Plastic Frame –
Study on the Dynamic Behaviour of a Plastic Frame
under Seismic Loads

0. Contents

1. General

This plastic frame is an example for seismic paper to be presented at the EuroSteel 2011 in Budapest.

2. Properties

System: single storey, two column, pin ended frame

3 m height

5 m width

infinite beam stiffness

HEA 240 – S235

column
cross section class 1/1
M,el,y,Rd = 144 kNm

M,pl,y,Rd = 160 kNm

base shear per column at full plasticity: 160 kNm / 3 m = 53 kN

elastic limit storey drift:

F,el,d = 144 kNm / 3 m = 48 kN

w = 1/3 * 48 kN * $(3\ m)^3$ / (2,1*10^5 N/mm^2 * 7760 cm^4) = 26,5 mm

building total: 8 x 5 m length; 12 m width, concrete slab 16 cm, seismic traffic load 2 kN/m^2

area for frame 20 m * 12 m / 2 = 120 m^2

areal load: 4 kN/m^2 + 2 kN/m^2 = 6 kN/m^2

equivalent mass: 120 m^2 * 6 kN/m^2 * 100 kg/kN = 72.000 kgs

3. Seismic Excitation

4 assumed behaviour factor for DCH

1,5 assumed soil factor

1,6 m/s^2 assumed ground acceleration

S,d = 1,6 m/s^2 * 1,5 * 2,5 / 4 = 1,50 m/s^2 effective acceleration ‘by hand’

F,base = 72000 kgs * 1,50 m/s^2 = 108 kN < 2 * 53 kN = 106 kN

Drive for time-history analysis

a,dyn = 1,6 m/s^2 * 1,5 = 2,4 m/s^2

F,dyn = 72000 kgs * 2,40 m/s^2 = 173 kN

4. Seismic Design

Design according to DCL:

S,d = 1,6 m/s^2 * 1,5 * 2,5 / 1,5 = 4,0 m/s^2

F,base = 72000 kgs * 4,0 m/s^2 = 288 kN

Utilisation of the present frame:

η = 288 kN / (2 * 48 kN) = 3,0

Design according to DCH:

S,d = 1,6 m/s^2 * 1,5 * 2,5 / 4 = 1,5 m/s^2

F,base = 72000 kgs * 1,5 m/s^2 = 108 kN

Utilisation of the present frame:

η = 108 kN / (2 * 48 kN) = 1,13

5. System Response

Dataset plastic_frame_10-12-05

A spread sheet has been set up with the above data, with a stepwise incremental time-history calculation.

The vibration period of the system is given by

$T = 2 \pi \sqrt{(m/c)}$

T = 0,886 s

with

$c = 2 * 3 * E * I / L^3$

c = 3620 kN/m

due to two cantilever columns.

A drive has been set up as

$F(t) = F_{,dyn} * \sin(\Omega * t)$

where Ω has been chosen to correspond to the system's eigenfrequency

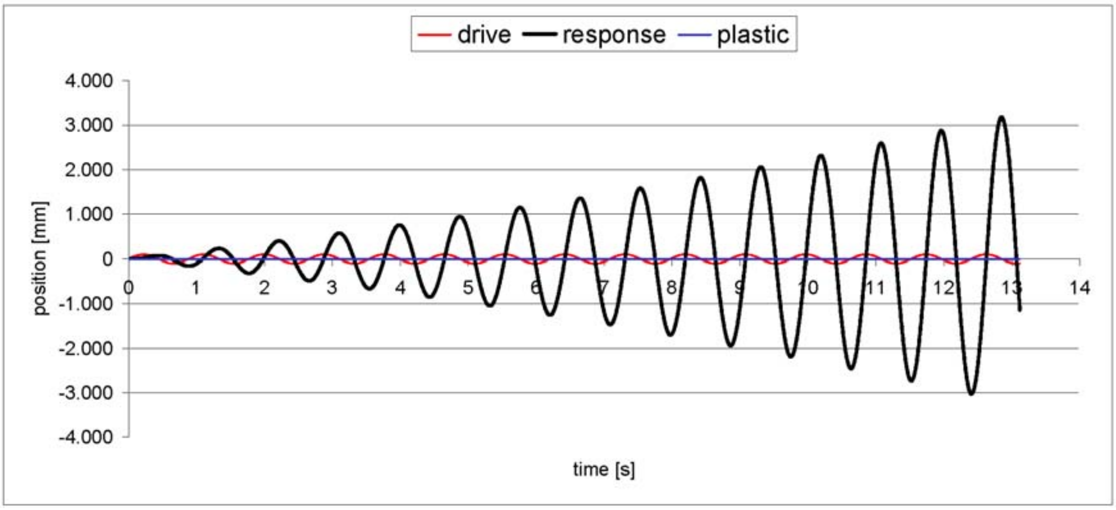
$\omega = \sqrt{(c/m)}$

ω = 7,092 rad/s

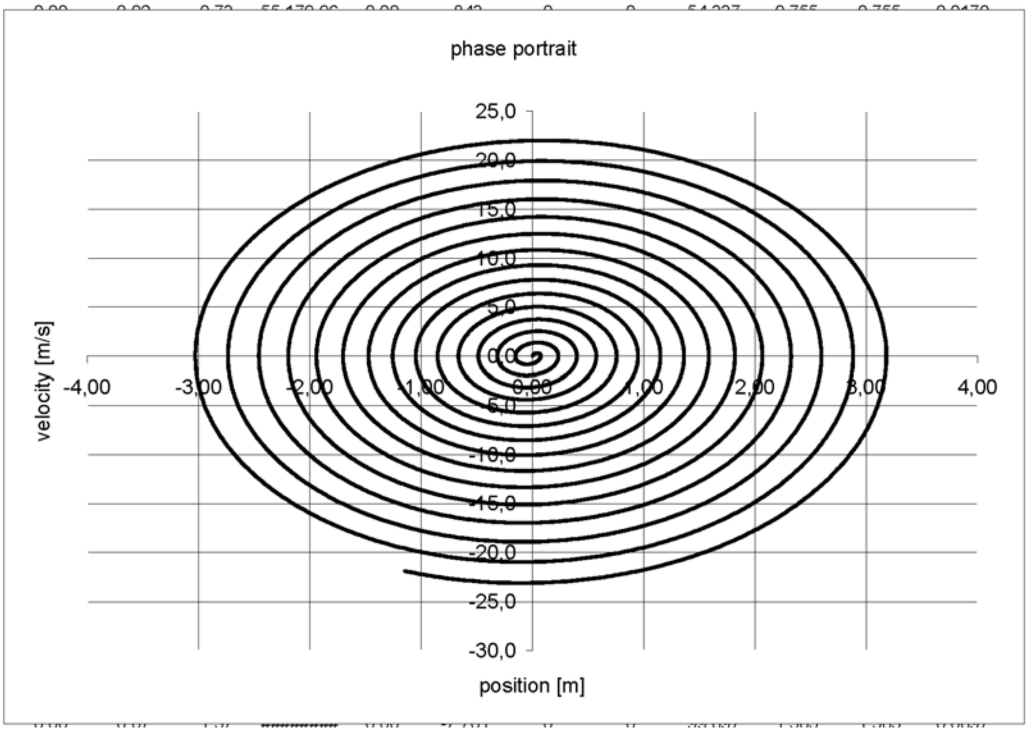
The static displacement due to F,dyn is

w,stat = 173 kN / 3620 kN/m = 48 mm

In a first test the plastic limit load has been set to infinity, so the system remains purely elastic. The system's response shows unlimited increase of displacements as should be expected with an undamped system.

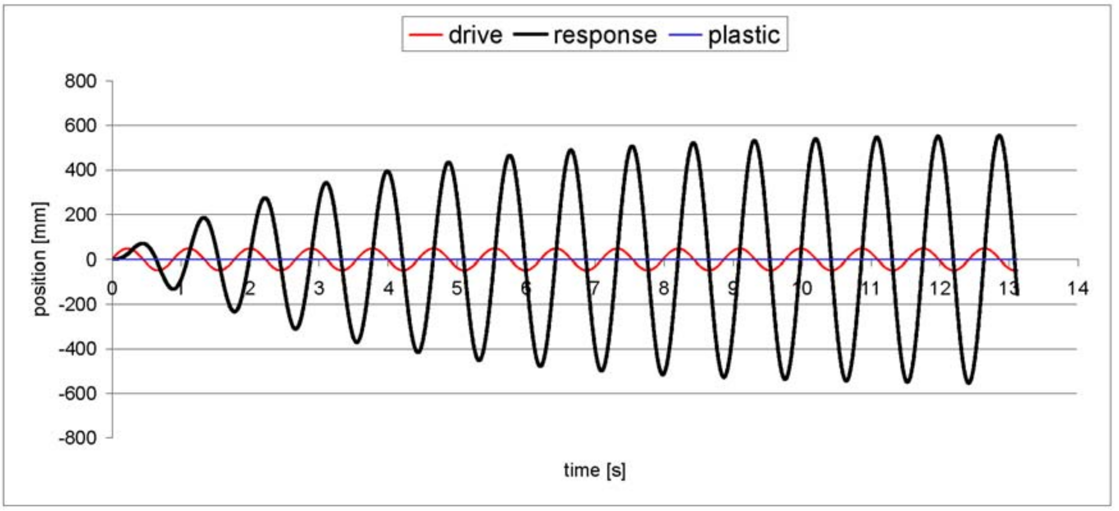


time-history plot of sway displacements, elastic system

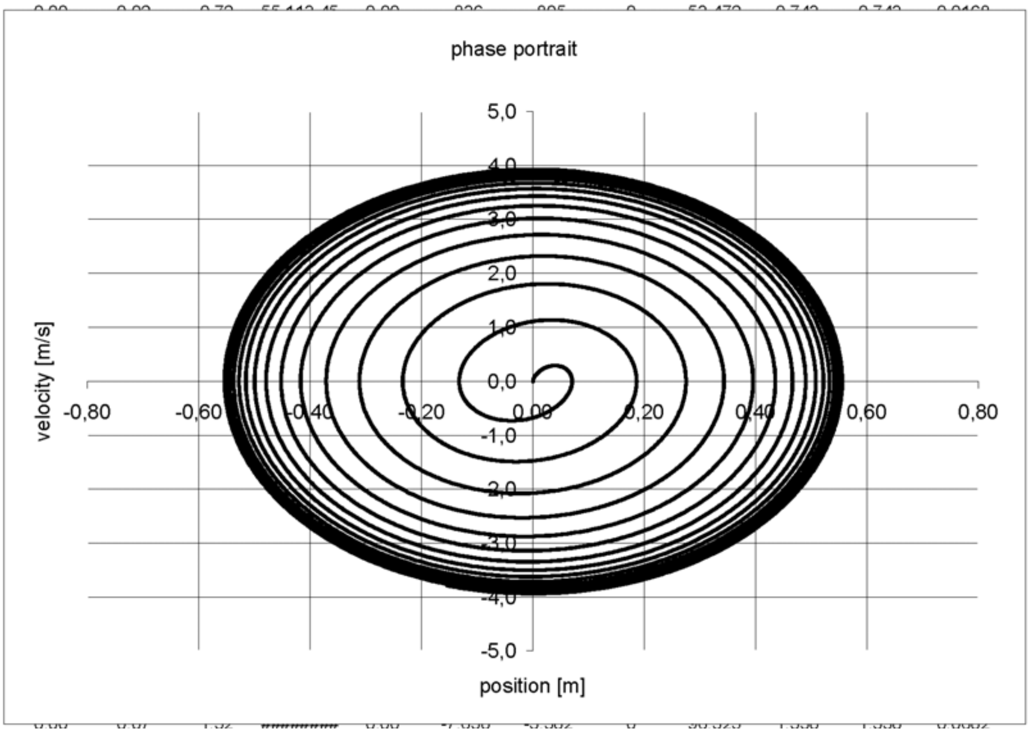


phase portrait of sway displacements, elastic system

In EC8 the system is assumed to be damped by $\zeta = 0{,}05$, which corresponds to a logarithmic decrement of $\delta = 0{,}05 * 2\pi = 0{,}314$. The maximum amplitude of the driven system should be $w_{,dyn} = w_{,stat} * \pi/\delta = w_{,stat} * 10$. According to the above numbers a dynamic amplitude of 480 mm should be expected. The actual maximum amplitude is 555 mm.

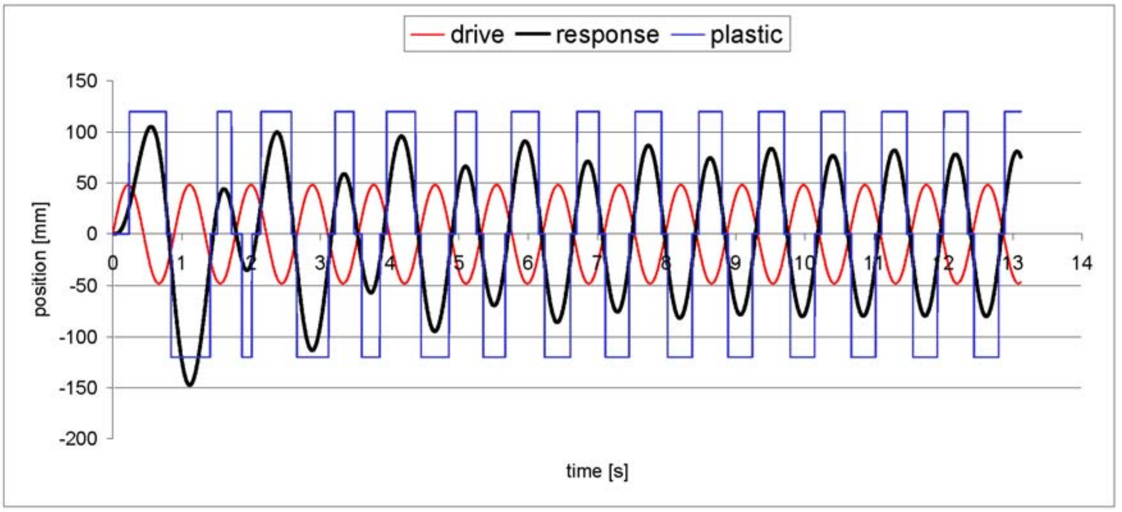


time-history plot of sway displacements, damped elastic system

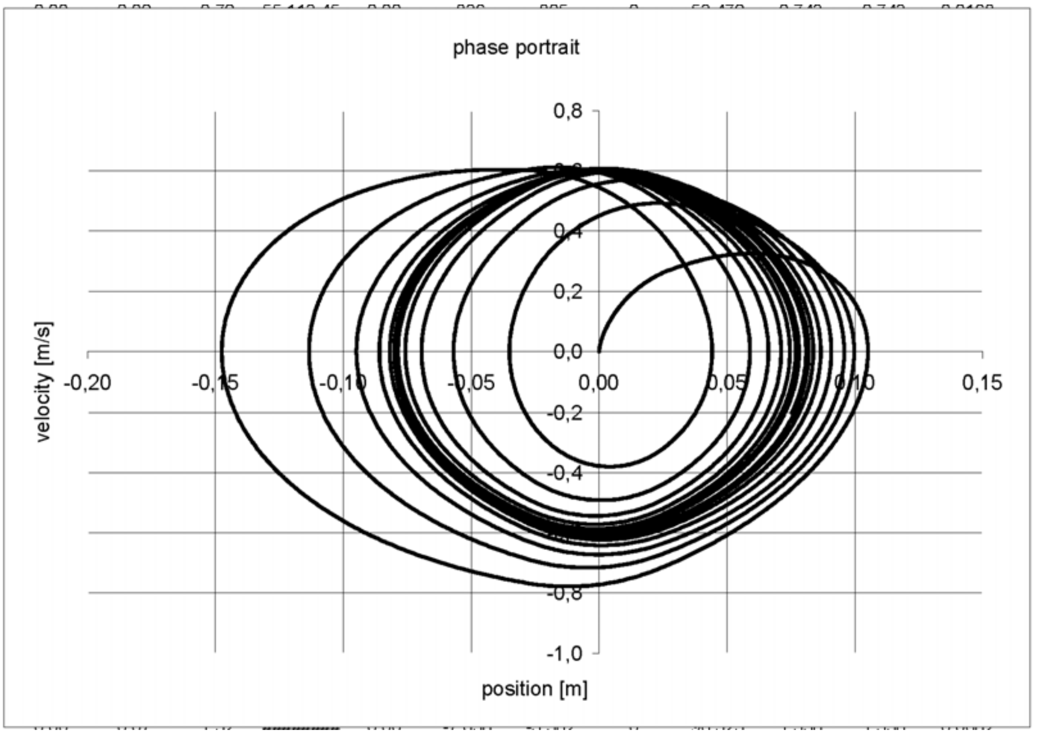


phase portrait of sway displacements, damped elastic system

With additional plastic hinges at the column-bar-joints the displacements of the plastic system are limited to some 80 mm, with a first peak reaching up to 150 mm. Due to the dissipation and a quasi-chaotic behaviour a phase-shift of 180° can be observed as soon as with the second negative amplitude.



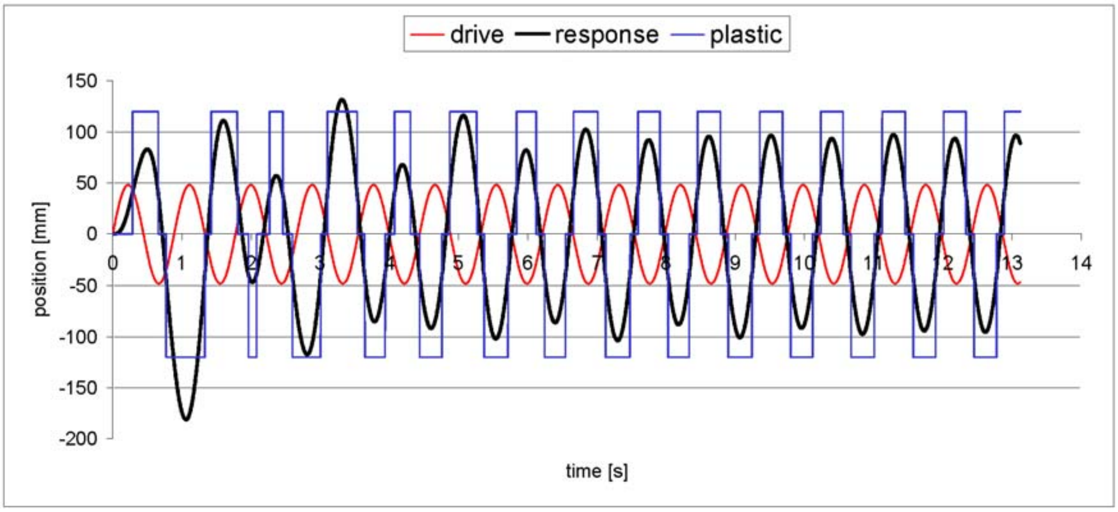
time-history plot of sway displacements, damped plastic system



phase portrait of sway displacements, damped plastic system

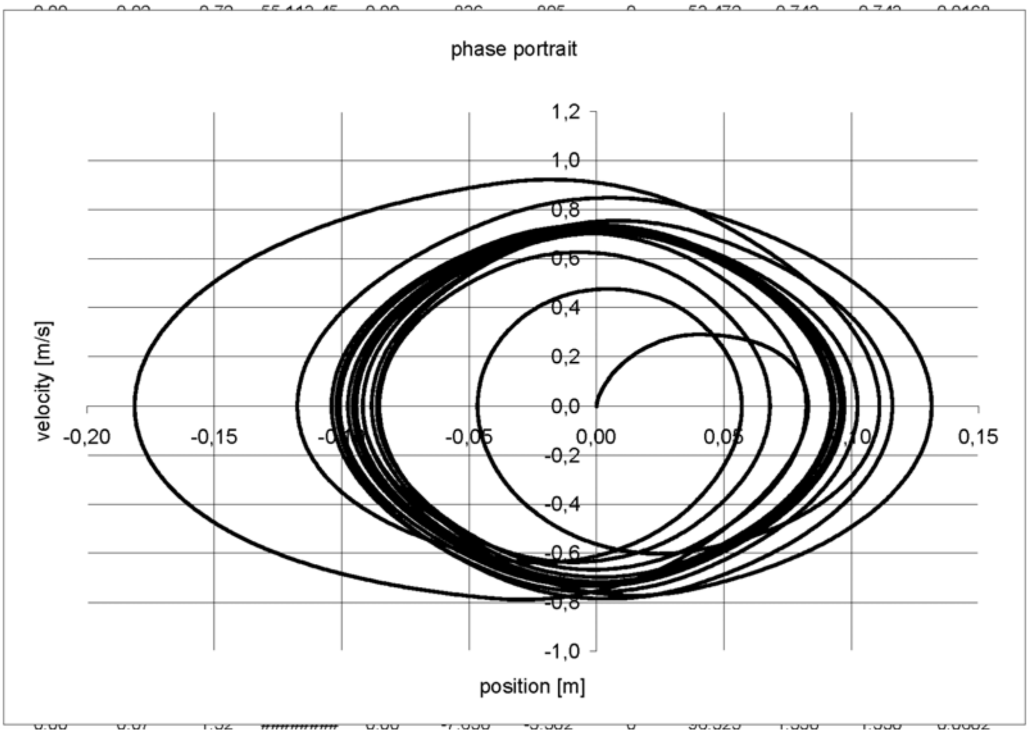
Vordersteig 52, D-76275 Ettlingen, GER
+49(0) 7243 – 32 40 913; Fax 76 54 16
Peterhofstr. 3 b, D-86438 Kissing, GER
+49(0) 8233 – 73 54 36 – 0; Fax – 3

Another system has been set up where the elastic limit load is increased by 50 %. This is to simulate different plastic response of bracing elements within the same structure. The displacements are slightly higher, as could have been expected.



time-history plot of sway displacements, damped plastic system

plastic limit load increased by 1,5



phase portrait of sway displacements, damped plastic system

plastic limit load increased by 1,5

System 1 elastic limit load 100 %		System 2 elastic limit load 150 %		System 2 – System 1	
[mm]	[ms]	[mm]	[ms]	[mm]	[ms]
+105,1	553	+83,1	499	–22,0	–54
–147,5	1110	–181,3	1058	–33,8	–52
+44,2	1607	+111,1	1598	+66,9	–9
–35,0	1939	–46,7	2019	–11,7	+80
+99,7	2371	+57,0	2364	–42,7	–7
–113,4	2879	–117,4	2810	–4,0	–69
+59,0	3340	+131,6	3313	72,6	–27
–56,9	3727	–85,2	3785	–28,3	+58

Comparing the peaks of the two systems with different elastic limit loads shows that the peaks are of different size and the occur not simultaneously.

The difference in the peak's height is in the order of half of the magnitude of the peaks themselves and these differences are coupled with different signs. Thus it might rather be sensible to regard both systems as completely different dynamic systems with completely different response (this could be proved by a cross-correlation check). Of course it should be expected, that those peaks would be more similar, if the difference of the elastic limit loads would be 10 % or 20 % only.

It should be expected, that due to a loss of stiffness due to plastic behaviour the vibration period should prolong and the eigenfrequency should become lower. However, the time-history plots show that the systems' responses remain perfectly synchronised to the drive. This may be due to the fact that the driving frequency is kept synchronised to the natural frequency of the elastic system.

In a more thorough investigation the drive should be adjusted stepwise to lower eigenfrequencies, in order to check, whether the system is sensible to a slower drive.