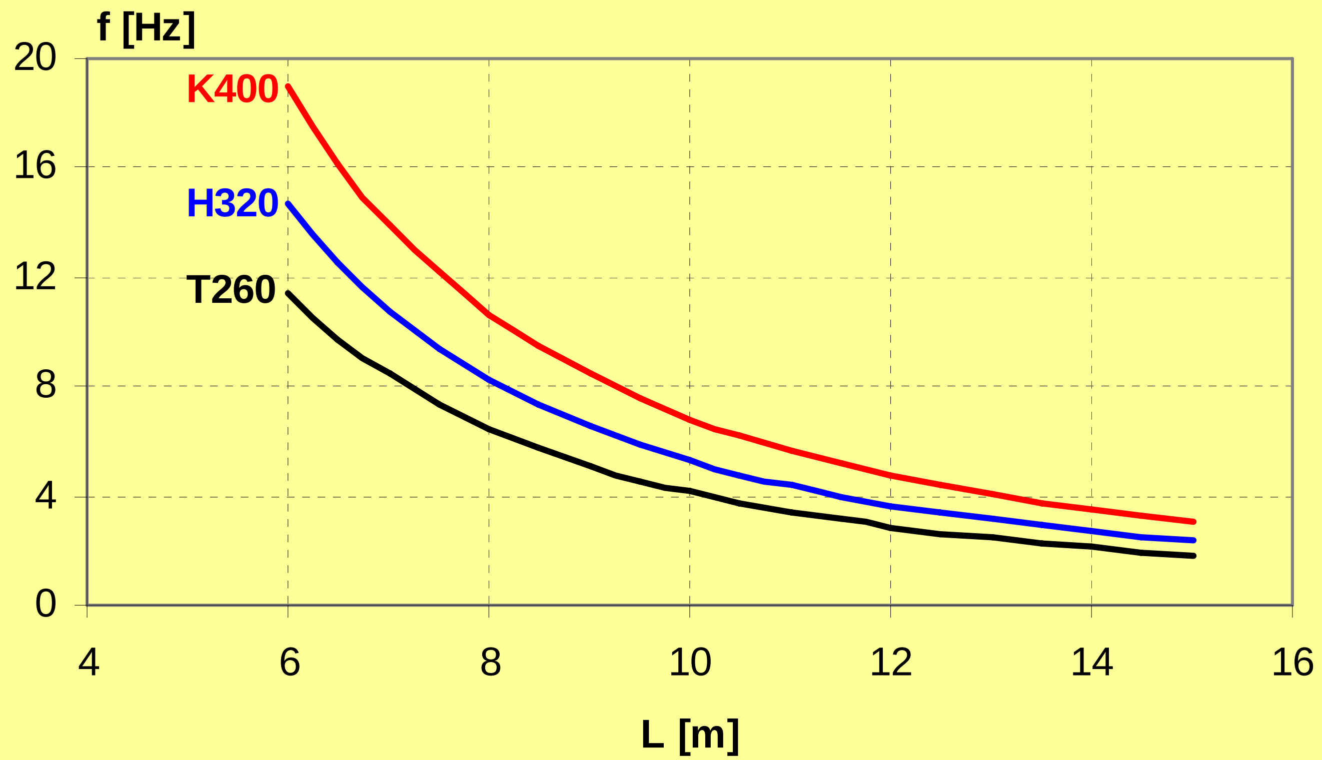
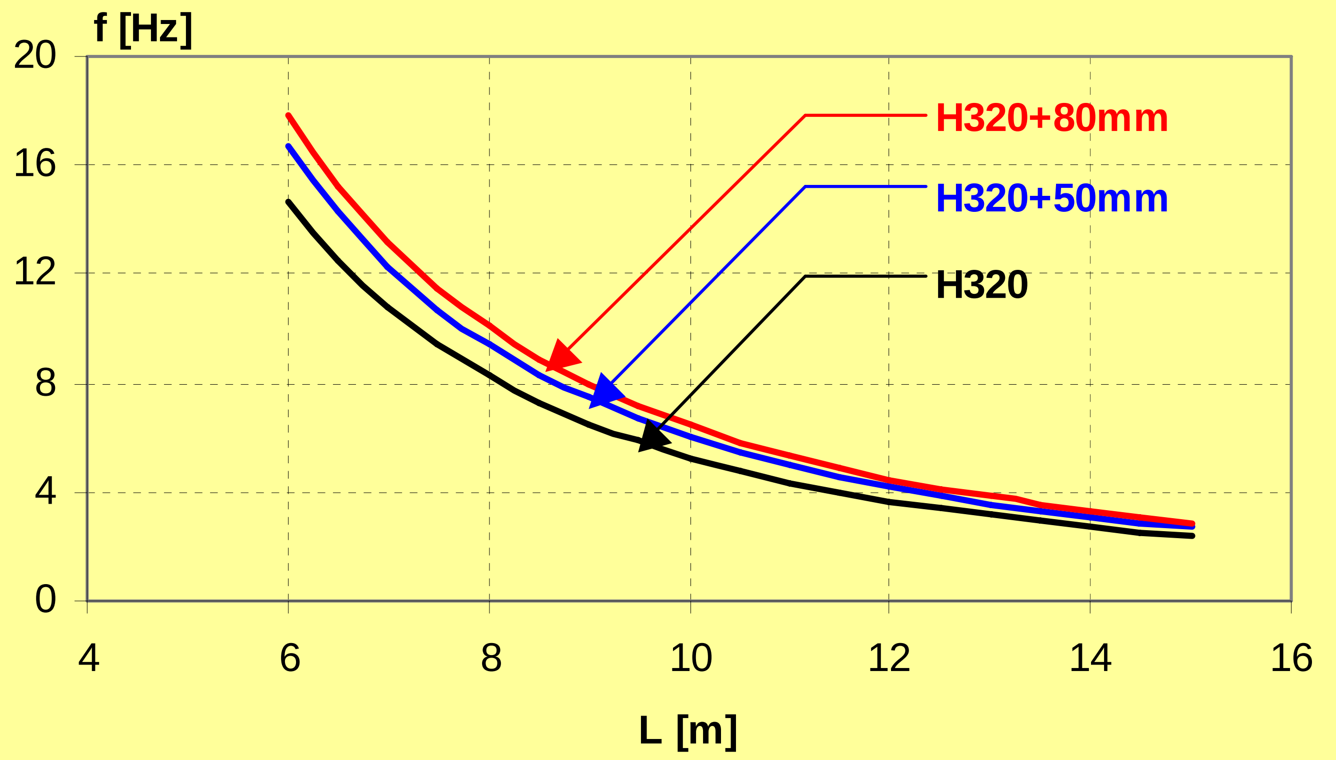
Frequency of hollow core slabs



Influence of a topping



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Methods to reduce vibrations in existing structures

- Increase of Mass/Stiffness
- Increase of damping

Expensive!!

London Millennium Bridge:

160 people – 70mm lateral displacement.

37 viscous dampers
52 tuned massed dampers

£4 million additional costs!

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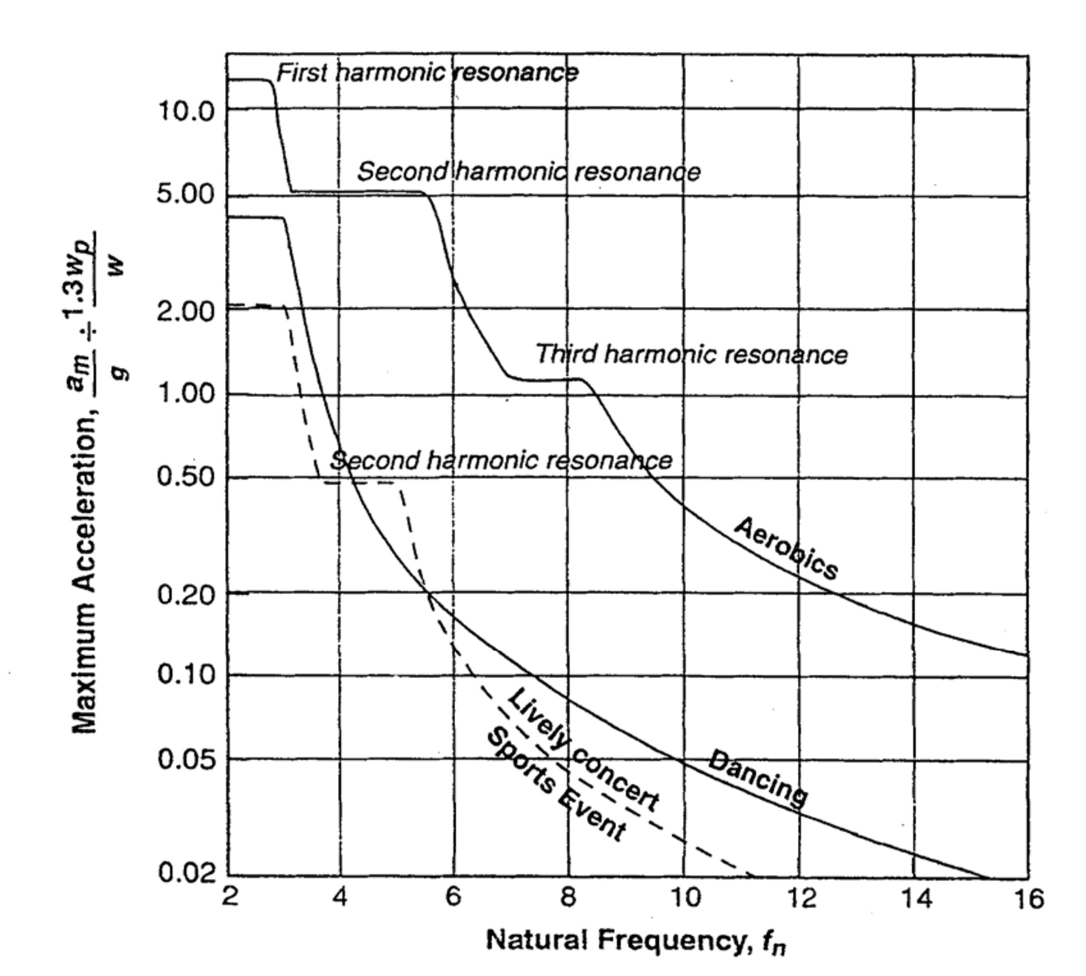
Guideline: ATC Design Code 1 Minimizing Floor Vibration



- Acceleration limits, for walking, but also rhythmic activities (Aerobics)

- Required values of eigenfrequencies for rhythmic events

Conclusions (vibrations):

- Eigenfrequency of hollow core slabs can be determined by simple supported beam formula – gives a reliable first estimate and can serve to point out critical design situations (for SLS).
- More complicated cases require a complete dynamic analysis.

Traffic loads
Parkdecks

Design as required by building codes.

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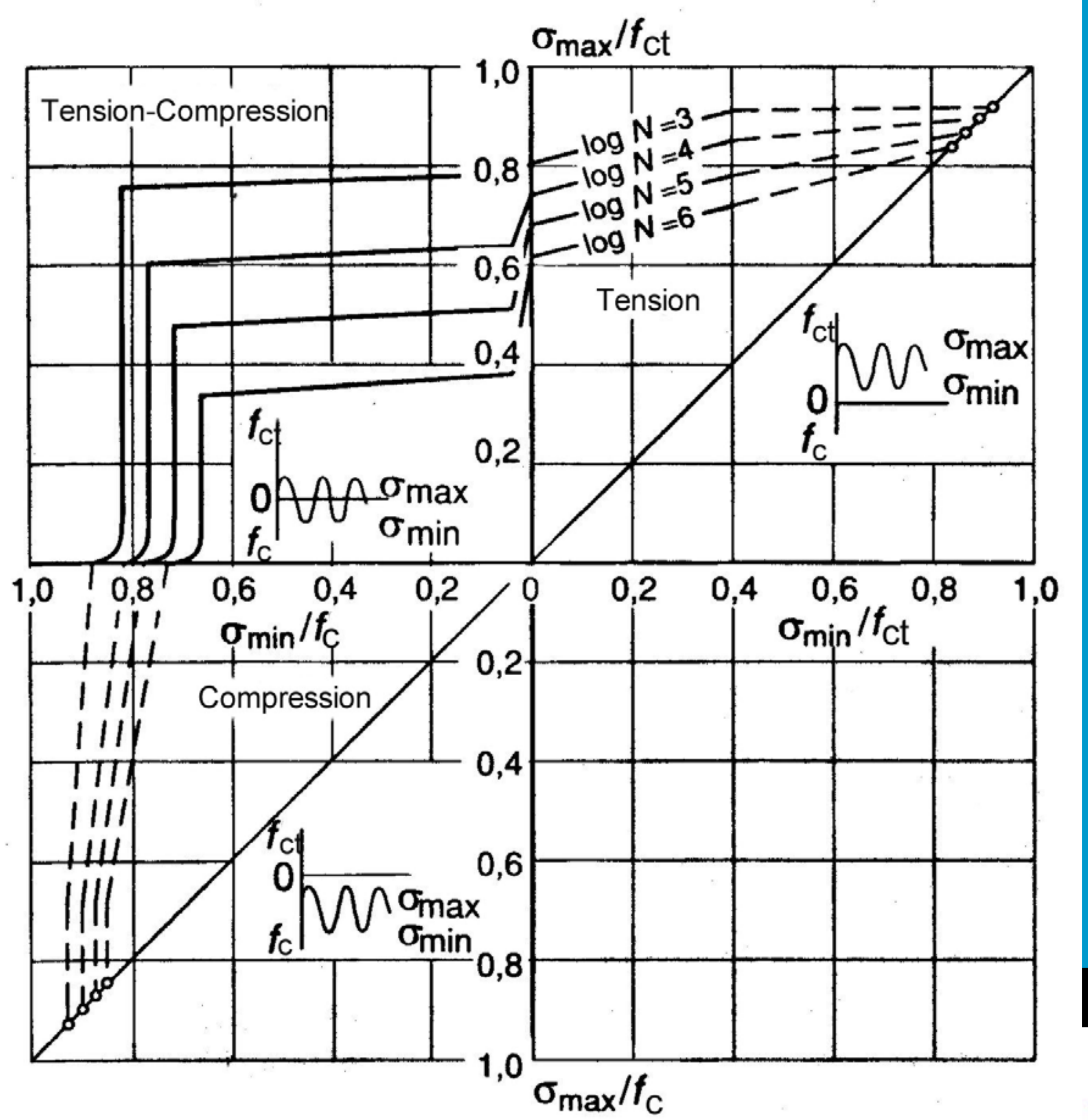
Floors subjected to traffic by trucks and forklift trucks

First case in the Netherlands: flower auction hall Westland, limited truck traffic allowed.

Fatigue verifications; critical failure mode:
Shear tension failure

Fatigue of Concrete



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Fatigue verifications in EC2

- Verifications form part of ULS.
- Separate verifications for reinforcing steel and concrete.
- Simplified verifications: Stress limitations (of max. compressive strength in concrete or max. shear force in concrete – with use of SLS load combinations and safety factors.
- Verifications with S-N lines for steel and concrete and with Palmgren Miner sum for damage accumulation.

But: No verifications for concrete under tension!

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Shear tension failure & fatigue

Static case:

$$V_{Rd,ct} = \frac{I \cdot b_w}{S} \sqrt{\left(\frac{f_{ctk;0.05}}{\gamma_c}\right)^2 - \alpha_1 \cdot \sigma_{cd} \cdot \frac{f_{ctk;0.05}}{\gamma_c}}$$

Fatigue: reduction of tensile strength by β_Z:

$$V_{Rd,ct,red} = \frac{I \cdot b_w}{S} \cdot \sqrt{\left(\frac{\beta_Z \cdot f_{ctk;0.05}}{\gamma_c}\right)^2 - \alpha_1 \cdot \sigma_{cd} \cdot \frac{\beta_Z \cdot f_{ctk;0.05}}{\gamma_c}}$$

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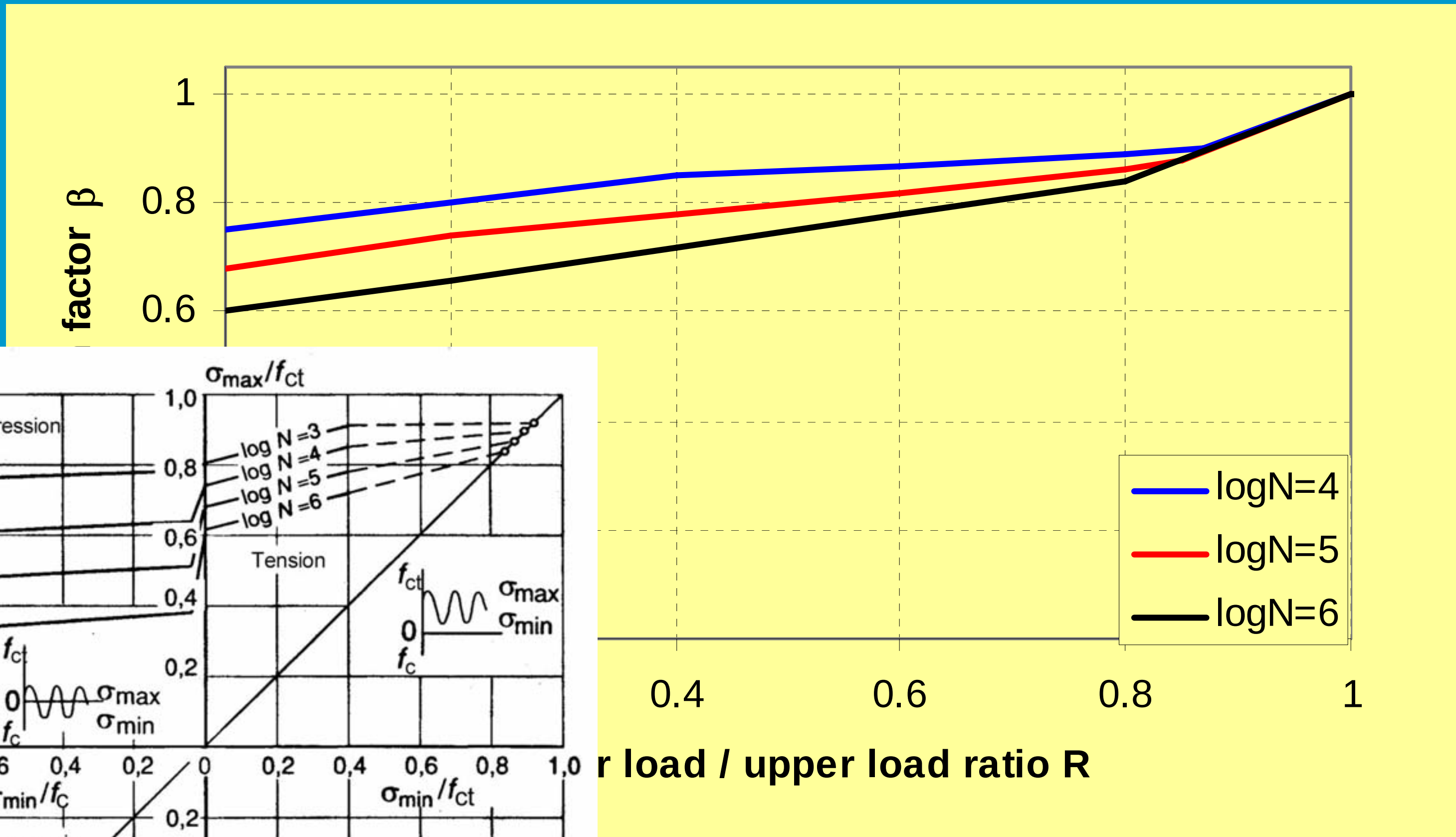
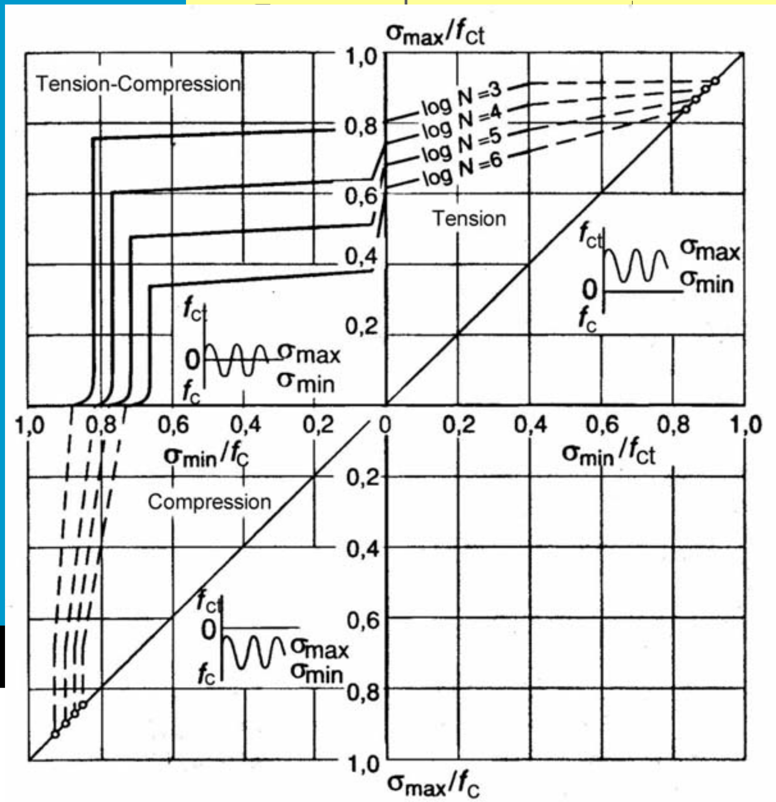
Reduction factor β_Z





Other verifications

- For other failure modes static design as in codes; in case of traffic loading that can cause fatigue failure additional fatigue verifications needed.
- Fatigue verifications for these failure modes are covered by building codes (EC2).

Conclusions

- Hollow core slabs for dynamic actions (sports- and dance halls): frequency tuning recommendend, even though it is not explicitely required in the codes. A frequency tuned structure will be less affected by vibrations which can limit the serviceability of a structure, and can prevent expensive correction measures.

Conclusions

- Floors subjected to traffic might need fatigue verifications. These are covered by the codes for most failure modes except shear tension failure. It is recommended to include this failure mode by reducing the concrete tensile strength, as presented here.

Relevant publication:
Concrete plant & precast technology (BFT)

Walraven, Lappa: Precast prestressed hollow core floors subjected to dynamic loading (5/2004)

http://www.bft-online.info/en/

Hauptversagensarten von Spannbetonhohlplatten

- Reines Biegeversagen
- Schubzugbruch
- Biegeschubbruch
- Verankerungsbruch
- Schubversagen in den Plattenlängsfugen

Kritisch bei Ermüdung!

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Abminderungsbeiwert β_Z

β_Z = 0.6 für N=10^6 und Unterspannung σ_{min} = 0
(R = 0)

Anzahl Lastspiele bis zum Bruch N anhand von
zu erwartender Verkehrsbelastung im Betrieb bestimmen

Nachweis empfohlen, da DIN 1045-1 keine
Ermüdungsnachweise für Beton unter Zug enthält

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