Vibration of hollow core floors

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IPHA Technical Seminar

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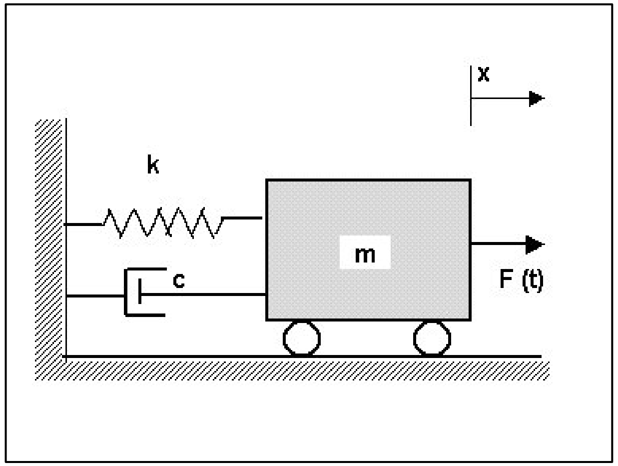
1. *Introduction to dynamics of hollow core slabs*
2. *Presentation of study by JJJ Consult, Norway*
3. *Results obtained by use of ATC Design Guide 1*
4. *Methods of analysis: Summary*
5. *Reduction of vibrations*

SINGLE DEGREE OF FREEDOM SYSTEM :



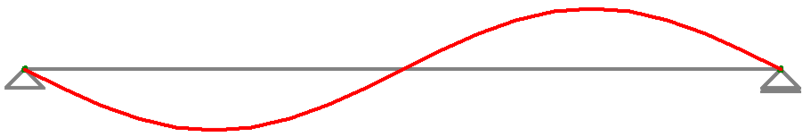
$$Natural\ \ frequency : fn = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$Critical\ damping\ :\ Ccrit = 2\sqrt{mk}$$

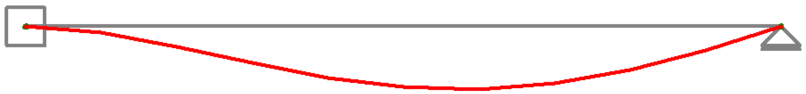
$$Damping\ ratio : \beta = \frac{C}{Ccrit}$$

$$f_n = \frac{a_n}{2\pi}\sqrt{\frac{EI}{mL^4}}$$

$$a_1 = \pi^2 \left(= 9.87\right)$$

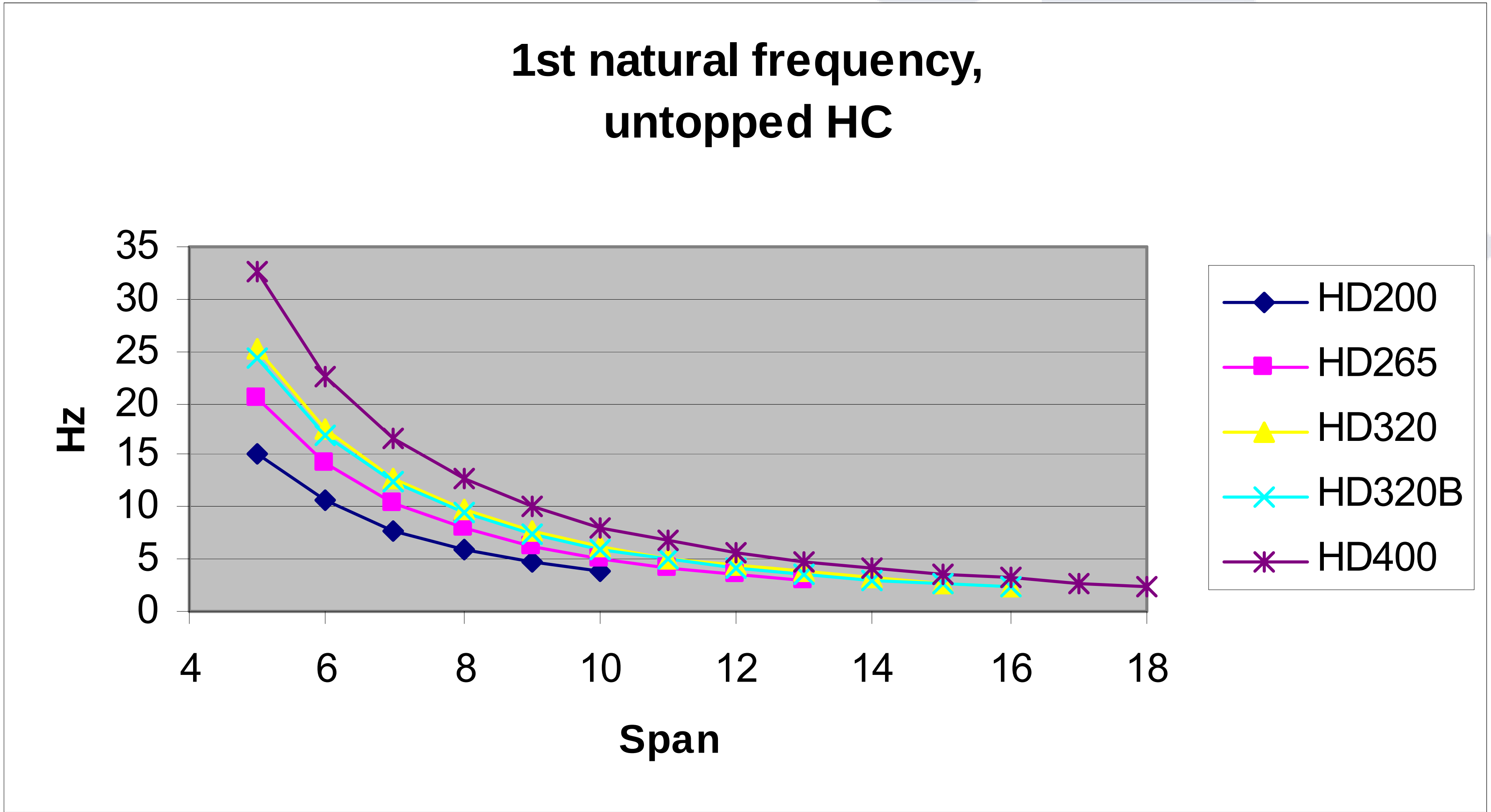


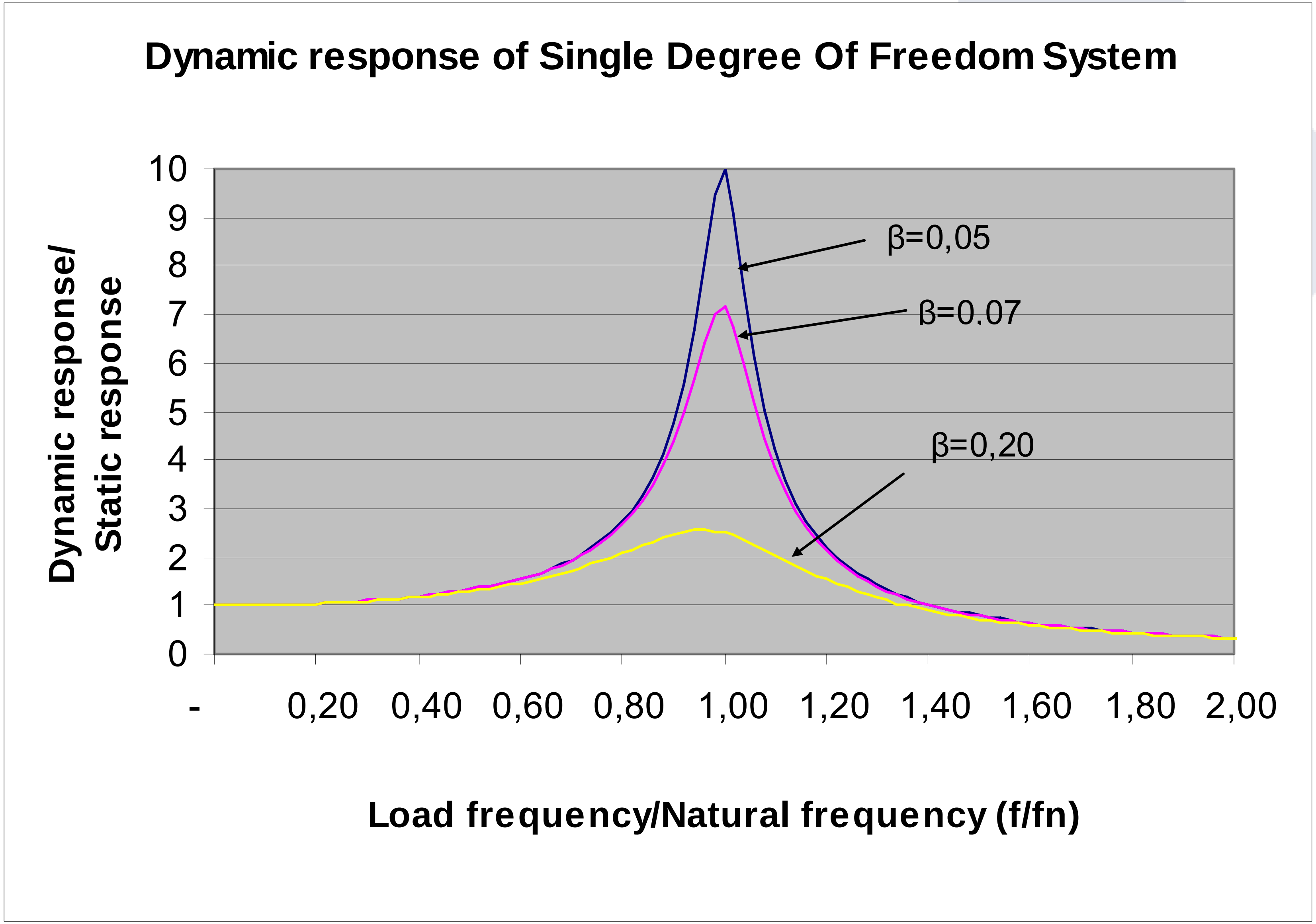
$$a_2 = 4\pi^2 \left(= 39.5\right)$$



$$a_1 = 15.4$$

$$a_1 = 22.0$$


1st natural frequency,
untopped HC
Hz
35
30
25
20
15
10
5
0
4
6
8
10
12
14
16
18
Span
HD200
HD265
HD320
HD320B
HD400



Dynamic response of Single Degree Of Freedom System
Dynamic response/
Static response
10
9
8
7
6
5
4
3
2
1
0
β=0,05
β=0.07
β=0,20
-
0,20
0,40
0,60
0,80
1,00
1,20
1,40
1,60
1,80
2,00
Load frequency/Natural frequency (f/fn)

Criteria are often expressed as requirements to1st natural frequency of the floor:

Example: Betongelementboken, Betongelementforeningen (Design Guide for Norwegian Prefabricators):

-*Walking:* $f_n > 5.2$ *Hz*
- *Aerobics:* $f_n > 8$ *Hz*
- *Dancing:* $f_n > 7$ *Hz*

More refined methods have become available

Vibration
of
Precast Concrete elements

JJJ Consult
Dr.techn. Jens Jacob Jensen AS

Spenncon

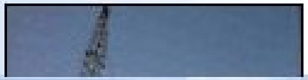
Textbook

Contents
Introduction
Criteria
Calculation methods
Guidance for analysis
Measurements
References

1. Introduction

Figure 1.1
Office - industry building

Figure 1.2
Sports centre, aerobics



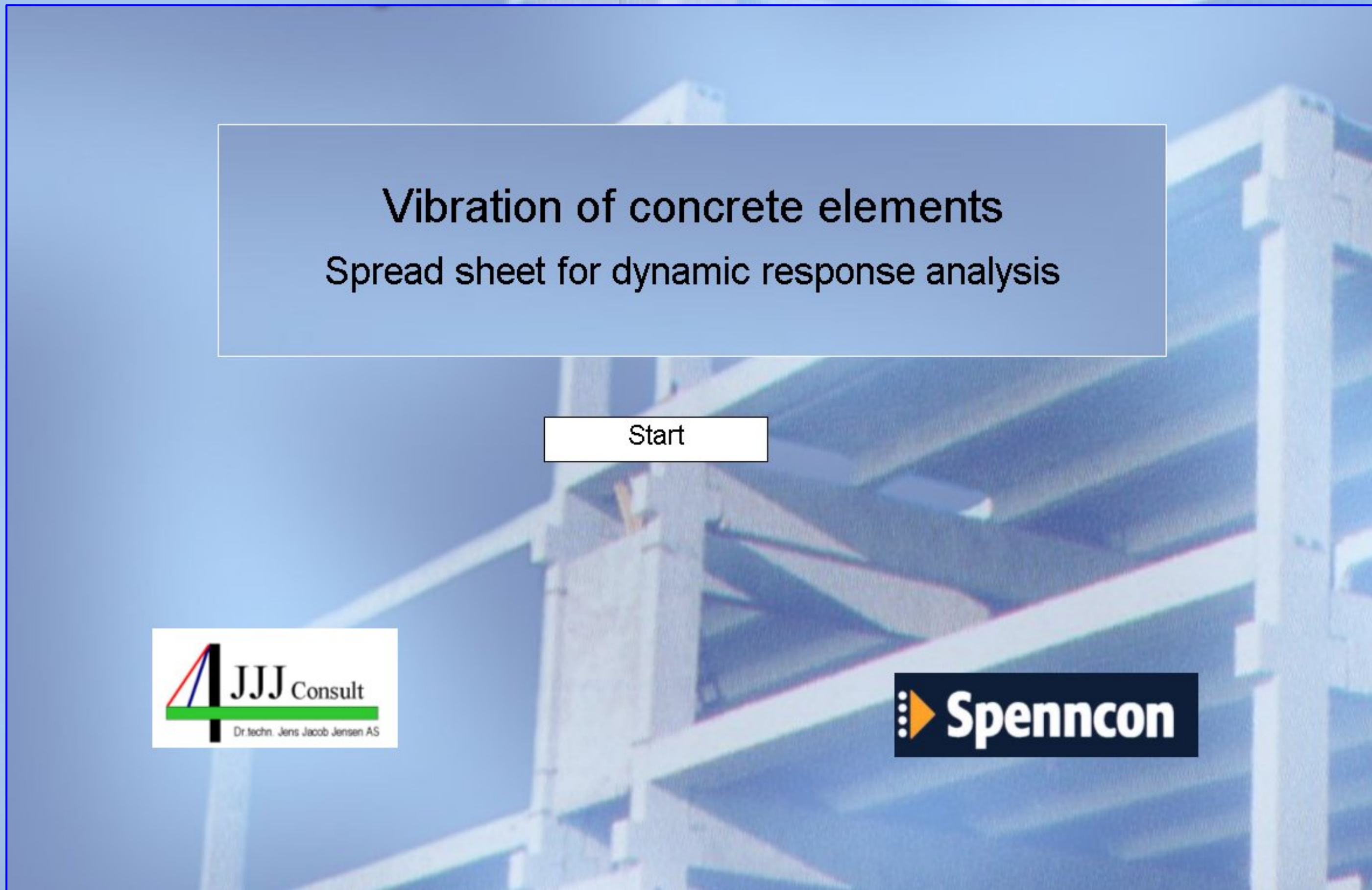
Precast concrete elements are often used as floors in office and industry buildings. They are also often used as floors in sports centres and assembly buildings (Figure 1.1).

Standardized precast concrete elements are also used for simple pedestrian bridges.

Common to all these buildings is that they can be exposed to dynamic loads caused by human activities and machines.

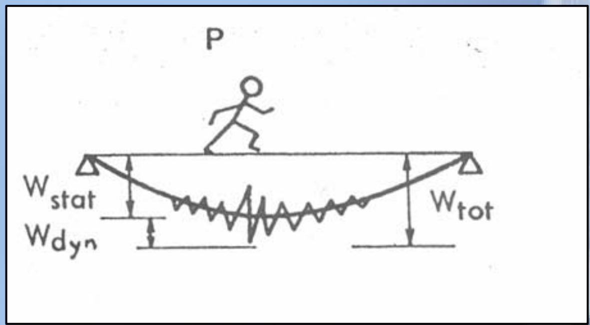
In office and industry buildings machines can cause vibrations. Ventilation systems and revolving machines are examples of this. Resonance phenomena should be avoided. Furthermore vibrations from e.g. traffic, piling or explosions can be transferred to a building through the ground.

Spreadsheet



Presentation

Sport activity buildings

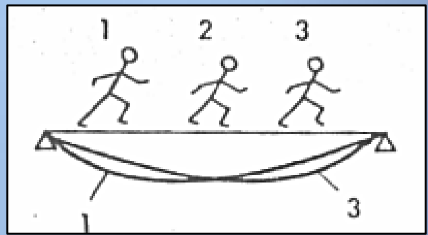


- In gymnasiums and sports centres activities such as running and jumping have to be regarded as dynamic loading.
- Especially rhythmic aerobic activities may cause unwanted vibrations in floors.
- This is related with high probability to give structural resonance. The load frequency of aerobics is in the range 1.8 - 3.4 Hz.

Stands

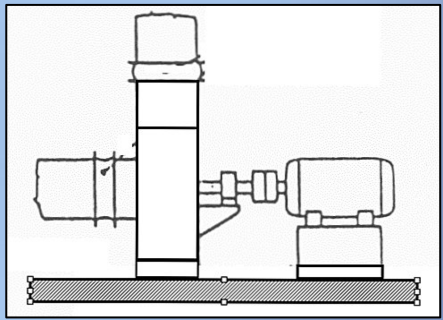
- Precast concrete elements are often used for stands in sports arenas or concert halls. During sports events, concerts or other congregations, rhythmic trampling may cause structural vibrations.
- Stands therefore have to be examined for dynamic response.

Bridges



- Precast concrete elements are also used for bridges. Loading by cars and trains cause dynamic response.
- For footbridges standardised concrete elements are often used.
- Steady march on bridges has to be avoided.

Office and industry buildings



- In office and industry buildings mechanical equipment may cause vibrations.
- Ventilation systems and rotating machines are such equipment. Resonance phenomena have to be avoided.
- Vibrations caused by traffic, piling, explosions etc. may also be transferred to buildings through the ground.

2 Criteria for the evaluation of vibrations

Evaluation criteria

Structural behaviour ↔ Human sensitivity

Structural behaviour ↓

Strength, safety

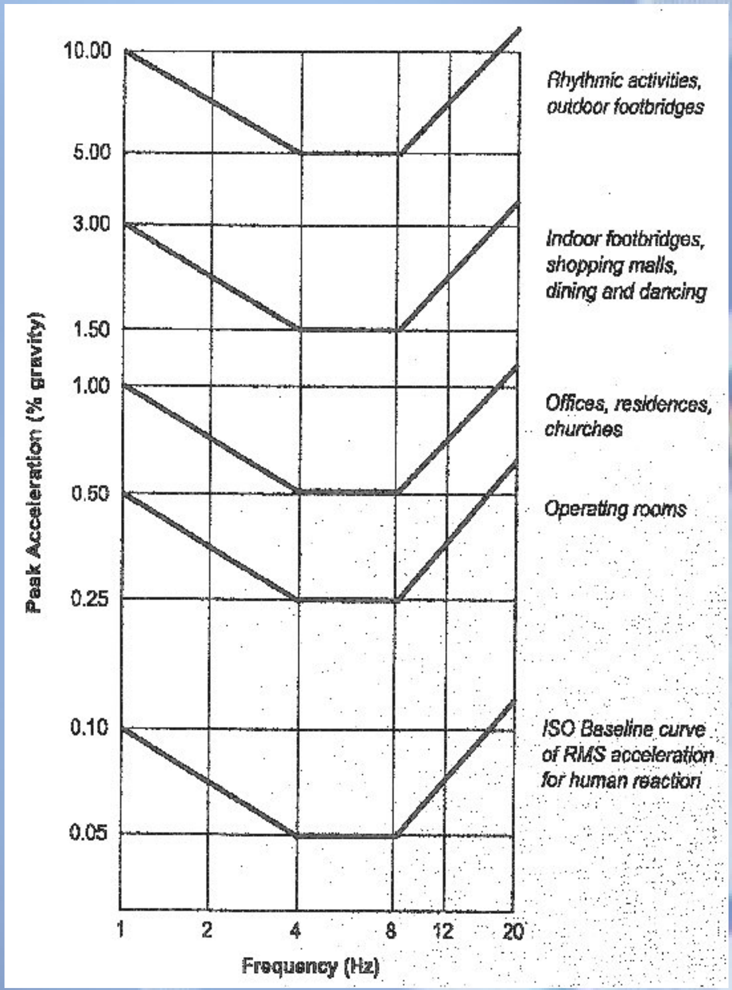
Analysis, design, standards and codes.

Human sensitivity ↓

Comfort, Criteria for use

Analysis, control structural design and codes

Human sensitivity



- Human comfort, health and work capacity are often related to accelerations or velocities and time (duration).
- The performance of sensitive equipment (hospitals) and damage to buildings are often related to structural accelerations and velocities.
- International codes and standards may give guidelines for the evaluation of vibrations.

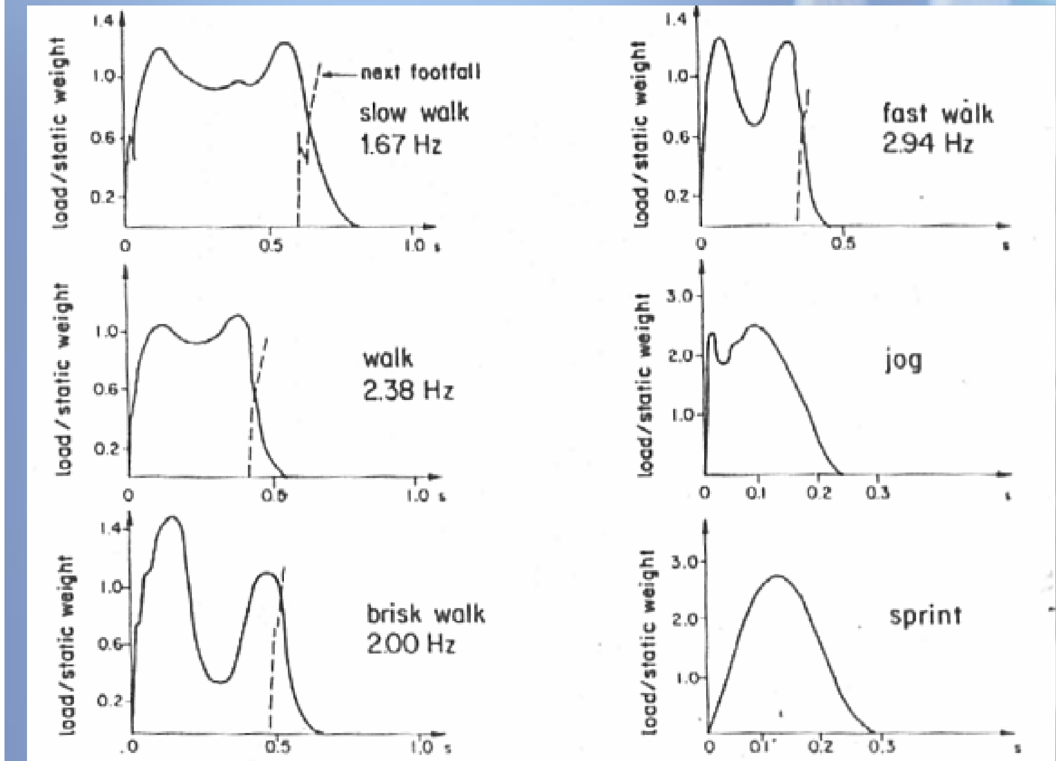
Human activity

- Typical frequencies for human activities

Activity	Frequency
Walking touching the floor	1,4-2,6 Hz
Running with partly touching the floor	2,0-3,5 Hz
Rhythmic jumping, example: aerobic	1,8-3,4 Hz
Dancing, classic and modern dance, waltz, rumba	1,5-3,0 Hz
Pop concert, Rhythmic jumping	1,5-3,0 Hz

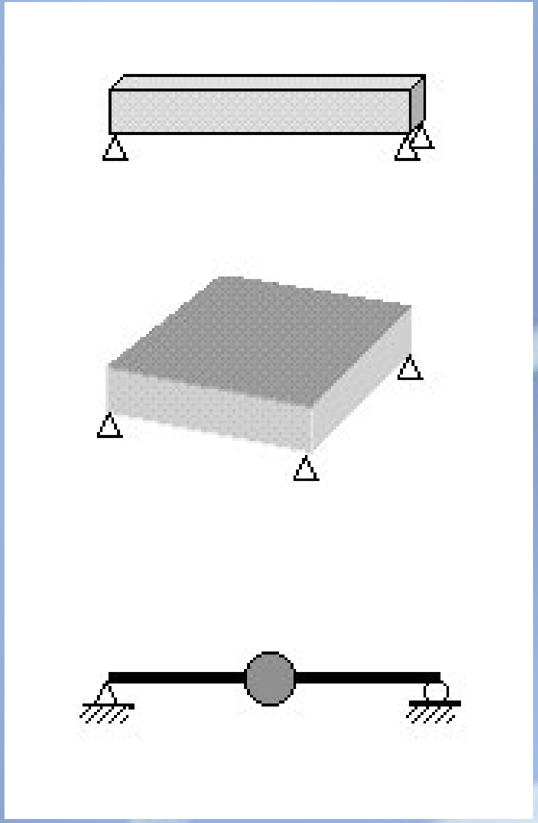
A simple rule for the design of structures exposed to dynamic loading caused by walking, running, jumping and dancing is to ensure that the resonance frequency of the floor is more than twice the highest load frequency. For walking it means a resonance frequency above 5,2 Hz.

Human activity



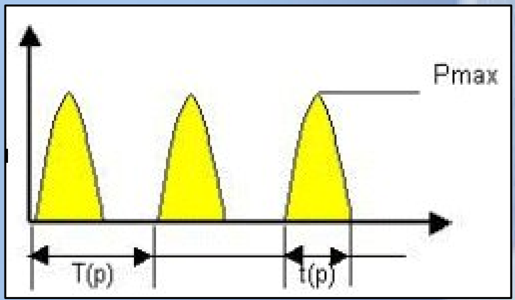
- A recommendation for the design of floors where dance and sports activities take place is to ensure that the resonance frequency of the floor is more than twice the highest load frequency.
- The resonance frequency of floors for sports activities has to be above 8 Hz, while floors where dancing takes place have to be above 7 Hz.

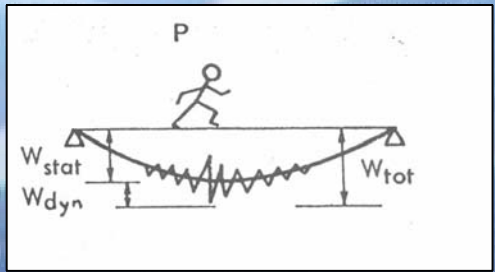
3 Methods for analysis and models for loading

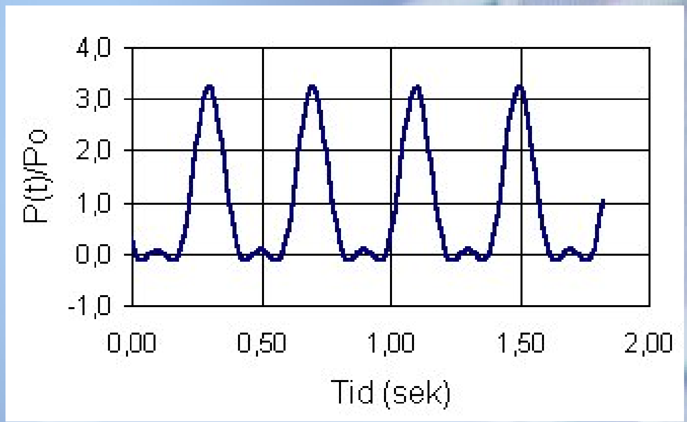


- For the dynamic response analysis of floor systems exposed to human activities, rotating machines etc. simplified models and methods of analysis may be used.
- For beams and slabs models with one degree of freedom are chosen.
- The dynamic response is analysed assuming elastic behaviour and by the method of stepwise time-integration. (Linear acceleration, damped system.)

Aerobic as periodic impact loading

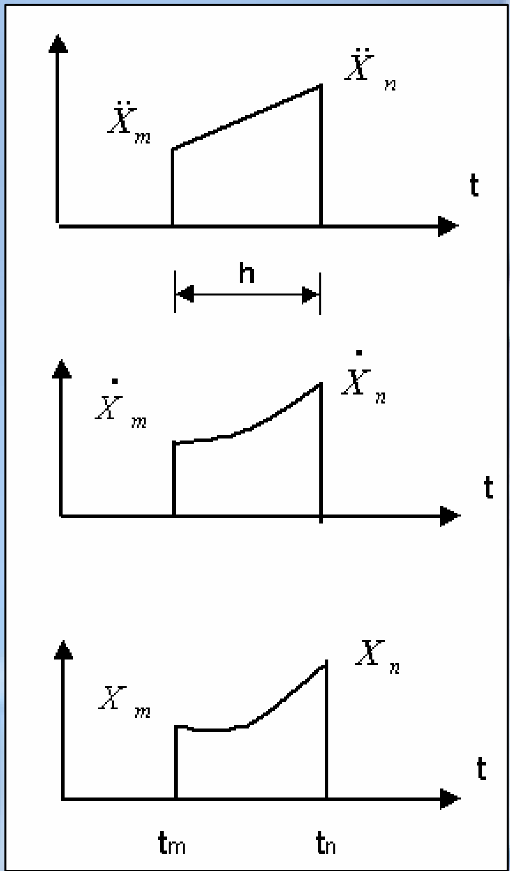






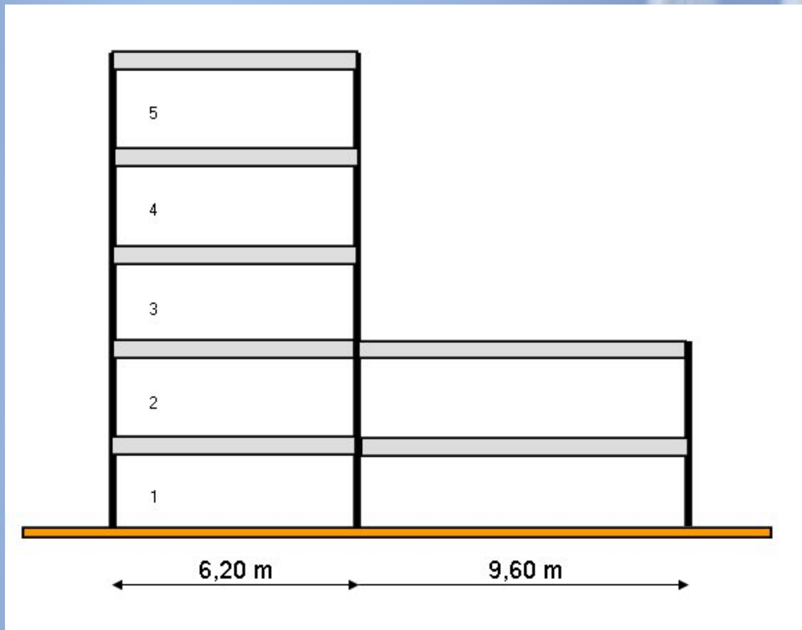
- The load induced by jumping may be defined as a sum of periodic sinusoidal impulses.
- The load may be expressed by Fourier-transformations

Dynamic response by arbitrary time dependent loading



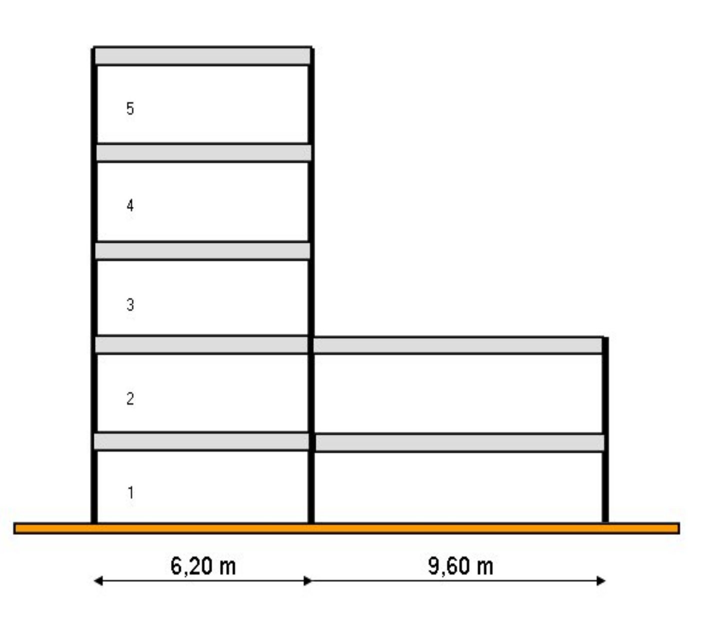
- The numerical procedure which is used for analysing the dynamic structural response is based on a time-step-by-step integration of accelerations into velocities and further into displacements.

Use of spread sheets. Example



- On the first floor of an existing building, as shown in the figure, a fitness studio is planned. The possibilities for unwanted vibrations caused by aerobics are considered:

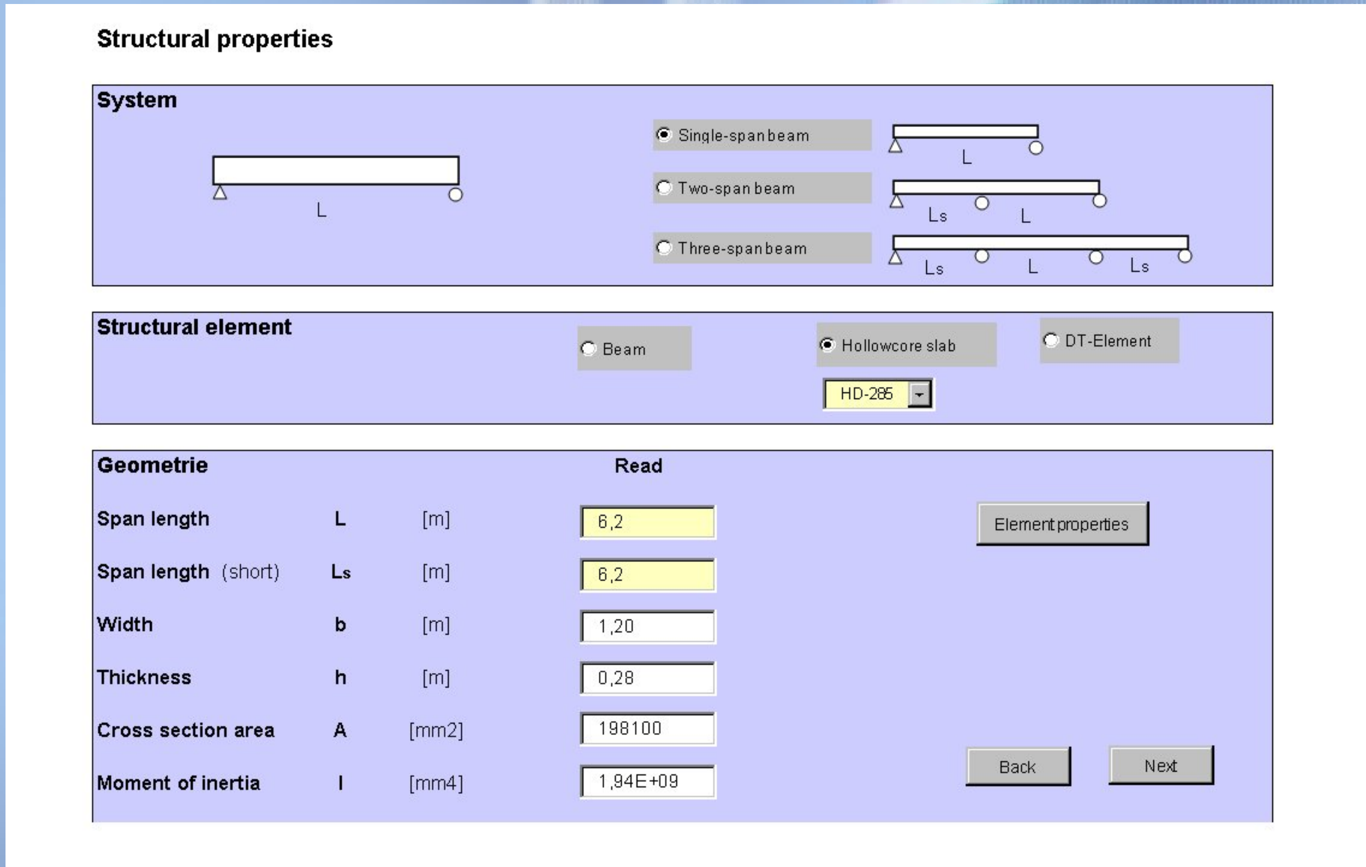
Use of spread sheets. Example



- Element type: HD285
- Length of element l = 9,60 m
- Width of element b = 1.20 m
- Mass element me = 537 kg/m2, (Me= 537*9,60*1.20=6186kg)
- Mass of people (25kg/m2) Mp=9,60*1,2 *25 kg/m2 =288 kg
- I = 1,94 10E9 mm4
- E = 3.0 10E4 N/mm2
- Structural damping 0,025
- Time interval tp=0,2 sec, Tp=0,4 s
- Load/weight of participants P=2880N.

Use of spread sheets. Example

Read structural data



Use of spread sheets. Example

Read material properties and masses

Material properties

			Read	
Concrete	Type		C55	Comments
E-modulus	E	[N/mm2]	29563	
Density	γ	[kg/m3]	2400	

Element properties

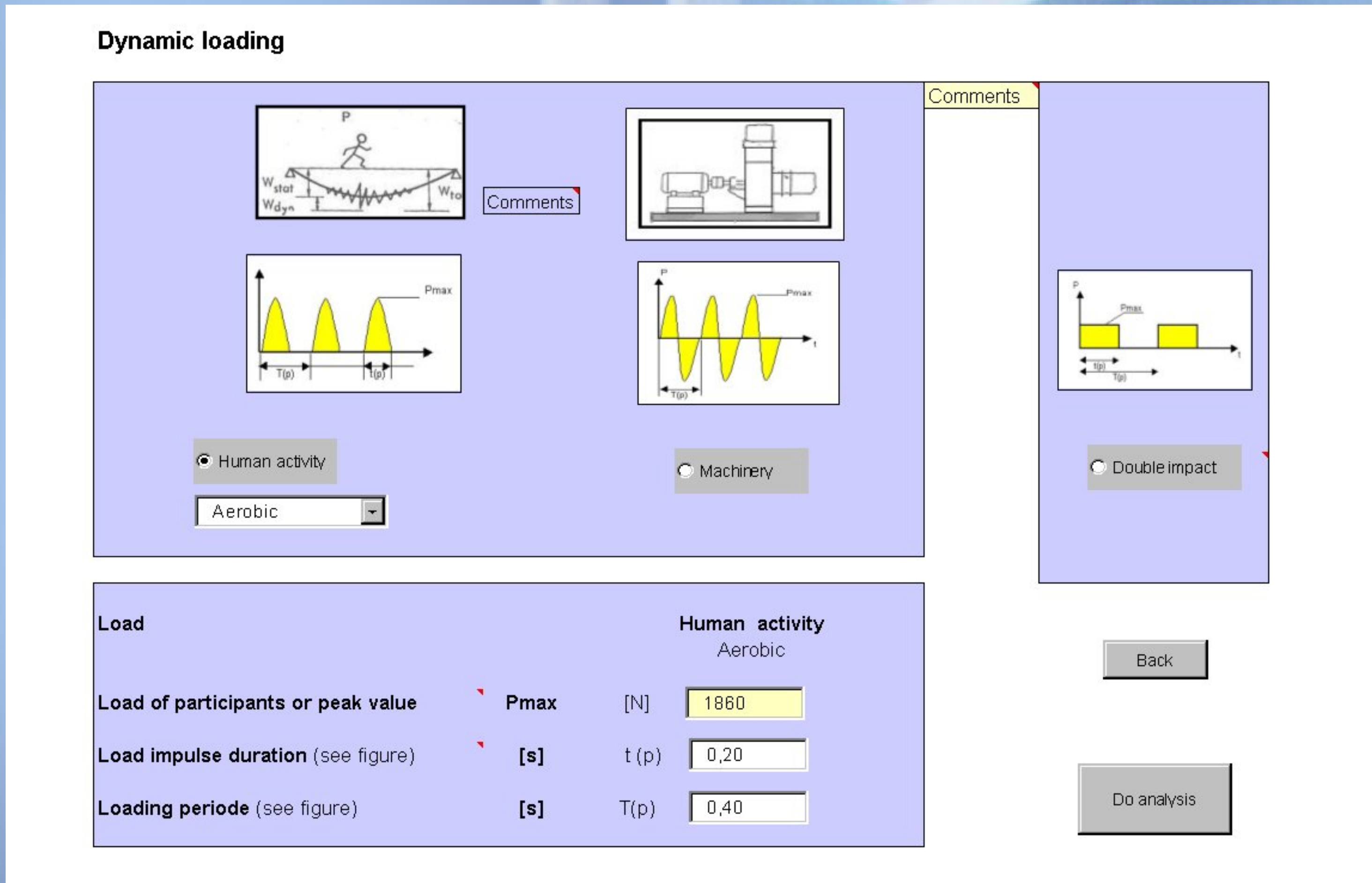
Mass			Read	Comments
Mass (Structure)	Mk	[kg]	3995	
Mass (load)	Ms	[kg]	0	
Mass (dynamic load)	Mp	[kg]	0	

Dampning				Comments
Damping (Critical)	λ	None dim.	0,025	

Back   Next

Use of spread sheets. Example

Read loading



Use of spread sheets. Example

Results

Vibration of concrete elements

Dynamic response analysis

Print | Control | New analysis

Structural properties

Structure Type		Single span beam	
Geometrie			
Span length	L	6,200	[m]
Span length (short)	Ls	6,200	[m]
Width	b	1,200	[m]
Thickness	h	0,280	[m]
Cross section area	A	1,98E+05	[mm2]
Moment of inertia	I	1,94E+09	[mm4]
Materials			
Concrete	Type	C55	
E-Modulus	E	29563	[N/mm2]
Density	γ	2400	[kg/m3]
Mass			
Mass (structure)	Mk	3995	[kg]
Mass (distributed load)	Mp		[kg]
Mass (single load)	Mp	0	[kg]
Damping			
Dampning (δ/δcrit)	δ	0,025	δ/δcrit

CALCULATED DYNAMIC PROPERTIES

Calculated natural frequency	f	12,10	[Hz]
Calculated periode of vibration	T	0,083	[sec]

LOADS (Read, or set)

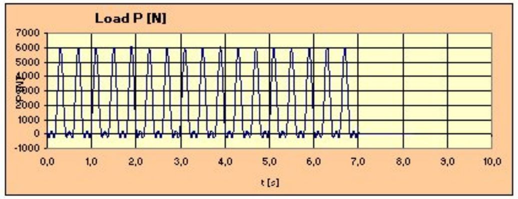
Dynamic load	Aerobic		
Weight of participants or peak va	Pdyn	1860	[N]
Duration (set)	t(p)	0,200	[s]
Periode (set)	T(p)	0,400	[s]

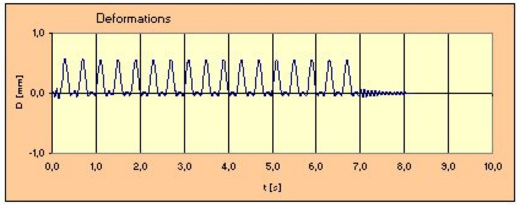
Evaluation of results

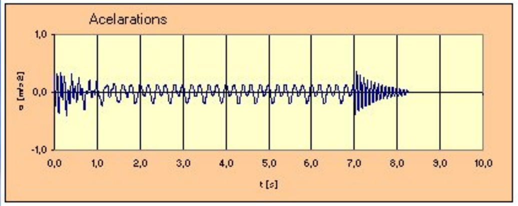
RESULTS OF ANALYSIS

Human activity
Aerobic

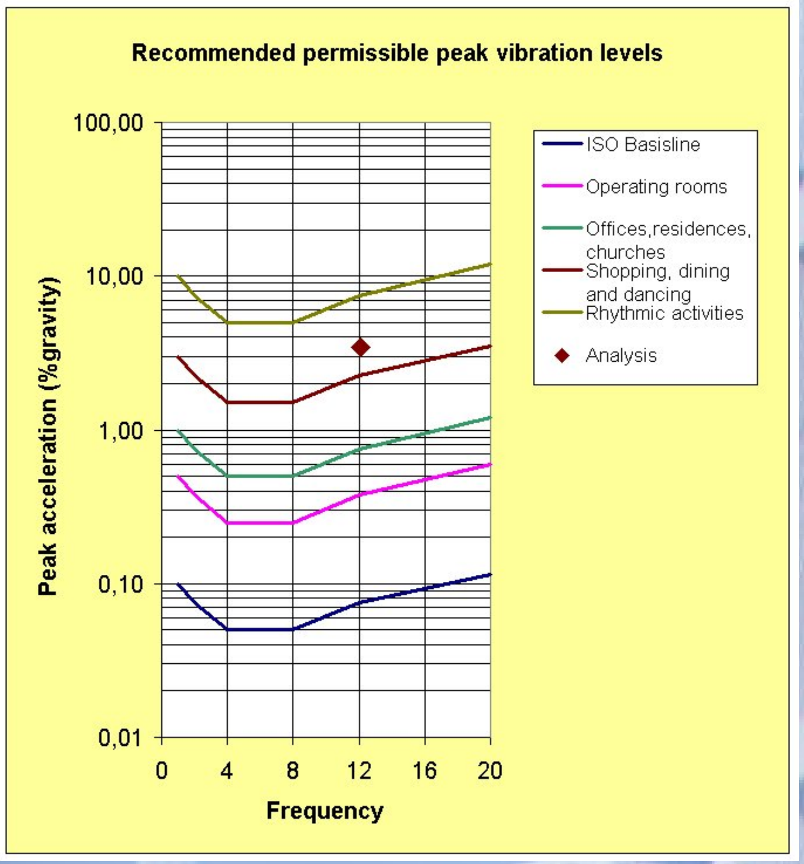
Max dynamic deflection	δ_{max}	0,57	mm
Max velocity	v_{max}	0,010	m/s
Maks accelereation	a_{max}	0,34	m/s2
Max (peak) contact force	P_{cont}	6022	[N]







Use of spread sheets. Evaluation



- The results of analysis have to be compared with recommended permissible peak vibration levels.
- The results are automatically plotted as shown in the graph and may be evaluated as acceptable for rhythmic activities.

ATC Design Guide 1

Minimizing Floor Vibration

ATC Applied Technology Council

ATC Design Guide 1

Vibration due to walking:

$$\frac{a_p}{g} = \frac{p_0 e^{-0,35 f_n}}{\beta W}$$

a_p = peak acceleration

p_0 = the walking force

f_n = the natural frequency of the floor

β = the damping ratio

W = the effective weight of the floor $= w \times L \times B$

For hollowcore slabs : $B = L$

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ATC Design Guide 1

Vibration due to walking, recommended values:

		Constant force p0	Damping ratio	Acceleration limit (% g)
Offices, Churches, Residences	*Few nonstructural components*	*65 lb (290 N)*	*0,02*	*0,5*
	Some furnishing and small partitions		*0,03*	
	Full height partitions		*0,05*	
Shopping malls		*65lb (290 N)*	*0,02*	*1,5*

Effective weight per Unit Area:
Offices: Include live load of 11 psf (527 N/m2)
Residences: Include live load of 6 psf (287 N/m2)

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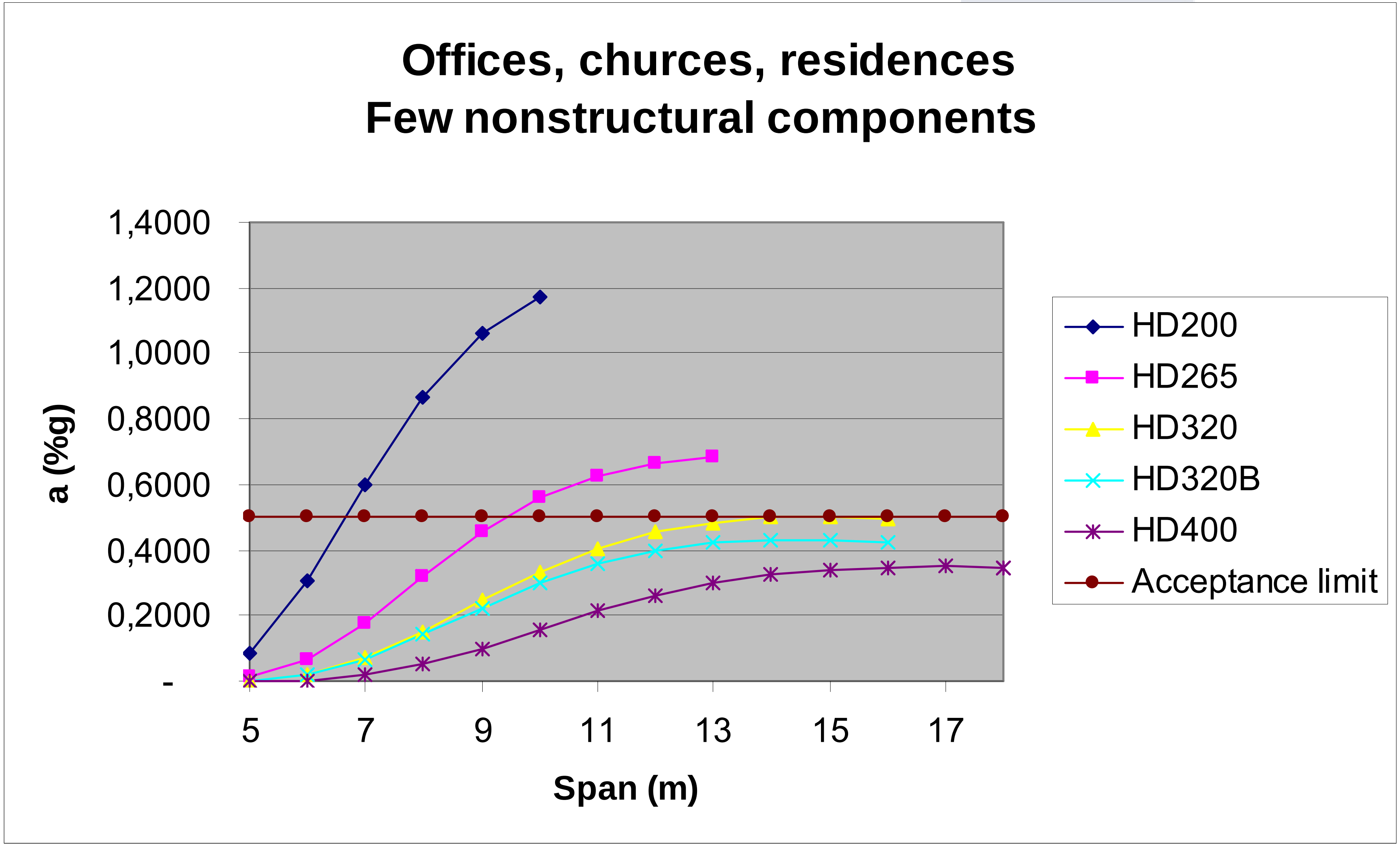

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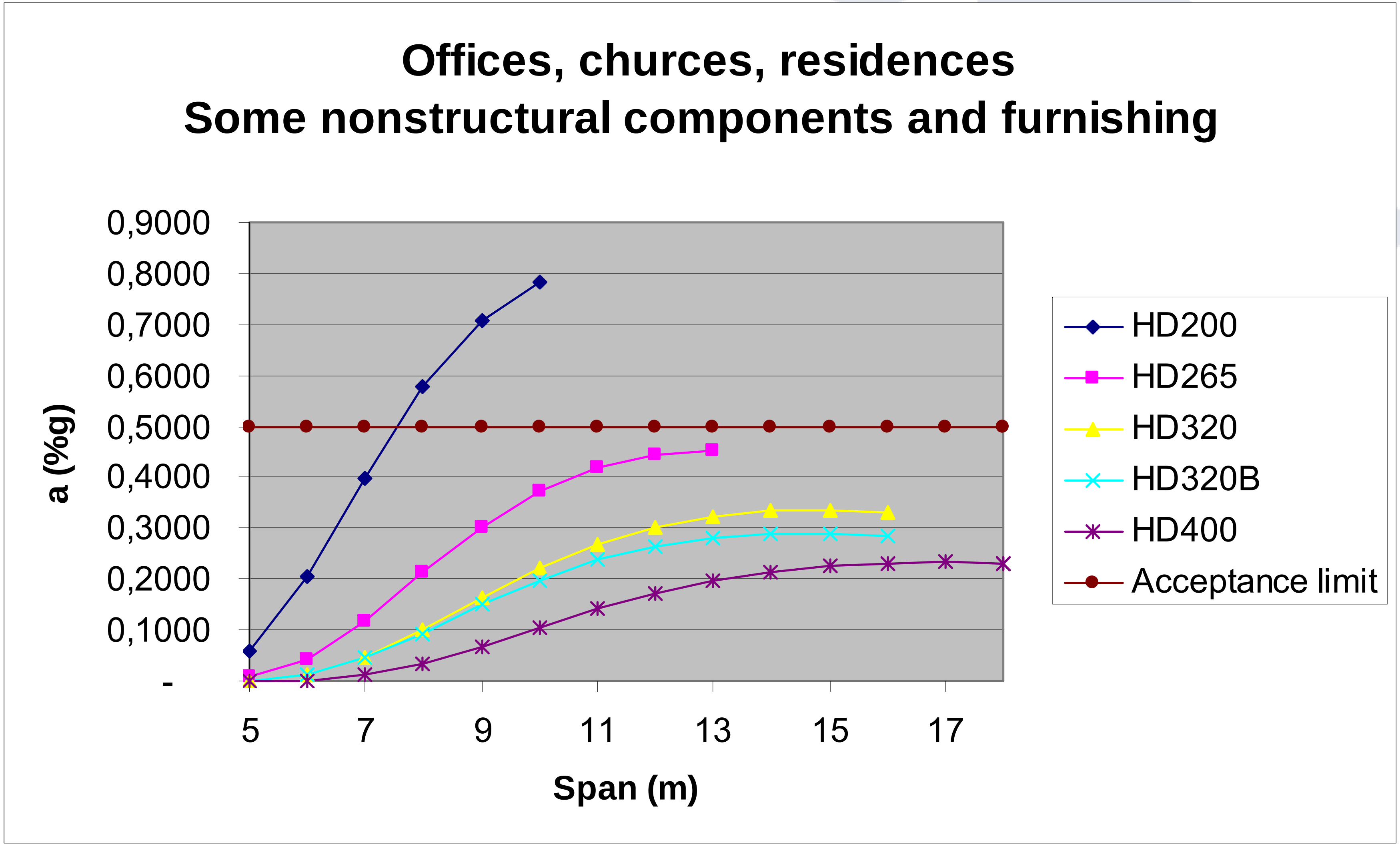

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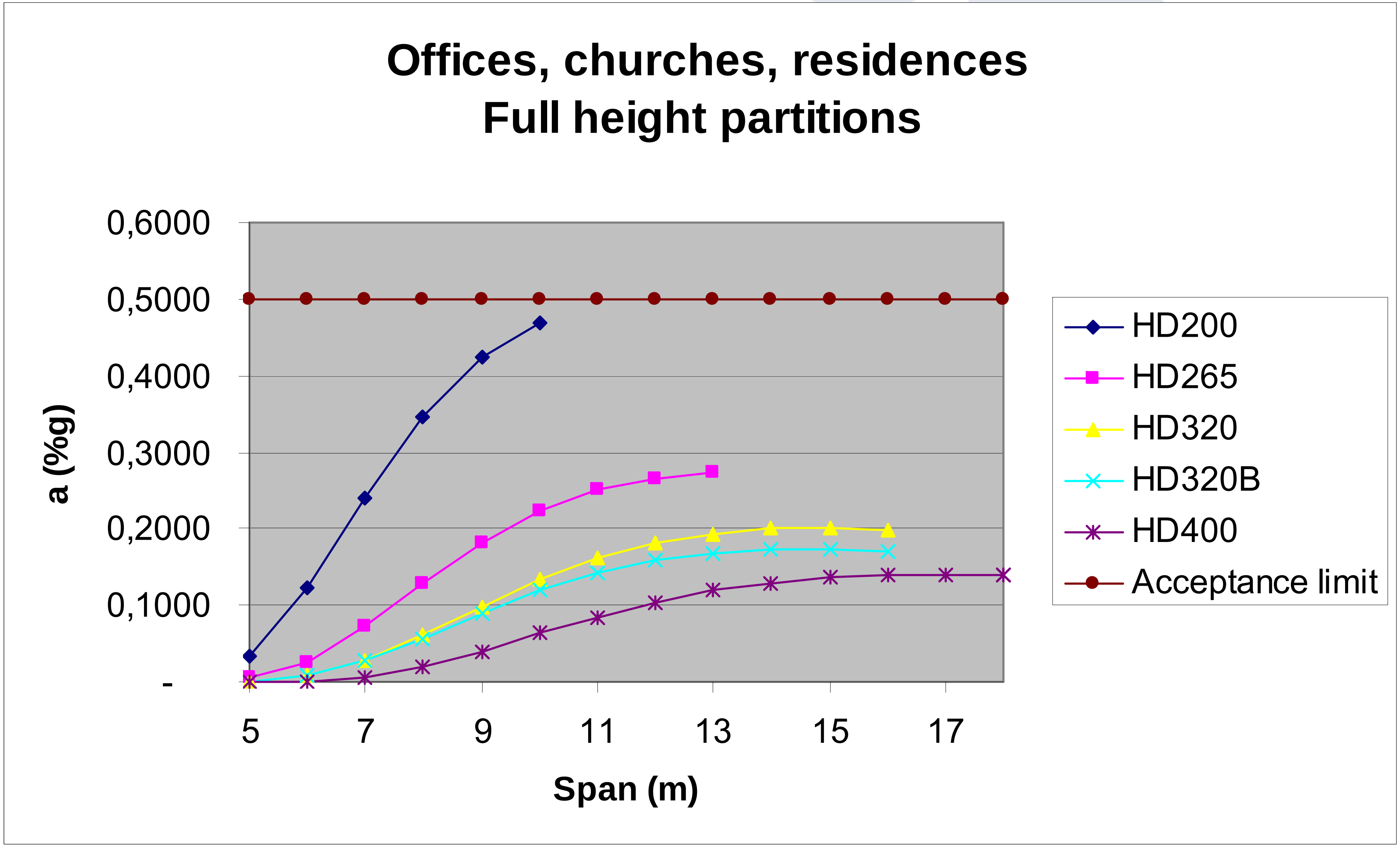

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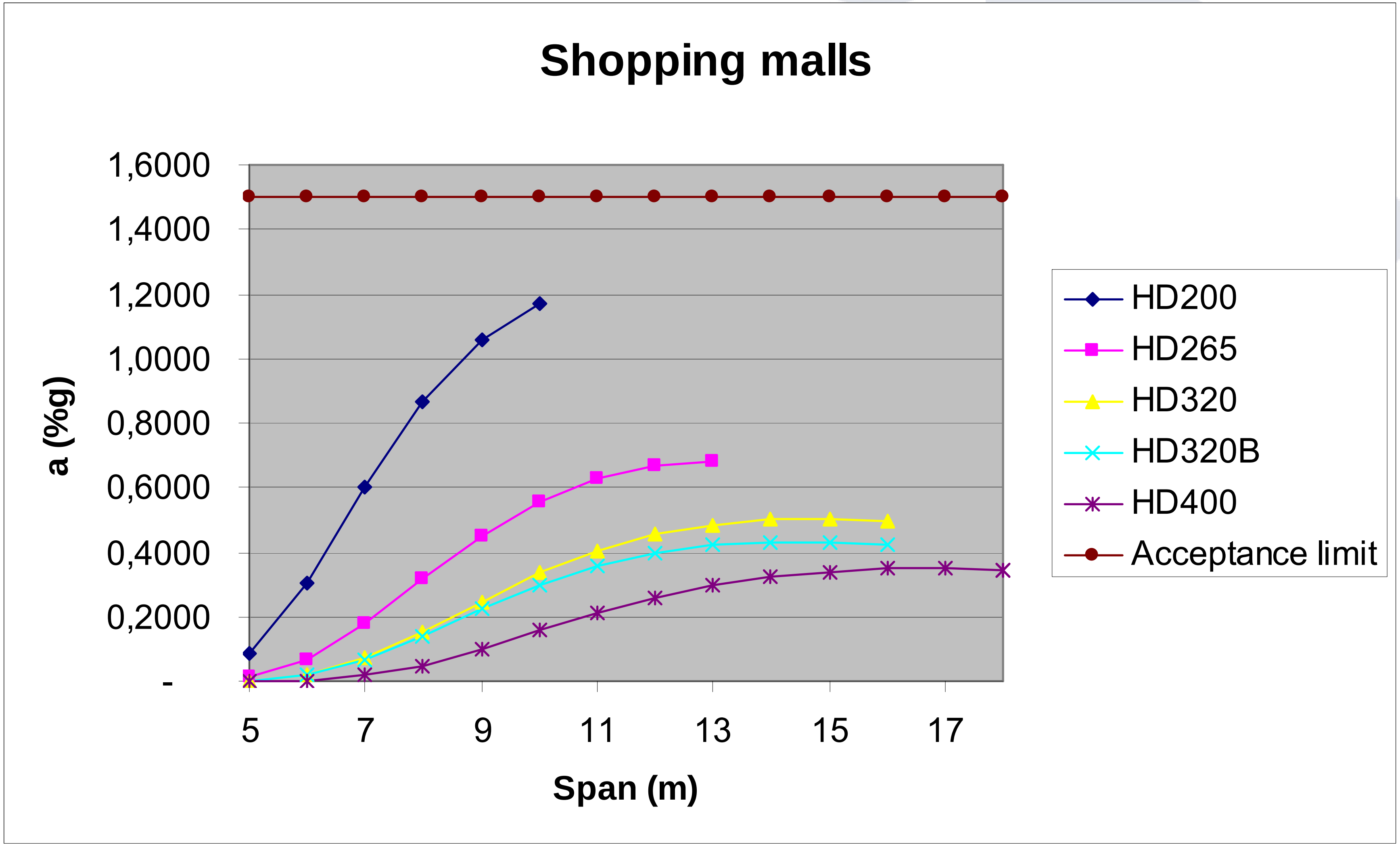
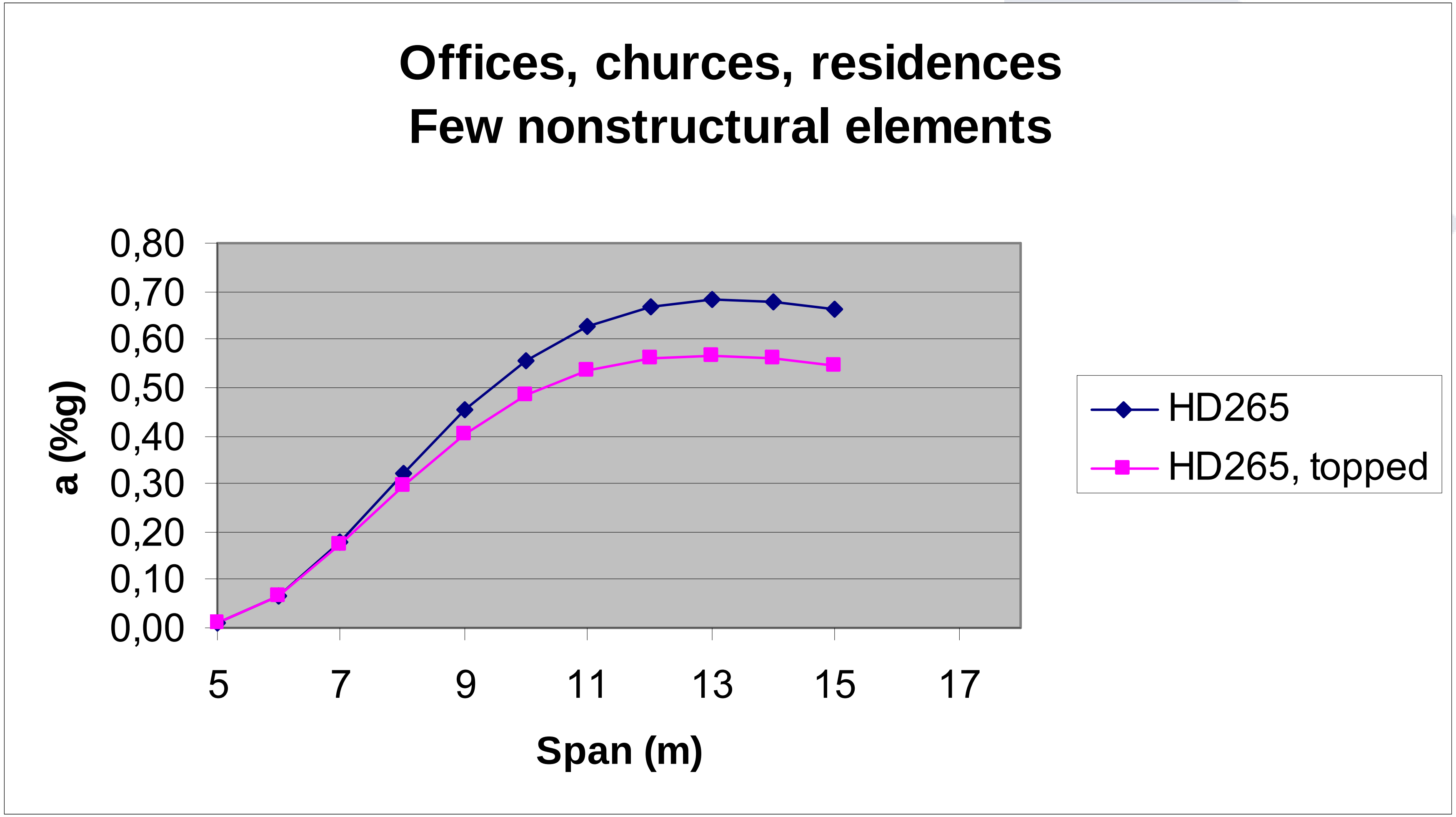

Shopping malls
a (%g)
1,6000
1,4000
1,2000
1,0000
0,8000
0,6000
0,4000
0,2000
-
5
7
9
11
13
15
17
Span (m)
HD200
HD265
HD320
HD320B
HD400
Acceptance limit



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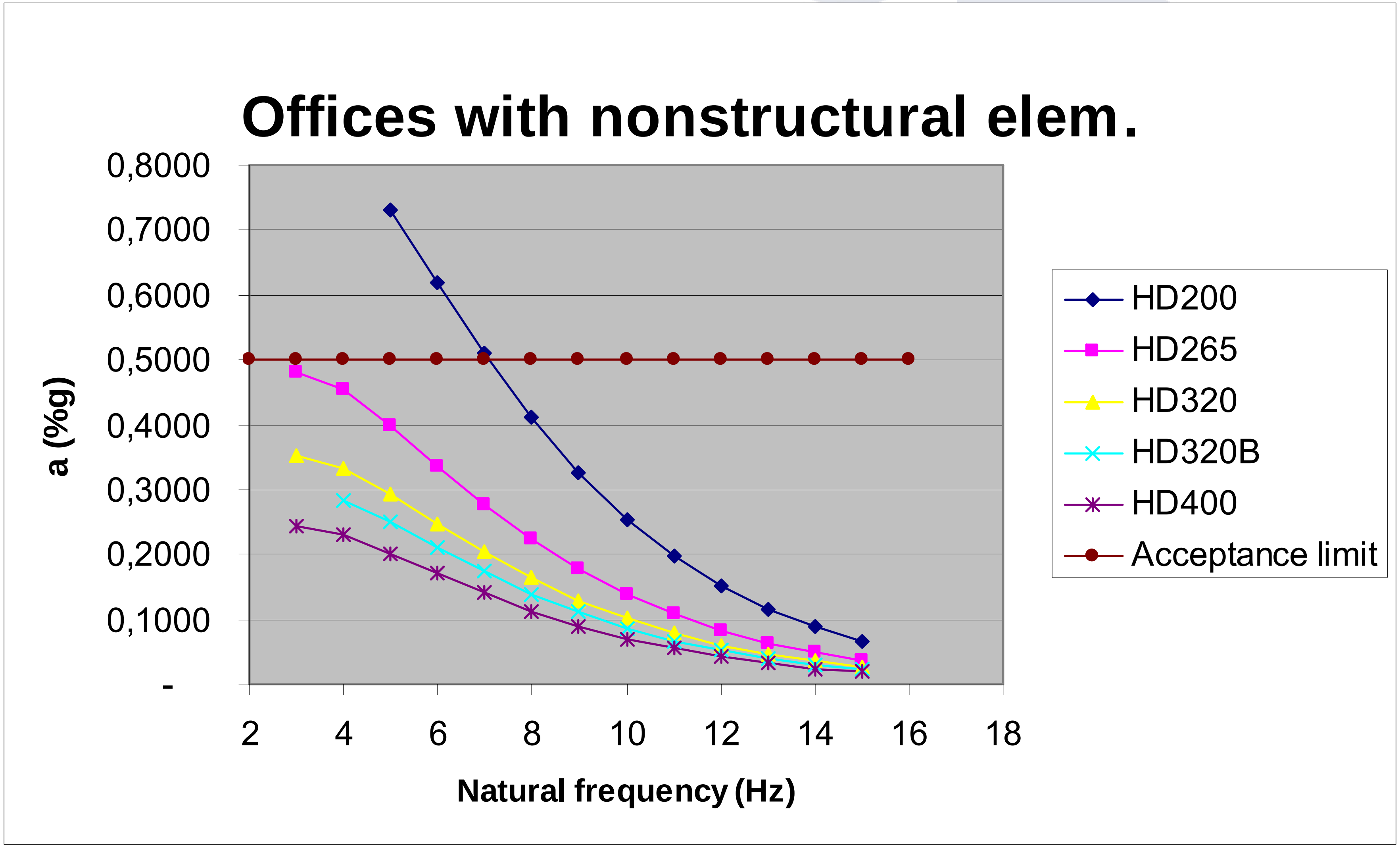

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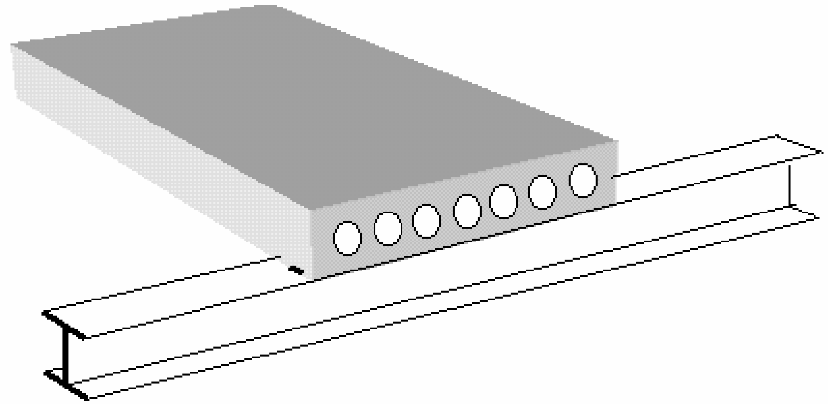
ATC Deign Guide 1

Effect of beam flexibility:



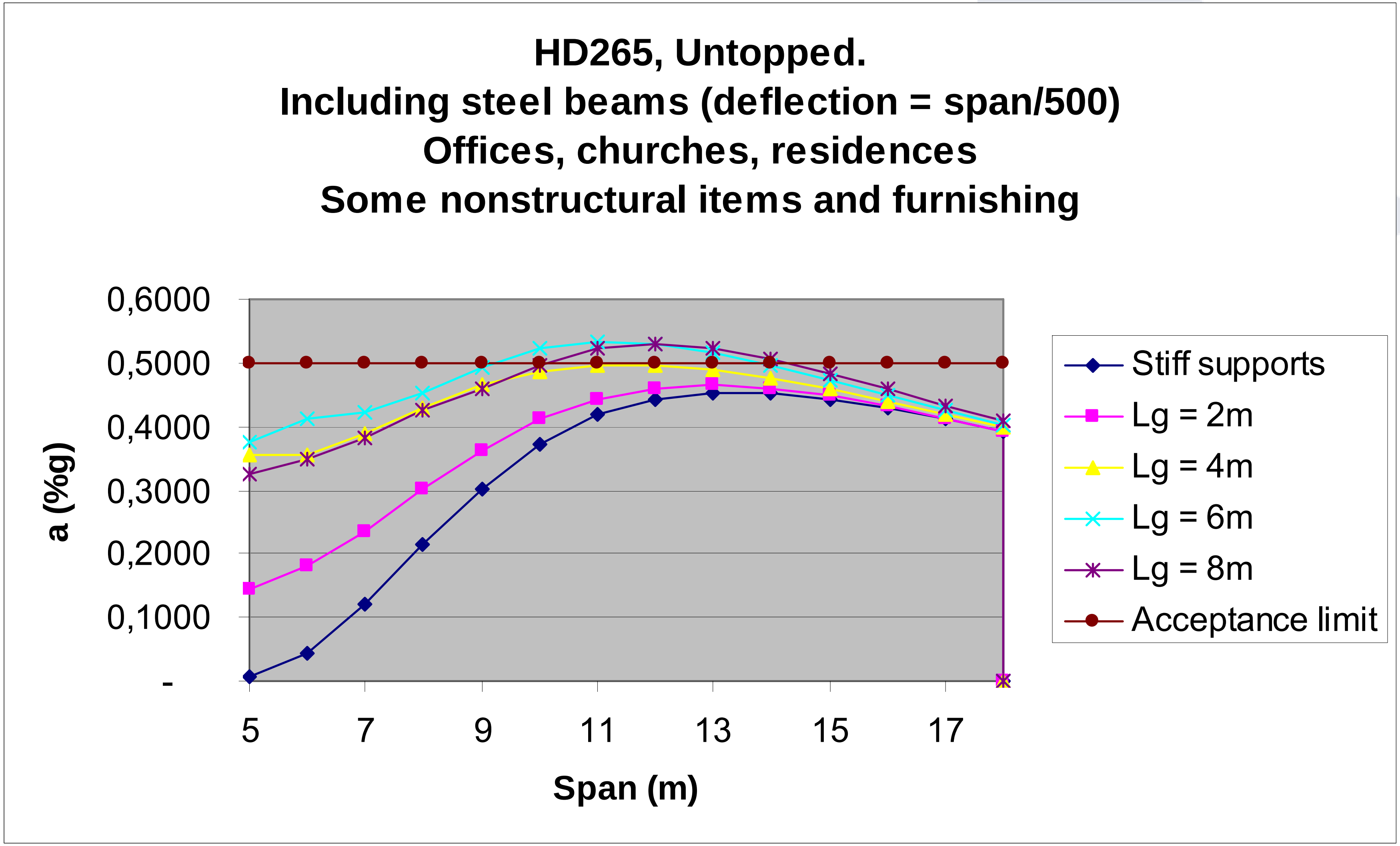
$$f_n = 0{,}18\sqrt{\frac{g}{\Delta}}$$

$\Delta = \textit{deflection due to weight}$

$\Delta = \Delta_j + \Delta_g$

$\Delta_j = \textit{deflection of floor element (joist)}$

$\Delta = \textit{deflection of beam (girder)}$



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ATC Deign Guide 1

Rythmic activities:

$$\frac{a_{pi}}{g} = \frac{1.3\alpha_i w_p / w}{\sqrt{\left[\left(\frac{f_n}{f_i}\right)^2 - 1\right]^2 + \left(\frac{2\beta f_n}{f_i}\right)^2}}$$

$$\alpha_{pi} = dynamic\ coefficient$$

$$w_p = equivalent\ weight\ of\ people\ per\ unit\ area$$

$$\beta = 0.06$$

$$a_m = \left(\sum a_{pi}^{\ 1.5}\right)^{\frac{1}{1.5}}$$

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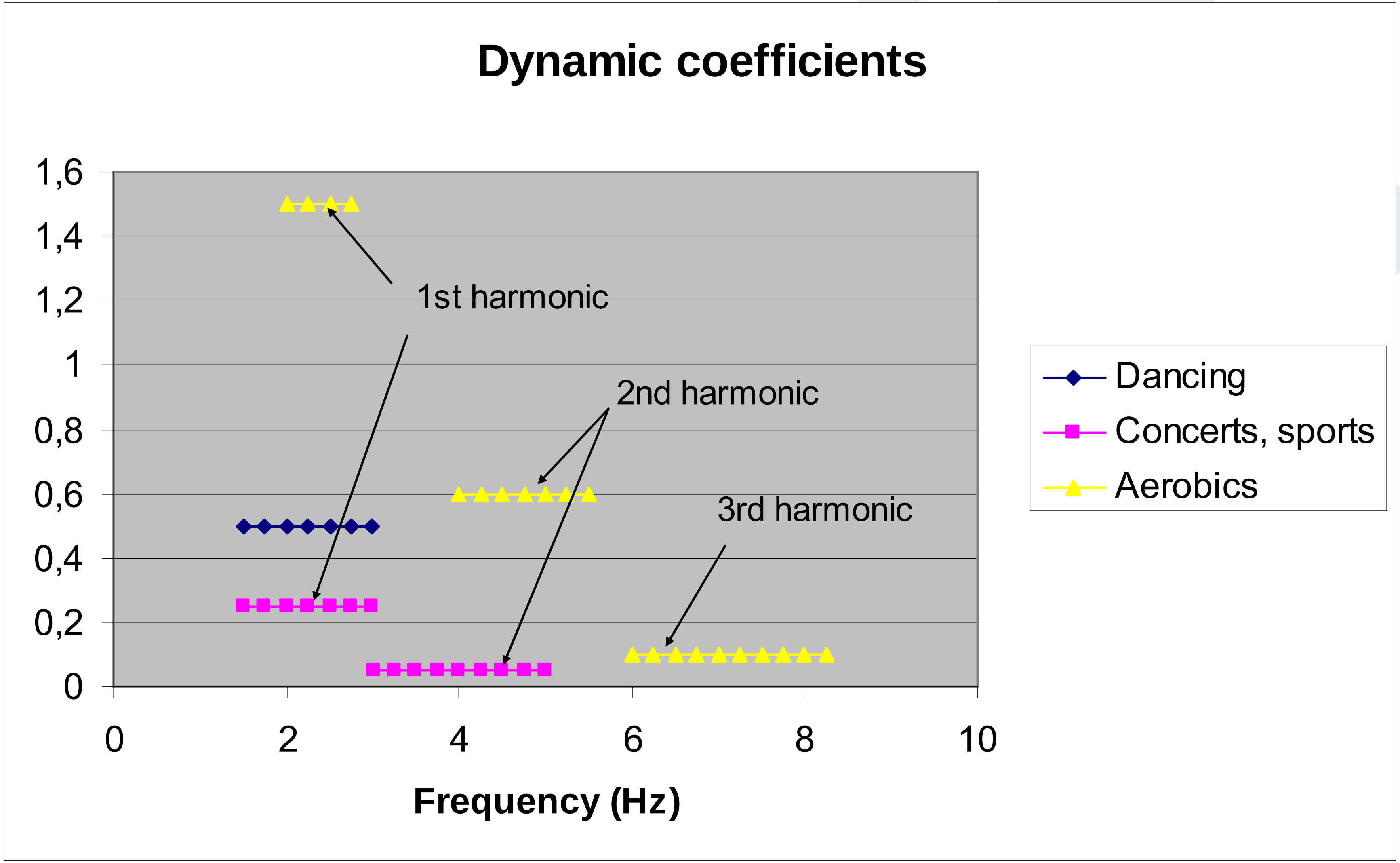

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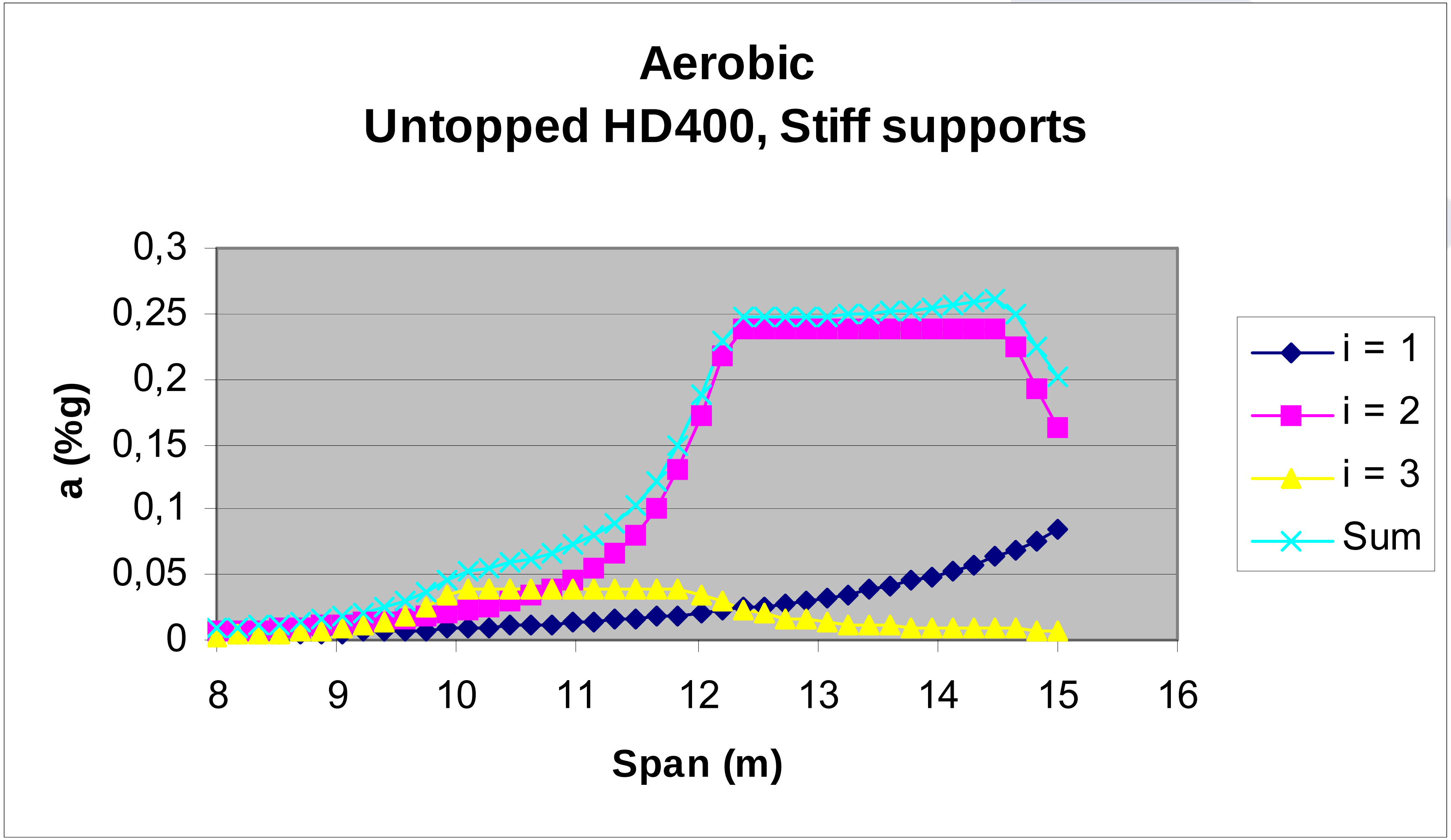

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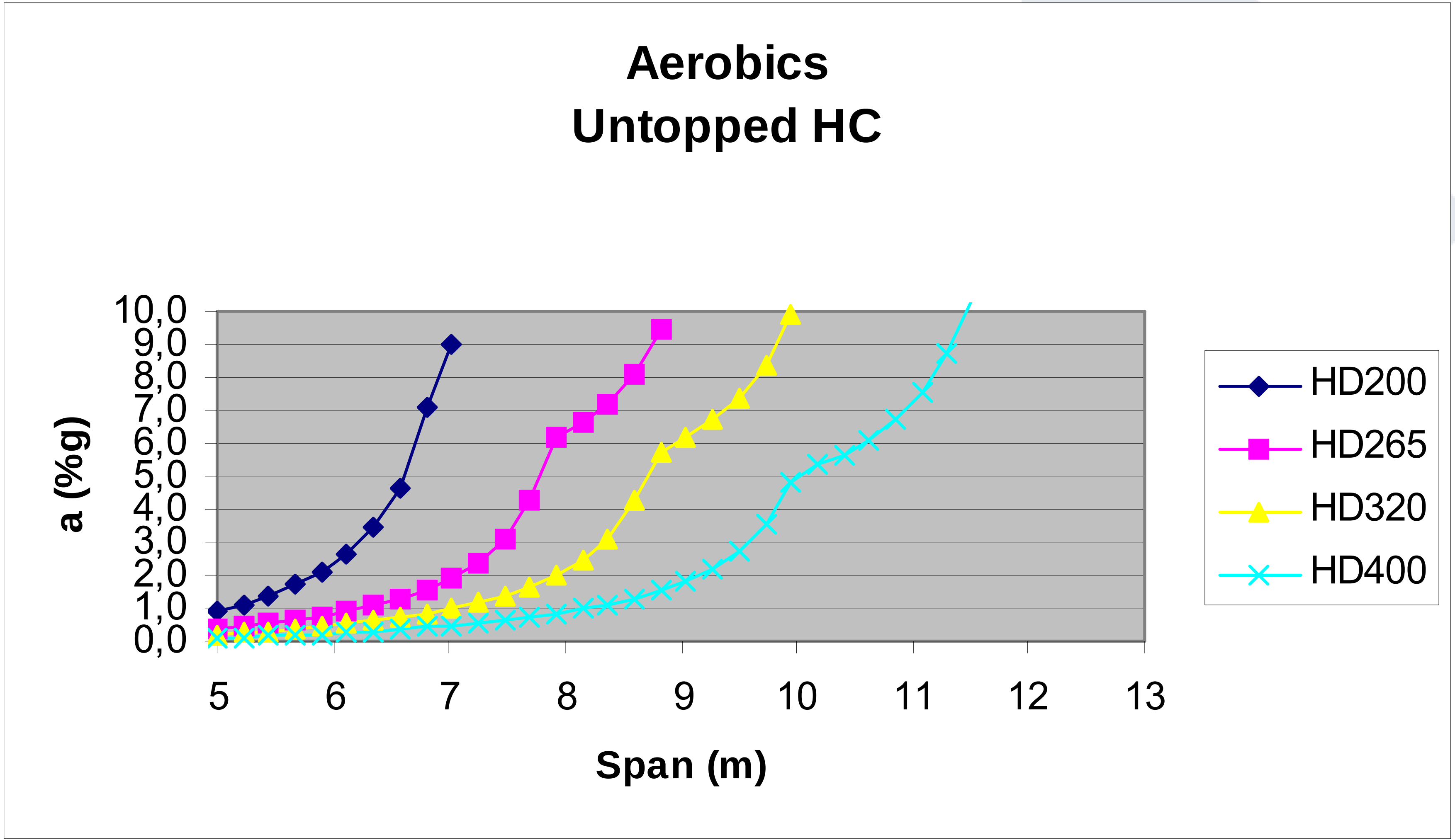

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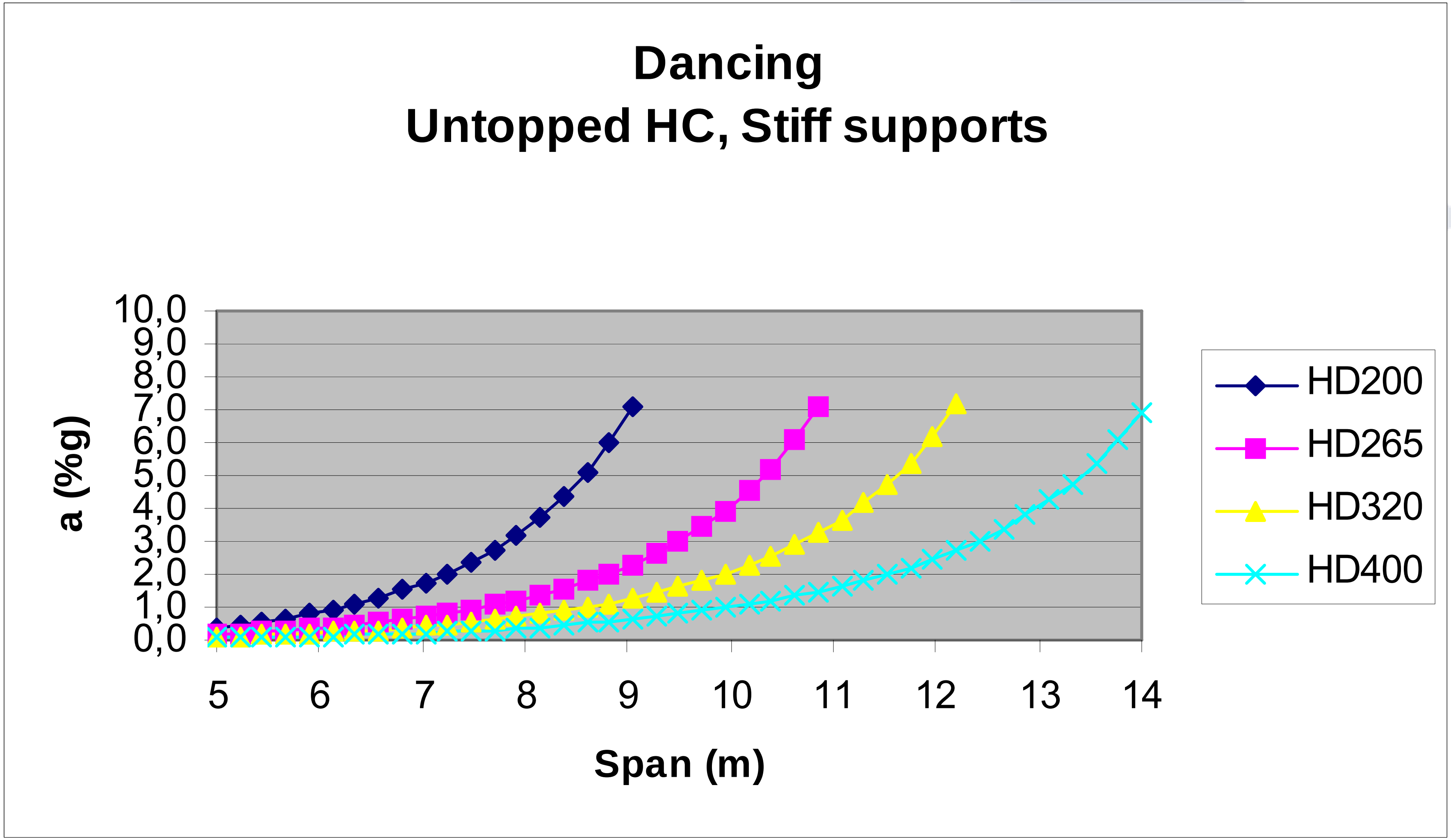

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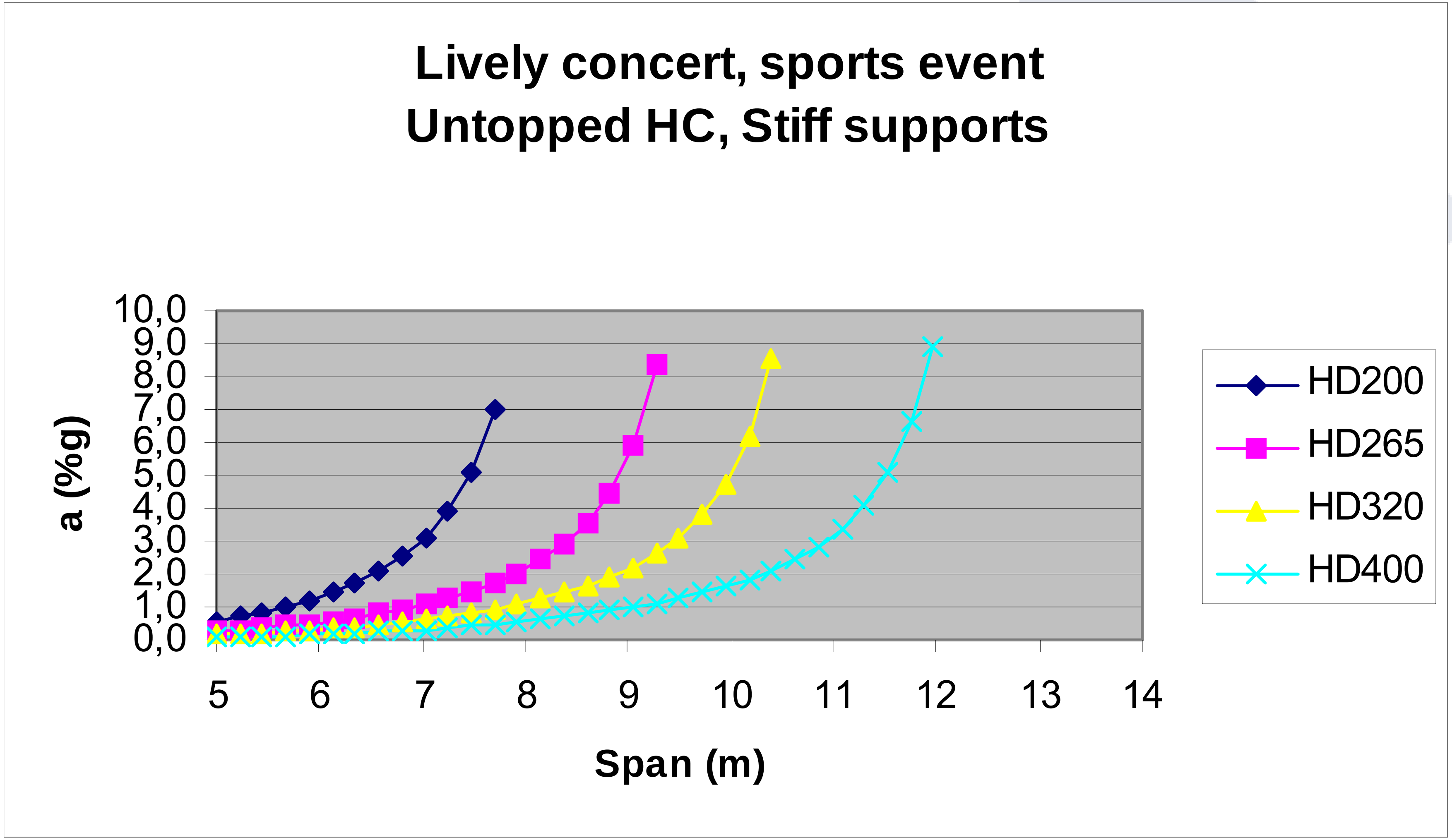

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MORE REFINED ANALYSIS:

Finite Element Method (FEM) gives better estimates for natural frequencies and mode shapes, but requires input for:

- ***Damping***
- ***Loading***
- ***Stiffness of joints***

STUDIED METHODS OF ANALYSIS, SUMMARY:

- The methods are relatively simple to use for simple cases: simply supported floor elements on stiff supports.

- More complex structures models leaves more decisions to the user: flexible supports, composite action beam/HC

- Results are sensitive to input parameters

The metods give a good understanding of the nature of the problem, but remember that all uncertainities in input are reflected in the results of the ananlyis

REDUCTION OF VIBRATIONS IN EXISTING BUILDINGS:

- ***Add stiffness***
- ***Add damping***
- ***Tuned mass dampers***

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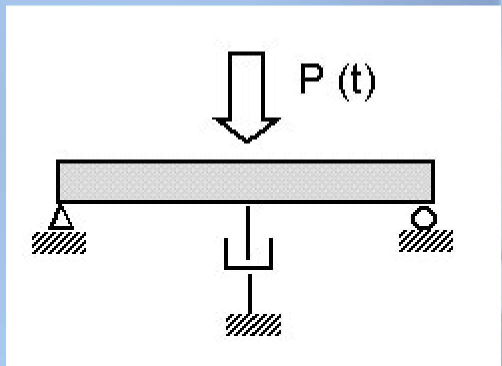
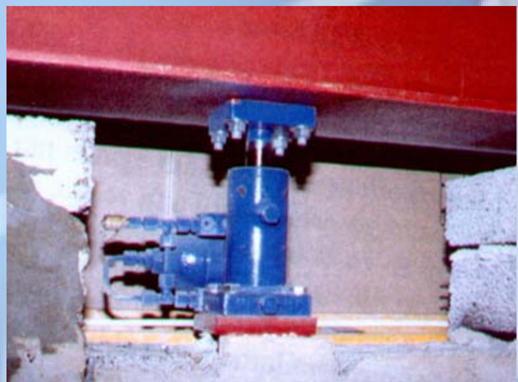
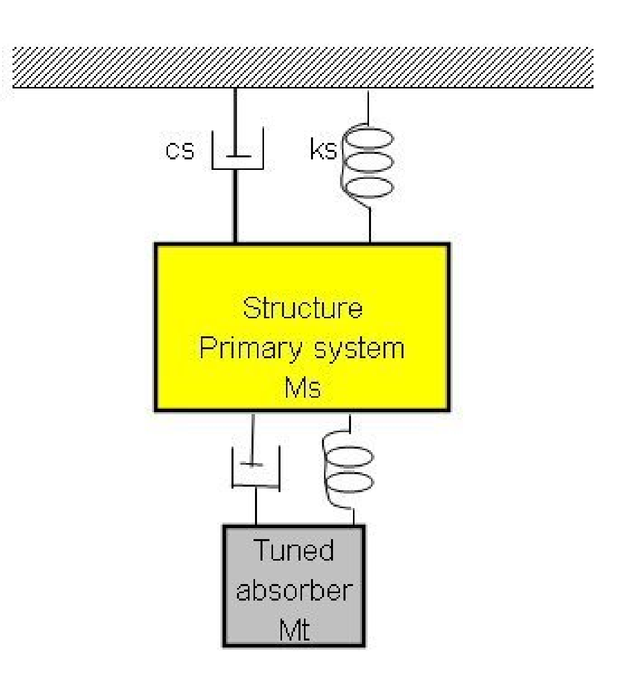
Attempts to reduce vibrations





- The structural frequency is influenced by the stiffness and the mass of the structure.
- The structural design in choosing the span width, the bending stiffness and mass is often given by the external conditions. However these parameters strongly influence the dynamic properties of the structure, and have to be taken into consideration.
- Structural damping is often small, but the possibility to arrange dampers or tuned mass dampers exists.

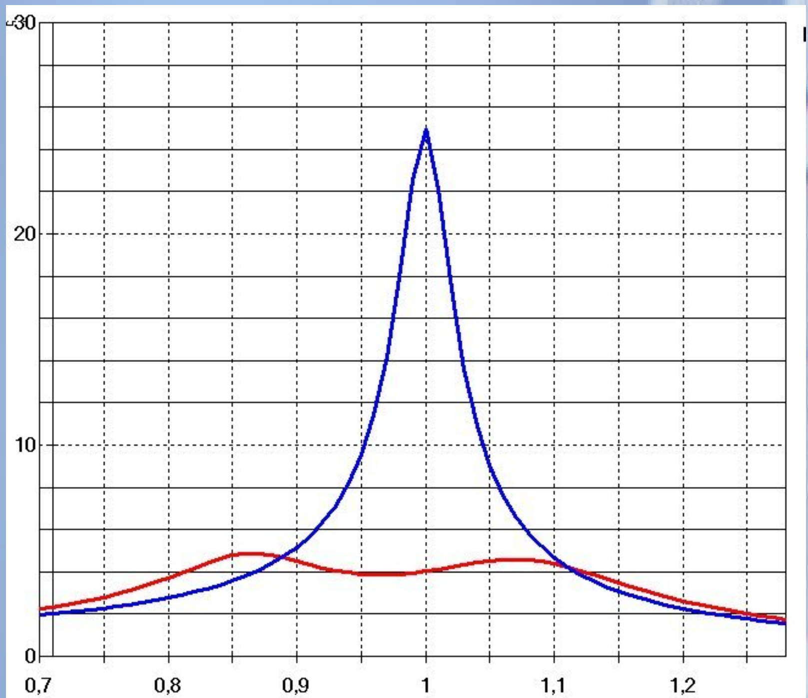
Attempts to reduce vibrations



- Tuned vibration absorbers

A tuned vibration absorber is a vibratory subsystem attached to a larger primary vibration system. It consists in general of a mass, a spring and a damper

Attempts to reduce vibrations



Tuned vibration absorbers

- Accurate tuning of the frequency of the absorber results in induced inertial forces of the absorber mass which counteract the forces applied to the primary system, The absorber is to reduce resonant oscillations of the primary system