NSCC 2015

Background document on ANSYS analyses

0 Contents

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1 Introduction

This document reports on the structural analyses for

Knoedel/Ummenhofer: Time History Simulation in Seismic Design

to be prepared for

Nordic Steel Construction Conference 2015, Tampere, Finland, 23-25 September 2015.

This paper has been accepted under ID 166.

This study is related to previous work of Knoedel (2011), Knoedel/Hrabowski (2011, 2012) and Knoedel/Hrabowski/Ummenhofer (2014). All these are seeking to excite a structure in their most unfavourable way, which would be the natural frequency with structures of linear response.

However, with structures of non-linear response, such as plastic frames, it is not quite clear a priori, which driving frequency leads to the largest storey-drift of the structure. This is due to the well known resonance foldover of the dynamic amplification function.

In this report we produce evidence to clarify this effect.

2 Terms

peak	"first peak" is referring to the first positive local maximum of the time-displacement curve a negative displacement corresponding to the "first peak" is the minimum after "first peak"
Amplification	largest storey drift (pos. or neg.) divided by the driving amplitude

3 Procedure

3.1 Structures

See report-11_14-03-09 for Napoli paper of Knoedel/Hrabowski/Ummenhofer (2014).

See model description below.

3.2 Elements

We used a 2-D ANSYS model with plastic BEAM23. For simplification all sections were chosen to be tubular so we can follow the structural needs without being restricted by the stepped dimensions of a profile table.

The element size was chosen in a range of 0,20 m to 0,05 m. A length of 0,20 m i.e. 20 elements for the columns and 30 elements for the waler proved to be sufficient for the present analysis.

3.3 Material

We used steel with a simplified bi-linear constitutive law with isotropic hardening.
Young's modulus with 2,1 GPa was used up to a yield limit of 235 MPa. Above that we used a straight line to the ultimate tensile stress 360 MPa at assumed 20 % strain. Thus we receive an 'engineering plastic modulus' with a slope of
(360 MPa – 235 MPa) / 0,20 = 625 MPa
This approach has been used before, see eq. 15 in Knoedel/Hrabowski (2012).

3.4 Damping

A parameter DAMP = 0,00235 was used to get

time [s]	displacement [mm]	description
0,818	196,2	first peak
18,803	167,4	12. peak

According to the Mensinger Formula
$\delta = 1/N * \ln (Amp_{,i} / Amp_{,i+N})$
the logarithmic decrement amounts to
$\delta = 1/11 * \ln (196{,}2 \text{ mm} / 167{,}2 \text{ mm}) = 0{,}015$

The damping ratio (Lehrsches Dämpfungsmaß D, critical damping ratio ζ) amounts to

$D = \delta / 2\pi$

$D = 0{,}015 / 2\pi = 0{,}00239$

3.5 Verification

See report-11_14-03-09 for Napoli paper of Knoedel/Hrabowski/Ummenhofer (2014).

See below for the individual models.

3.6 Time-History Analysis

We performed a straight forward Euler-type time integration, using 20 to 50 load steps within a period. Between these major steps automatic time stepping was used, which resulted in up to 100 sub steps in between.

20 load steps proved to be sufficient for a period within 1,2 % of the theoretical value.

Results are given in absolute values in the original coordinate system.
This can be seen from the calculations with a step base displacement, where the response-position of the base nodes is shown as offset and the dynamic response of the structure is seen as oscillation around an offset as well.

4 Investigated Structures

Frame with w/h = 6 m / 4 m and pinned column bases.

Tubular section chs 400x12.

5 Cross Sections and Properties

5.1 CHS properties

Stiffness of the tubes

$I = \pi * R^3 * T$

$R = (D - T)/2$

$A = 2\pi * R * T$

5.2 CHS 240x12

$R = (24 \text{ cm} - 1{,}2 \text{ cm})/2 = 11{,}4 \text{ cm}$

$I = \pi * (11{,}4 \text{ cm})^3 * 1{,}2 \text{ cm} = 5585 \text{ cm}^4$

$W = 5585 \text{ cm}^4 / 11{,}4 \text{ cm} = 490 \text{ cm}^3$

$A = 2\pi * 11{,}4 \text{ cm} * 1{,}2 \text{ cm} = 85{,}6 \text{ cm}^2$

For information:

HEA 240:

$I = 7760 \text{ cm}^4$

$W = 645 \text{ cm}^3$

$N,R,k = 85{,}6 \text{ cm}^2 * 235 \text{ N/mm}^2 = 2010 \text{ kN}$

$M,gr,el = 490 \text{ cm}^3 * 235 \text{ N/mm}^2 = 115{,}2 \text{ kNm}$

5.3 CHS 400x12

CHS 400x12

$R = (40 \text{ cm} - 1{,}2 \text{ cm})/2 = 19{,}4 \text{ cm}$

$I = \pi * (19{,}4 \text{ cm})^3 * 1{,}2 \text{ cm} = 27500 \text{ cm}^4$

$W = 27500 \text{ cm}^4 / 19{,}4 \text{ cm} = 1420 \text{ cm}^3$

$A = 2\pi * 19{,}4 \text{ cm} * 1{,}2 \text{ cm} = 146{,}3 \text{ cm}^2$

$N,R,k = 146 \text{ cm}^2 * 235 \text{ N/mm}^2 = 3430 \text{ kN}$

$M,gr,el = 1420 \text{ cm}^3 * 235 \text{ N/mm}^2 = 333{,}7 \text{ kNm}$

5.4 CHS 1000x12

$R = (100 \text{ cm} - 1{,}2 \text{ cm})/2 = 49{,}4 \text{ cm}$

$I = \pi * (49{,}4 \text{ cm})^3 * 1{,}2 \text{ cm} = 454500 \text{ cm}^4$

(80 times bigger than 240x12)

$W = 454500 \text{ cm}^4 / 49{,}4 \text{ cm} = 9200 \text{ cm}^3$

(19 times bigger than 240x12)

$A = 2\pi * 49{,}4 \text{ cm} * 1{,}2 \text{ cm} = 372 \text{ cm}^2$

N,R,k = 372 cm^2 * 235 N/mm^2 = 8742 kN

M,gr,el = 9200 cm^3 * 235 N/mm^2 = 2162 kNm

6 Models

6.1 Model 1 – elastic, static

6.1.1 General

single storey

6 m frame width

4 m frame height

element divisor 1 m / 5

steel elastic

no density

0,00235 damping constant

1000x12 tubular waler

240x12 tubular columns

36.000 kgs mass added in each of the frame’s corners

dx,dy boundary conditions: feet displacements blocked

9,81 m/s^2 gravity loads

6.1.2 Horizontal stiffness

1.e+06 horizontal load in left corner

919,96 mm = 920 mm associated horizontal displacement (storey-drift)

919,96 mm with EFAK 20

reduces to 911,49 with waler 5000x12

stiffness:

c = 1.e+06 N / 919,96 mm = 1087 N/mm = $1{,}09 \cdot 10^6$ N/m calculatory horizontal displacement with infinitely stiff waler

$c = 2 * 3 * EI / L^3$

$c = 2 * 3 * 2{,}1*10^5 \text{ N/mm}^2 * 5585 \text{ cm}^4 / (4 \text{ m})^3 = 1100 \text{ N/mm} = 1{,}10*10^6 \text{ N/m}$

$u = F / c$

$u = 1.e{+}06 \text{ N} / 1{,}10*10^6 \text{ N/m} = 909 \text{ mm}$

seems OK for engineering purposes

6.1.3 Natural frequency

time history decay calculation

calculatory natural frequency – with theoretical stiffness

$\omega = \sqrt{(c/m)}$

$\omega = \sqrt{(1{,}10*10^6 \text{ N/m} / 72000 \text{ kgs})} = 3{,}91 \text{ rad/s}$

$f = \omega / 2\pi$

$f = 3{,}91 \text{ rad/s} / 2\pi = 0{,}622 \text{ /s}$

$T = 1 / 0{,}622 \text{ /s} = 1{,}607 \text{ s}$

calculatory natural frequency – with model stiffness

$\omega = \sqrt{(c/m)}$

$\omega = \sqrt{(1{,}09*10^6 \text{ N/m} / 72000 \text{ kgs})} = 3{,}89 \text{ rad/s}$

$f = \omega / 2\pi$

$f = 3{,}89 \text{ rad/s} / 2\pi = 0{,}619 \text{ /s}$

$T = 1 / 0{,}619 \text{ /s} = 1{,}615 \text{ s}$

(without detuning due to damping)

Numerical results for 20 increments per period and a given period of 1,673 with EFAK = 5

11 periods with peak values (first/last) 0,8365 s / 18,821 s

T,single,mean = (18,821 s – 0,837 s) / 11 = 1,635 s

Model period is longer – compared to model stiffness – by a factor of

$k = 1{,}635 \text{ s} / 1{,}615 \text{ s} = 1{,}012$

Numerical results for 20 increments per period and a given period of 1,635 with EFAK = 5

(triggering period adjusted)

11 periods with peak values (first/last) 0,8175 s / 18,803 s

T,single,mean = (18,803 s – 0,818 s) / 11 = 1,635 s

Model period is longer – compared to model stiffness – by a factor of

k = 1,635 s / 1,615 s = 1,012

(no change)

Numerical results for 50 increments per period and a given period of 1,635 with EFAK = 5

(smaller time steps, same elements)

11 periods with peak values (first/last) 0,8175 s / 18,639 s

T,single,mean = (18,639 s – 0,818 s) / 11 = 1,620 s

Model period is longer – compared to model stiffness – by a factor of

k = 1,620 s / 1,615 s = 1,003

(smaller period, more accurate)

Numerical results for 20 increments per period and a given period of 1,635 with EFAK = 20

(smaller time steps, same elements)

11 periods with peak values (first/last) 0,8175 s / 18,639 s

T,single,mean = (18,803 s – 0,818 s) / 11 = 1,635 s

Model period is longer – compared to model stiffness – by a factor of

k = 1,635 s / 1,615 s = 1,012

(same as EFAK = 5 and ninc = 20)

Numerical results for 50 increments per period and a given period of 1,635 with EFAK = 20

(smaller time steps, smaller elements)

11 periods with peak values (first/last) 0,8175 s / 18,639 s

T,single,mean = (18,639 s – 0,818 s) / 11 = 1,620 s

Model period is longer – compared to model stiffness – by a factor of

k = 1,620 s / 1,615 s = 1,003

(smaller period, more accurate)

conclusion:

1 % error in the period seems to be ok for engineering purposes

EFAK = 5 and NINC = 20 are used throughout

6.1.4 Stress design

Horizontal force in/at waler

F = 100 kN

Base shear per column

F = 50 kN

Corner moment

M = 50 kN * 4 m = 200 kNm

outer fibre stress

$\sigma = 200 \text{ kNm} / 490 \text{ cm}^3 = 408 \text{ N/mm}^2$

(in waler: $200 \text{ kNm} / 9200 \text{ cm}^3 = 21{,}7 \text{ N/mm}^2$)

Normal forces in columns from tilting

F = 100 kN * 4 m / 6 m = ±66,67 kN

Normal force in waler, depending on position of horizontal force: ±50 kN

Numerical results:

66,67 kN	normal force	ok
50,00 kN	shear	ok
200,0 kNm	moment	ok
$0{,}416 \cdot 10^9$ Pa = 416 MPa	max sigma	rel. err. +2,0 %
$-0{,}416 \cdot 10^9$ Pa = –416 MPa	max sigma	rel. err. +2,0 %

6.1.5 Elastic limit

Horizontal force:

$F = 100 \text{ kN} \cdot 235 \text{ N/mm}^2 / 408 \text{ N/mm}^2 = 57{,}60 \text{ kN}$

Horizontal displacement with model stiffness:

w = 57,60 kN / 1,09*10^6 N/m = 52,3 mm

Numerical results with horizontal load 57,6 kN:

w = 52,99 mm	rel. err. +1,3 %
σ = 240 N/mm^2	rel. err. +2,1 %

6.1.6 Plastic design

Numerical results with horizontal load 57,6 kN (elastic limit load):

w = 53,0 mm	plausible
σ = 235 N/mm^2	ok

ε,pl = 0,312*10^{-4} corresponds to 6,6 N/mm^2 – plausible

left corner only, right shows no plastic strains

Numerical results with horizontal load 65 kN (little above half to fully plastic):

w = 61,9 mm	plausible
σ = 235 N/mm^2	ok
ε,pl = 0,444*10^{-3}	corresponds to 93 N/mm^2;
235 + 93 = 328 N/mm^2	plausible, must be over 270 N/mm^2

0,5 * 65 kN * 4 m / 490 cm^3 = 265,3 N/mm^2

Counter check – 65 kN with linear material:

w = 59,8 mm	plausible
σ = 270 N/mm^2	rel. err. +1,8 %

7 Constant Drive

7.1 Model 1 – elastic – 5 mm

Driving period 1,635 s at resonance, driving amplitude 5 mm.

Calculatory amplitude for δ = 0,015:

A,steady = A,drive * π / δ

A,steady = 5 mm * π / 0,015 = 5 mm * 209,4 = 1047 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 20

after 100 sec; 1223 load steps; 61 periods: +399 mm/–389 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 50

after 200 sec; 6116 load steps, 122 periods:

max at 60 seconds +284 mm / –284 mm, after that decaying to +228 mm/–229 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 40

after 100 sec; 2446 load steps, 61 periods:

max at 66 seconds +294 mm / –294 mm, after that decaying to +279 mm/–279 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 30

after 80 sec; 1467 load steps, 48 periods:

max at 80 seconds +319 mm/–319 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 30

after 100 sec; 1834 load steps, 61 periods:

max at 83 seconds +320 mm/–320 mm, after that decaying to +315 mm / –315 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 20

after 200 sec; 2446 load steps, 122 periods:

max at 200 seconds +413 mm/–413 mm

Numerical results with driving period 1,635, EFAK = 5 and NINC = 20

after 300 sec; 3669 load steps, 183 periods:

max at 190-220 seconds +413 mm/–413 mm, after that decaying to +411 mm / –411 mm

at 150 seconds +410 mm/–411 mm – 99 %;

at 120 seconds +402 mm/–403 mm – 97 %;

at 100 seconds +390 mm/–390 mm – 94 %;

at 90 seconds +380 mm/–380 mm – 92 %;

Numerical results with driving period 1,635*0,9, EFAK = 5 and NINC = 20

after 200 sec; 2718 load steps, 135 periods:

max at 6,9 seconds +42,4 mm/–42,7 mm (5. peak), after that beating occurs with decaying amplitudes;

at 191 seconds +21,4 mm/–21,4 mm

Numerical results with driving period 1,635*0,95, EFAK = 5 and NINC = 20

after 200 sec; 2575 load steps, 128 periods:

max at 15 seconds +85,5 mm/–85,2 mm (10. peak), after that beating occurs with decaying amplitudes;

at 184 seconds +49,7 mm/–49,7 mm

Numerical results with driving period 1,635*0,98, EFAK = 5 and NINC = 20

after 200 sec; 2496 load steps, 124 periods:

max at 42 seconds +191 mm/–191 mm (26-27. peak), after that beating occurs with decaying amplitudes;

within 200 sec one other beating maximum occurs at 134 seconds +143 mm/–143 mm

Numerical results with driving period 1,635*0,99, EFAK = 5 and NINC = 20

after 200 sec; 2471 load steps, 123 periods:

max at 90 seconds +311 mm/–311 mm, after that beating occurs with decaying amplitudes;

Numerical results with driving period 1,635*0,992, EFAK = 5 and NINC = 20

after 200 sec; 2466 load steps, 123 periods:

max at 110 seconds +355 mm/–355 mm; after that decaying amplitudes;

Numerical results with driving period 1,635*0,995, EFAK = 5 and NINC = 20

after 200 sec; 2471 load steps, 123 periods:

max at 90 seconds +432 mm/–432 mm

Numerical results with driving period 1,635*0,997, EFAK = 5 and NINC = 20

after 300 sec; 3680 load steps, 184 periods:

max at 300 seconds +465 mm/–465 mm

Numerical results with driving period 1,635*0,997, EFAK = 5 and NINC = 20

after 500 sec; 6134 load steps, 306 periods:

at 50 seconds +297 mm/–299 mm – 64 %

at 100 seconds +406 mm/–407 mm – 87 %

at 150 seconds +445 mm/–445 mm – 95 % ... 92 peaks – sufficient for engineering purposes

at 199 seconds +458 mm/–458 mm – 98 % ... 122 peaks – selected for this paper

at 250 seconds +463 mm/–463 mm – 99,4 %

at 300 seconds +465 mm/–465 mm – 99,8 %

at 349 seconds +466 mm/–465 mm – 99,8 %

at 400 seconds +466 mm/–466 mm – 100 %

at 450 seconds +466 mm/–466 mm – 100 %

at 500 seconds +466 mm/–466 mm – 100 %

Numerical results with driving period 1,635*1,005, EFAK = 5 and NINC = 20

after 150 sec; 1825 load steps, 91 periods:

max at 82 seconds +304 mm/–304 mm

Numerical results with driving period 1,635*1,01, EFAK = 5 and NINC = 20

after 100 sec; 1211 load steps, 60 periods:

max at 52 seconds +235 mm/–235 mm

Numerical results with driving period 1,635*1,02, EFAK = 5 and NINC = 20

after 100 sec; 1199 load steps, 59 periods:

max at 32+33 seconds +162 mm/–162 mm (20-21. peak), after that beating occurs with decaying amplitudes;

Numerical results with driving period 1,635*1,05, EFAK = 5 and NINC = 20

after 50 sec; 582 load steps, 29 periods:

max at 14 seconds +84,6 mm/–84,7 mm (9. peak), after that beating occurs with decaying amplitudes;

Numerical results with driving period 1,635*1,1, EFAK = 5 and NINC = 20

after 50 sec; 556 load steps, 27 periods:

max at 9 seconds +48,7 mm/–49,0 mm (6. peak), after that beating occurs with decaying amplitudes;

7.2 Model 1 – plastic – 5 mm

Driving period 1,635 s at resonance, driving amplitude 5 mm.

Plastic constitutive law as described above with fy = 235 N/mm^2

Elastic limit storey-drift   w = 52,3 mm

Numerical results with driving period 1,635*1,00, EFAK = 5 and NINC = 20

after 20 sec; 244 load steps, 12 periods:

max at 9 seconds +66,1 mm/–66,2 mm (6. peak), after that steady state with constant amplitudes;

Numerical results with driving period 1,635*1,00, EFAK = 5 and NINC = 40

after 40 sec; 978 load steps, 24 periods:

6. peak with +66,1 mm/–66,4 mm

after 34 seconds there are some amplitudes around 68 mm, such as 68,5 mm/–68,3 mm; but this seems to be some “aliasing” rather than a steady increase of the response amplitudes.

conclusion: NINC = 40 does not lead to significant improve

Numerical results with driving period 1,635*1,00, EFAK = 20 and NINC = 20

after 15 sec; 183 load steps, 9 periods:

5. peak with +63,9 mm/–65,6 mm
6. peak with +65,6 mm/–65,9 mm (loadstep 110, substep 10)
7. peak with +66,2 mm/–66,1 mm
8. peak with +65,8 mm/–65,9 mm
9. peak with +66,1 mm/–66,1 mm

conclusion: EFAK = 20 does not improve significantly

Numerical results with driving period 1,635*1,00, EFAK = 20 and NINC = 20

after 200 sec; 2446 load steps, 122 periods:

see previous run – it is in fact steadily increasing up to 79,6 mm (loadstep 2430, substep 10) in the last period.

Numerical results with driving period 1,635*0,90, EFAK = 20 and NINC = 20

after 20 sec; 271 load steps, 13 periods:

max at 6. peak with +46,0 mm/–45,3 mm;

after that pronounced beating with smallest amplitudes around 5 mm

this run is purely elastic, since the limit drift is some 53 mm

Numerical results with driving period 1,635*0,95, EFAK = 20 and NINC = 20

after 20 sec; 257 load steps, 12 periods:

max at 5. peak with +59,2 mm/–60,3 mm; after that decaying amplitudes

12. peak with +55,1 mm/–54,7 mm

Numerical results with driving period 1,635*0,98, EFAK = 20 and NINC = 20

after 20 sec; 249 load steps, 12 periods:

max at 6. peak with +64,0 mm/–64,0 mm; after that decaying amplitudes

12. peak with +62,6 mm/–62,1 mm

Numerical results with driving period 1,635*0,99, EFAK = 20 and NINC = 20

after 20 sec; 247 load steps, 12 periods:

max at 6. peak with +65,4 mm/–65,3 mm; after that slightly decaying amplitudes

12. peak with +64,4 mm/–64,2 mm

Numerical results with driving period 1,635*1,003, EFAK = 20 and NINC = 20

after 100 sec; 1219 load steps, 60 periods:

6. peak with +66,0 mm/–66,4 mm – 90 % of value at 60. peak

10. peak with +66,4 mm/–66,3 mm

20. peak with +67,3 mm/–67,6 mm

30. peak with +68,9 mm/–69,2 mm

40. peak with +70,5 mm/–70,8 mm

50. peak with +72,1 mm/–71,8 mm

60. peak with +73,3 mm/–73,6 mm

61. peak with +73,5 mm/–73,7 mm

Numerical results with driving period 1,635*1,003, EFAK = 20 and NINC = 20

after 200 sec; 2439 load steps, 121 periods:

last peak (122.) +79,8 mm/–80,1 mm – seems as if the amplitudes were steadily increasing

Numerical results with driving period 1,635*1,005, EFAK = 20 and NINC = 20

after 50 sec; 608 load steps, 30 periods:

6. peak with +66,1 mm/–66,5 mm – 95 % of value at 30. peak

10. peak with +66,5 mm/–66,9 mm

15. peak with +67,4 mm/–67,5 mm

20. peak with +67,5 mm/–67,9 mm

25. peak with +68,6 mm/–68,7 mm

30. peak with +68,9 mm/–69,7 mm

Numerical results with driving period 1,635*1,01, EFAK = 20 and NINC = 20

after 20 sec; 242 load steps, 12 periods:

max at 6. peak with +66,2 mm/–66,3 mm; after that slightly decaying amplitudes (? see end values)

12. peak with +67,3 mm/–67,0 mm

Numerical results with driving period 1,635*1,01, EFAK = 20 and NINC = 20

after 40 sec; 484 load steps, 24 periods:

see previous run

24. peak with +68,8 mm/–68,5 mm

Numerical results with driving period 1,635*1,02, EFAK = 20 and NINC = 20

after 20 sec; 239 load steps, 11 periods:

max at 6. peak with +66,6 mm/–66,4 mm; after that like a plateau

12. peak (bottom is still visible) with +67,3 mm/–67,7 mm

Numerical results with driving period 1,635*1,05, EFAK = 20 and NINC = 20

after 20 sec; 232 load steps, 11 periods:

max at 6. peak with +64,1 mm/–64,4 mm; after that decaying amplitudes to 57 mm

Numerical results with driving period 1,635*1,10, EFAK = 20 and NINC = 20

after 20 sec; 222 load steps, 11 periods:

max at 5. peak with +46,1 mm/–45,5 mm; after pronounced beating with amplitudes down to -9 mm/+11 mm.

7.3 Model 1 – plastic – 50 mm

Driving period 1,635 s at resonance, driving amplitude 5 mm.

Plastic constitutive law as described above with fy = 235 N/mm^2

Elastic limit storey-drift   w = 52,3 mm

Numerical results with driving period 1,635*1,00, EFAK = 10 and NINC = 200

(seemed to be necessary to get the thing going over the first or second peak)

after 10 sec; 1224 load steps, 6 periods, 96269 cumulative iterations, app. 90 min I/O

1. peak; 0,81 sec; +78,6 mm / –102,3 mm (1,6922 s, loadstep208, substep 78)

2. peak; 2,5 sec; +65,6 mm / –97,4 mm

3. peak; 4,2 sec; +63,9 mm / –99,0 mm

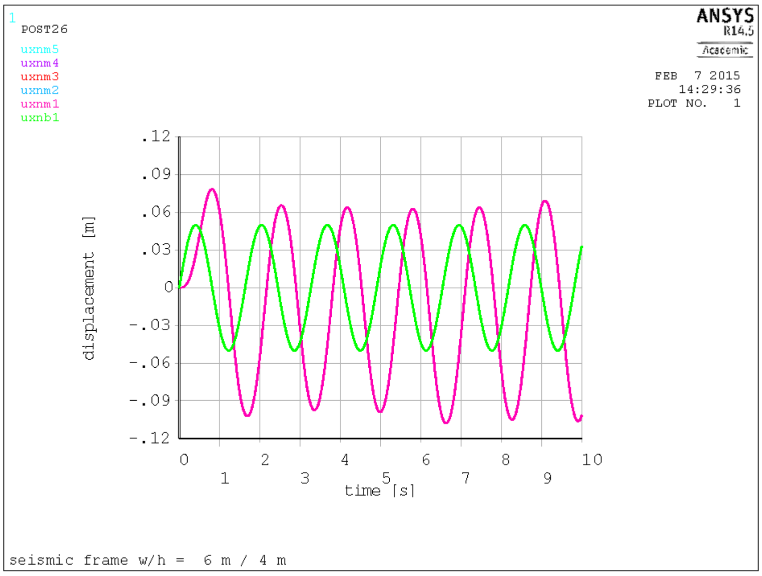
4. peak; 5,8 sec; +62,8 mm / –107,9 mm

5. peak; 7,4 sec; +64,0 mm / –105,0 mm

6. peak; 9,1 sec; +69,3 mm / –106,2 mm (9,9081 s, loadstep 1213, substep 64)

remark: up to 105 substeps were needed

remark 2: are the results of this run significant?

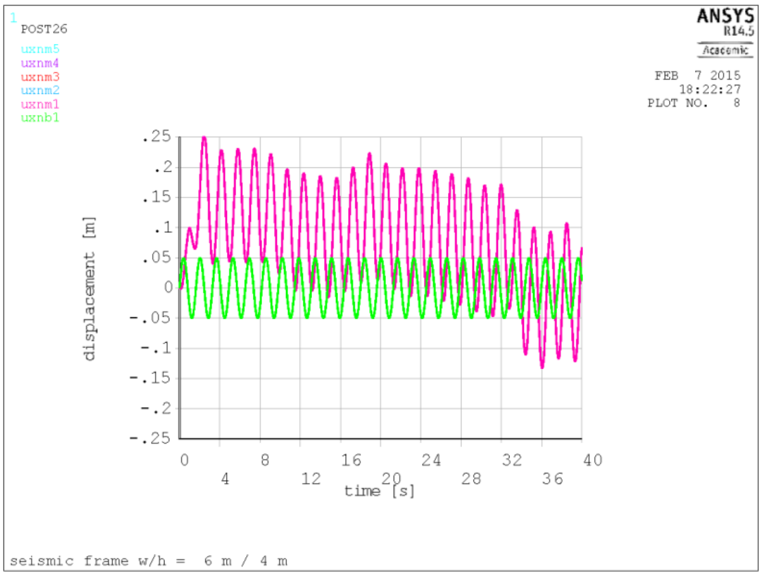


Second run with the quicker response due to use of NSUB,100,10000,10,1

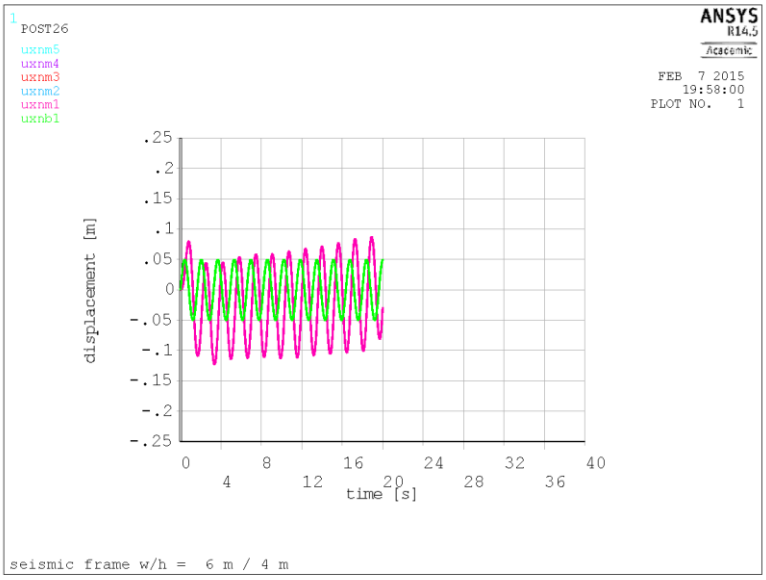
Numerical results with driving period 1,635*1,00, EFAK = 5 and NINC = 100

after 40 sec; 2447 load steps, 24 periods, 147311 cumulative iterations, app. 60 min I/O

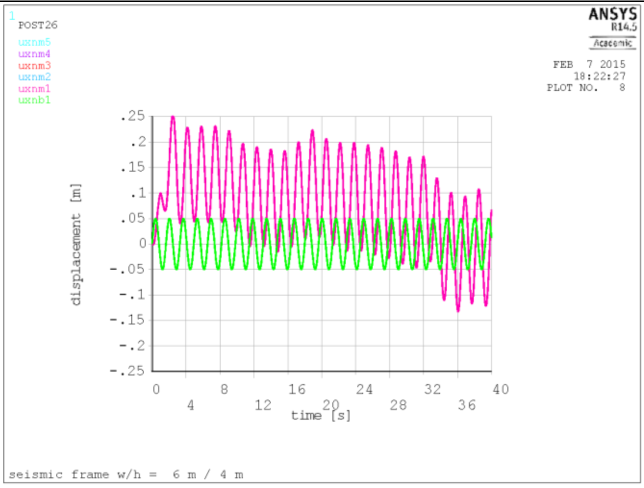
...quite different feature



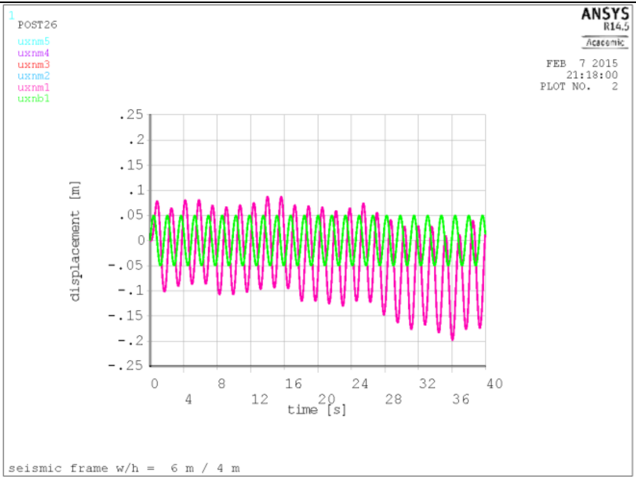
same as above, but with NINC = 200 and up to 20 sec



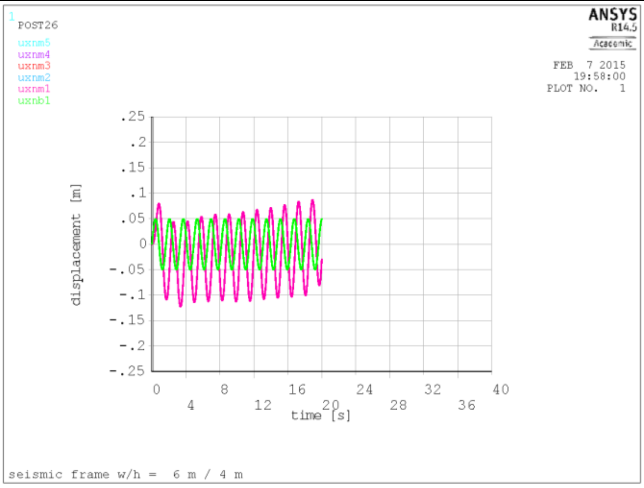
max at 3,3 sec –123 mm



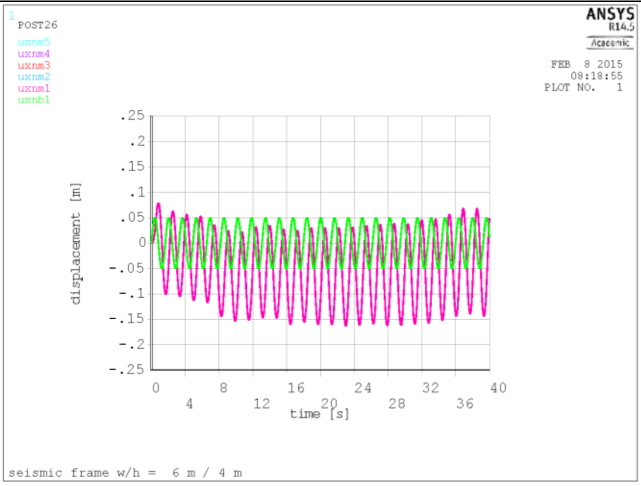
NINC = 100



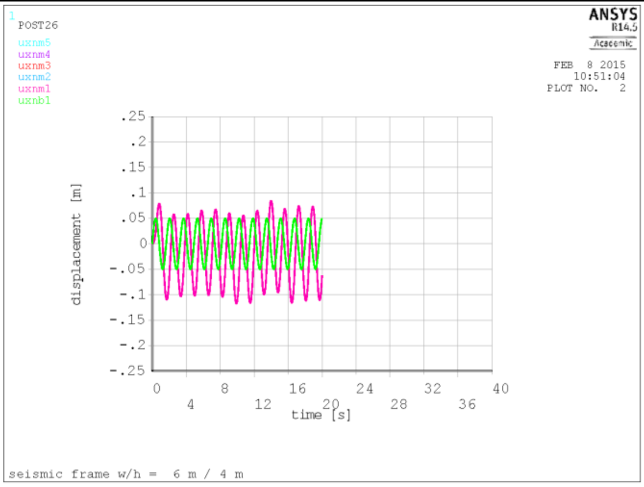
NINC = 150



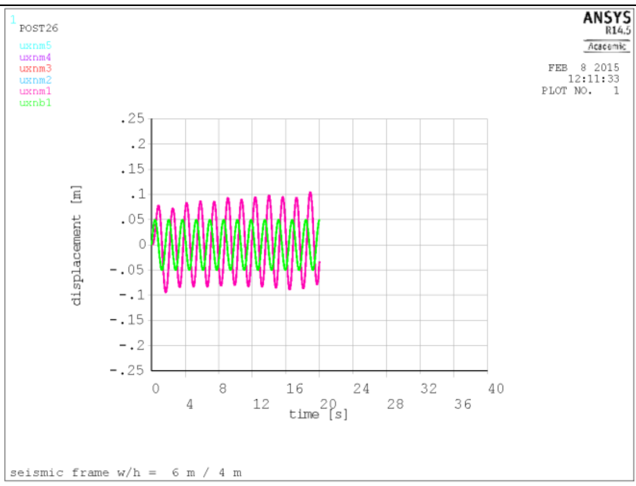
NINC = 200



NINC = 250



NINC = 300



NINC = 350

Numerical results with driving period 1,635*0,995, EFAK = 5 and NINC = 100

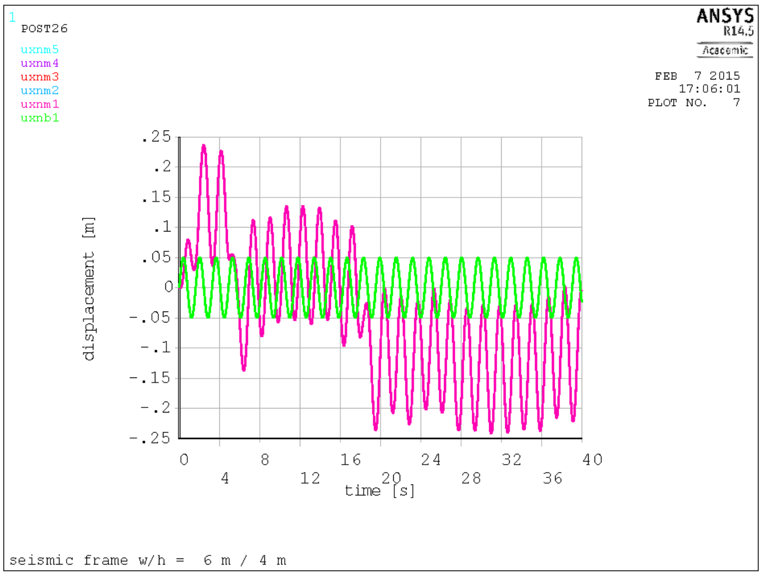
(seemed to be necessary to get the thing going over the first or second peak)

after 40 sec; 2458 load steps, 24 periods, 149896 cumulative iterations, app. 60 min I/O

max pos: 2. peak; 2,4 sec, +236,8 mm / –36,7 mm (!)

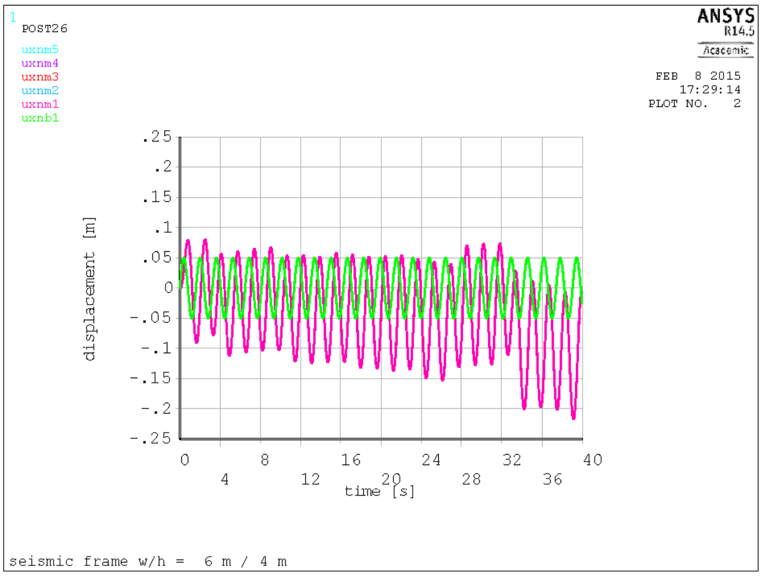
min neg: 19. peak; 30,2 sec –27,9 mm / –241,5 mm (!)

is seems that detuning which causes beating with elastic oscillators, causes a jump in the mean displacement: from app. 120 mm to app. 50 mm to app. –110 mm.



(compare run below with NINC = 200, otherwise identical)

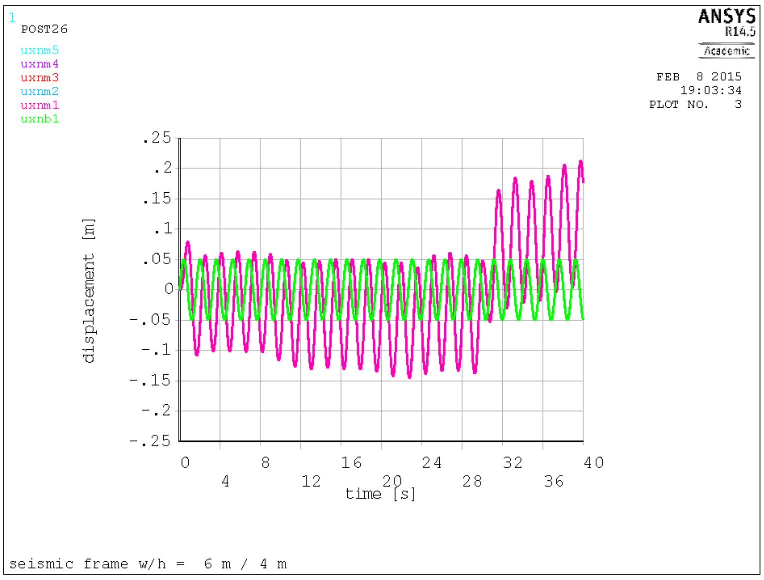
As a result of the above "6 pix on one page" page we decided that NINC = 200 would be a compromise for reasonable results.



40 seconds with 1,635*0,995, EFAK = 5 and NINC = 200

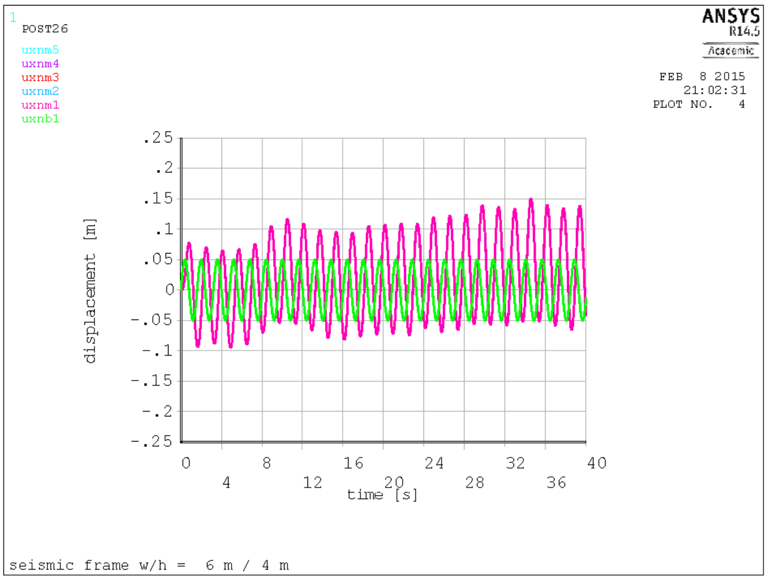
(compare above run with NINC = 100, otherwise identical)

max at 39,2 sec –217 mm



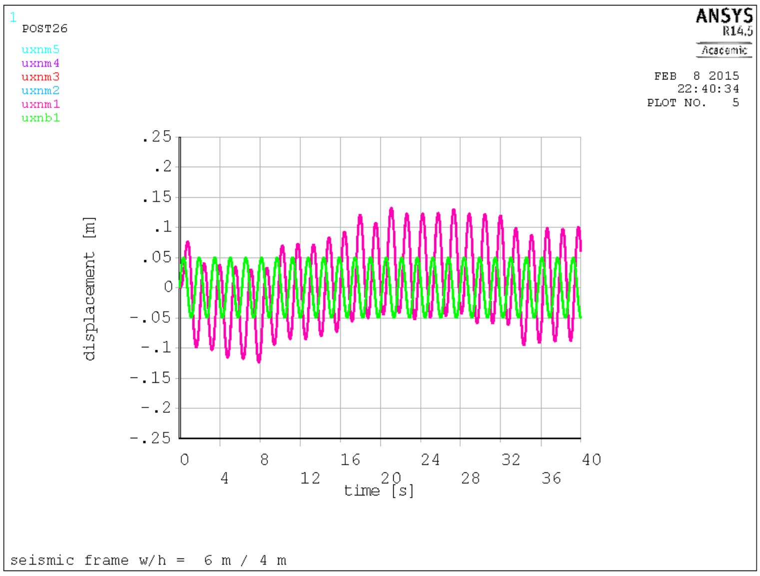
40 seconds with 1,635*0,990, EFAK = 5 and NINC = 200

max at 38,8 sec +213 mm



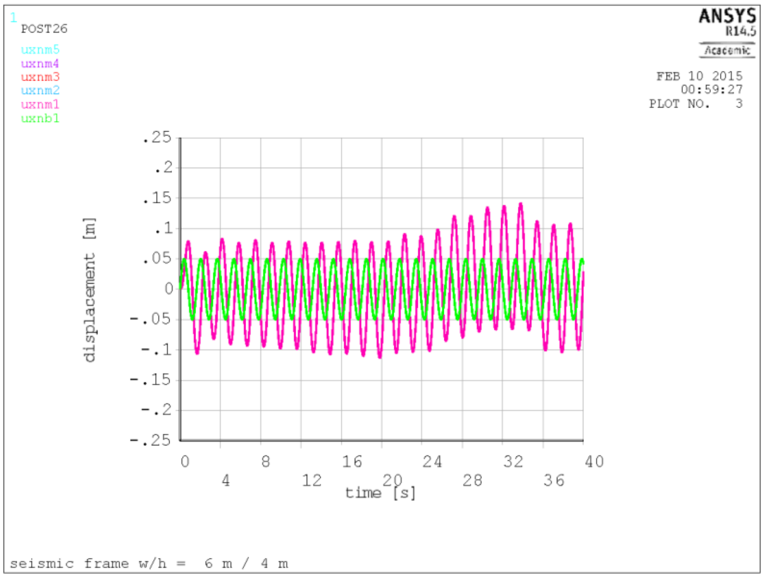
40 seconds with 1,635*0,980, EFAK = 5 and NINC = 200

max at 34,5 sec +150 mm



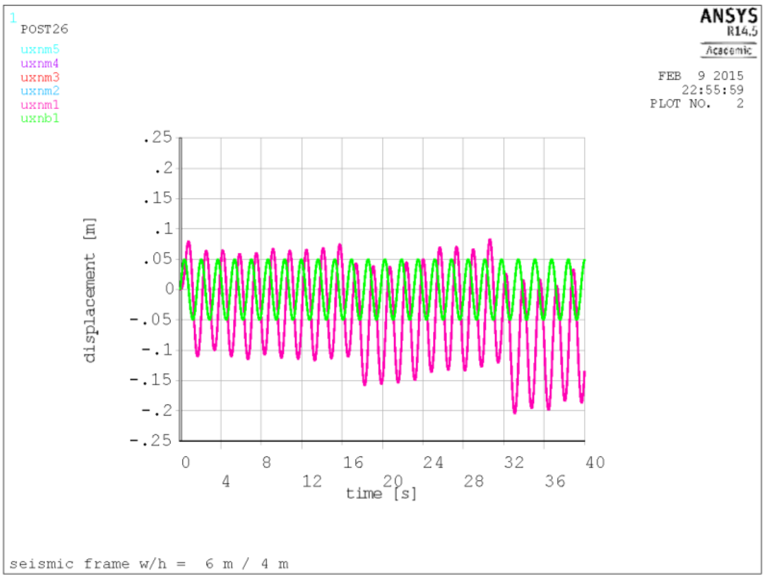
40 seconds with 1,635*0,950, EFAK = 5 and NINC = 200

max at 21,1 sec +132 mm



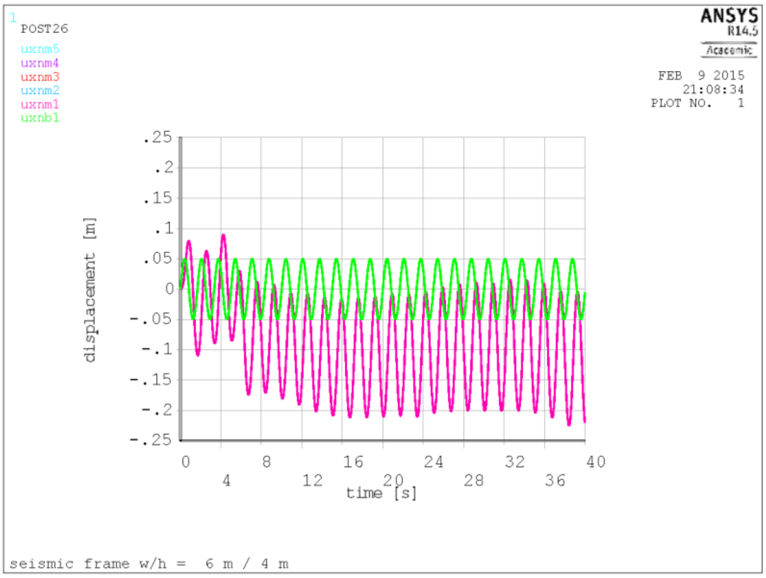
40 seconds with 1,635*1,005, EFAK = 5 and NINC = 200

max at 33,8 sec +142 mm



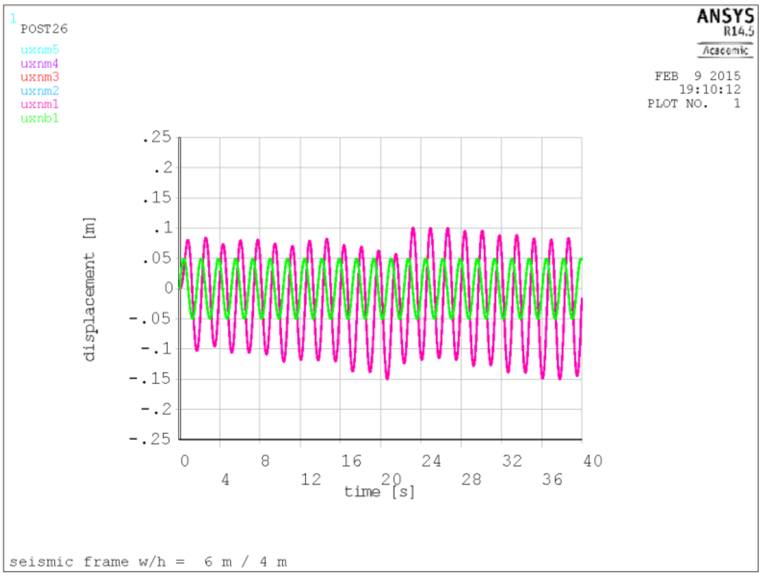
40 seconds with 1,635*1,010, EFAK = 5 and NINC = 200

max at 33,1 sec –204 mm



40 seconds with 1,635*1,020, EFAK = 5 and NINC = 200

max at 38,4 sec –225 mm



40 seconds with 1,635*1,050, EFAK = 5 and NINC = 200

max at 20,5 sec –150 mm

max at 36,1 sec –149 mm

max at 37,8 sec –150 mm

8 Open Questions

- What is a result?
  see Model 1 – plastic "1,635*1,003"
  is this going up forever?
  which is the steady state?

9 References

[1] Knoedel, P.: On the Dynamics of Steel Structures with X-Type Bracing. Stahlbau 80 (2011), No. 8, p. 566-571.

[2] Knoedel, P., Hrabowski, J.: Seismic Design in Plant Construction – Shortcomings of EC8. In: Dunai, L., Ivany, M., Jarmai, K., Kovacs, N., Vigh, L.G. (eds.): Proceedings Vol. B, p. 1083–1988, Eurosteel 2011, 6th European Conference on Steel and Composite Structures, Budapest, Hungary, 31.08.-02.09.2011.

[3] Knoedel, P., Hrabowski, J.: Yield Limit vs. Behaviour Factor in Seismic Design. Proceedings, NSCC 2012 Nordic Steel Construction Conference, 5-7 September 2012, Oslo, Norway, pp 147-155.

[4] Knoedel, P., Hrabowski, J., Ummenhofer, T.: Seismic behaviour factor in combined frame and braced structures. EuroSteel 2014, 7th EUROpean conference on STEEL and Composite Structures, Naples, Italy, 10-12 September 2014.