EU-Russia Regulatory Dialogue: Construction Sector Subgroup

Seminar ' Bridge Design with Eurocodes'

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European Committee for Standardization
TC250 Structural Eurocodes

Seismic design of bridges

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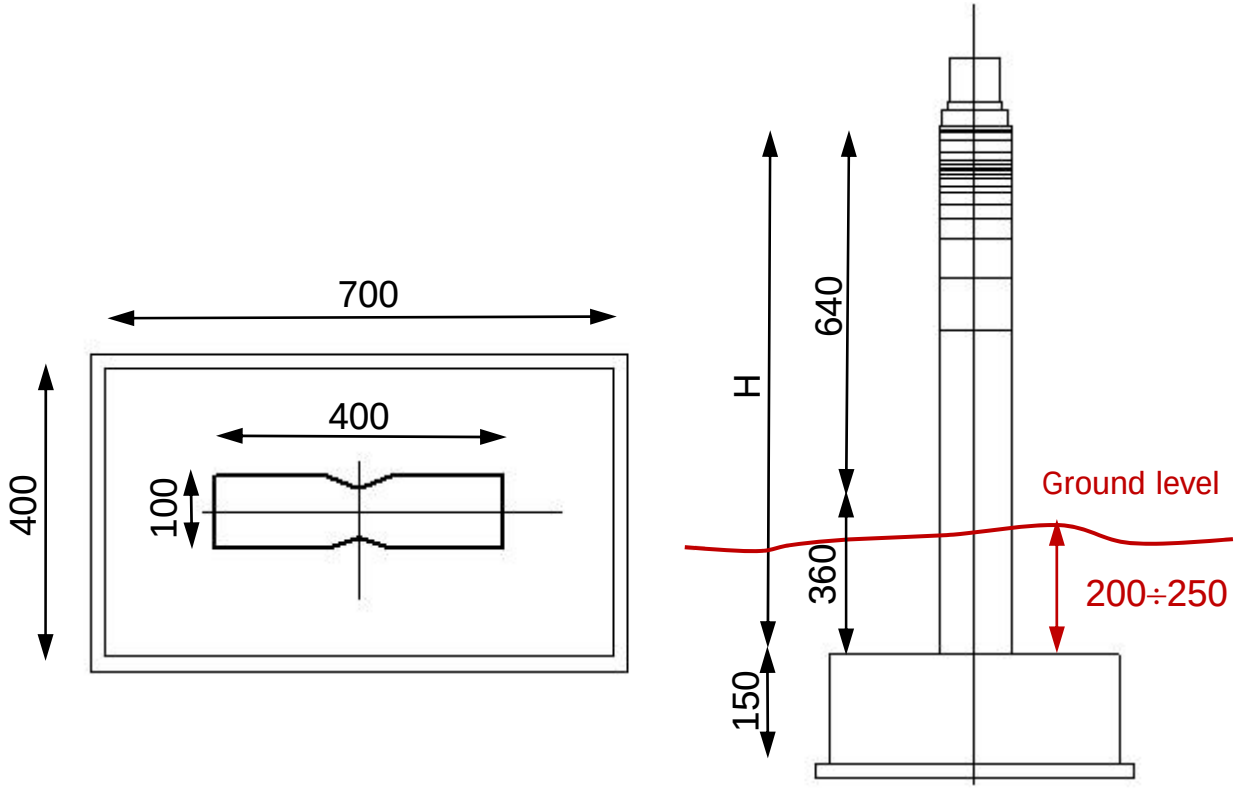
SEISMIC DESIGN OF BRIDGES

Taller piers work better:

Pinerolo bridge

Pier



The height of the pier has been enhanced to 10 m by placing the extrados of the foundation more than 2 m below the ground level. In such a way we get :

- longitudinal direction

  $H/L_X=10/1=10.0>3.5$ $q_x=3.5$

- transverse direction:

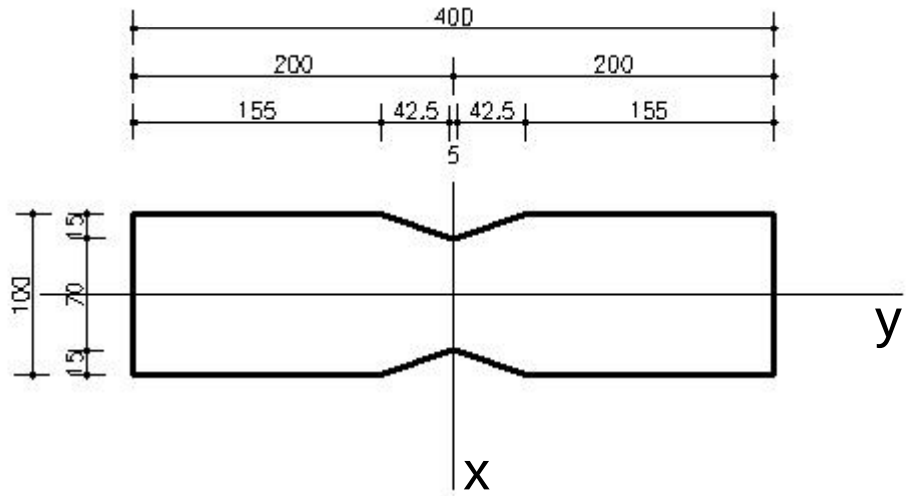
  $H/L_X=10.0/4.0=2.5$ $q_y=2.5$

Pier base section

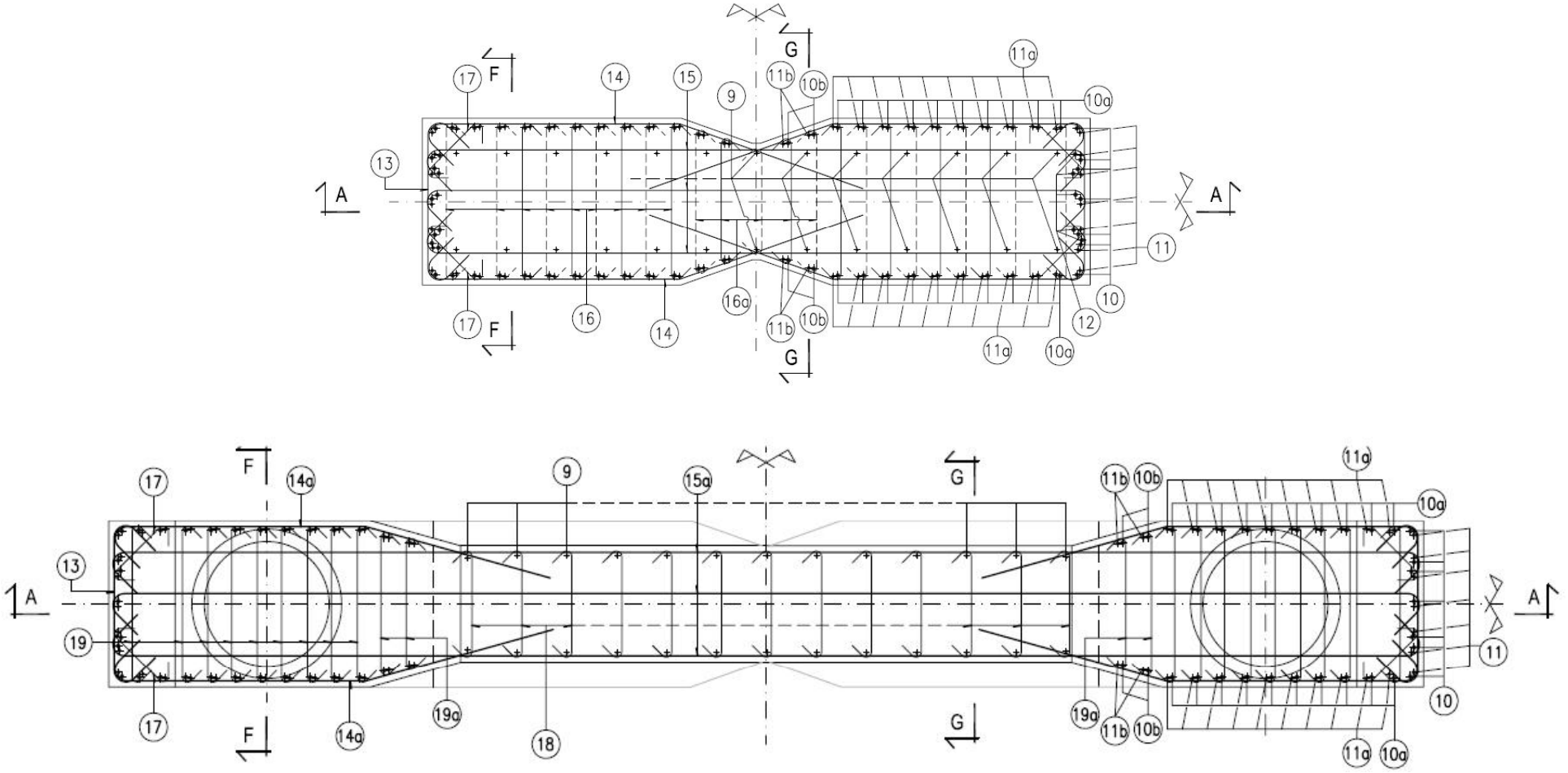
$A=3.858\ m^2$ $u=10.1\ m$

$J_x=5.329\ m^4$ $i_x=1.2\ m$

$J_y=0.305\ m^4$ $i_y=0.3\ m$



Pier reinforcement: base and top sections



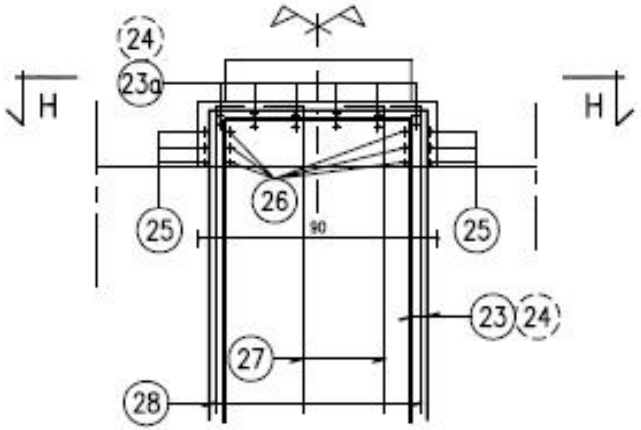
Pos	Ø (mm)	Shape	L (cm)	N°	W (Kg)
9	16 / 30	1140, 20	1160	13 + 13	476
10	20 / 15	524, Ri=706, 27, 605	1156	7 + 7	399.1
10a	20 / 15	560, Ri=760, 27, 605	1192	(10+10) x 2	1175.9
10b	20 / 15	568, Ri=875, 27, 605	1200	(2+2) x 2	236.8
11	26 / 15	524, Ri=706, 36, 605	1165	7 + 7	679.8
11a	26 / 15	559, Ri=760, 36, 605	1200	(10+10) x 2	2000.5
11b	26 / 15	559, Ri=875, 36, 605	1200	(2+2) x 2	400.1

Pos	Ø (mm)	Shape	L (cm)	N°	W (Kg)
12	26	135, Ri=706, 36, 605	776	5 + 5	323.4
13	20 / 15	27, 45°, 93, 27	147	60 + 60	435
14	20 / 15	150, 116, 27, 45°, 160°	293	(24+24) x 2	693.7
14a	20 / 15	150, 116, 27, 45°, 164°	293	(33+33) x 2	953.8
15	20 / 15	393, 27, 45°, 27	447	24 x 3	793.7
15a	20 / 15	393÷783, 27, 45°, 27	447 ÷ 837	33 x 3	1567.4
16	16 / 30x15	20, 45°, 93, 20, sfalsati	133	124 x 2	520.6
16a	16 / 30x15	20, 45°, 86÷63, 20, sfalsati	126 ÷ 103	60	108.4
17	16 / 30x15	40, 20, 45°, 20	80	60 x 4	303

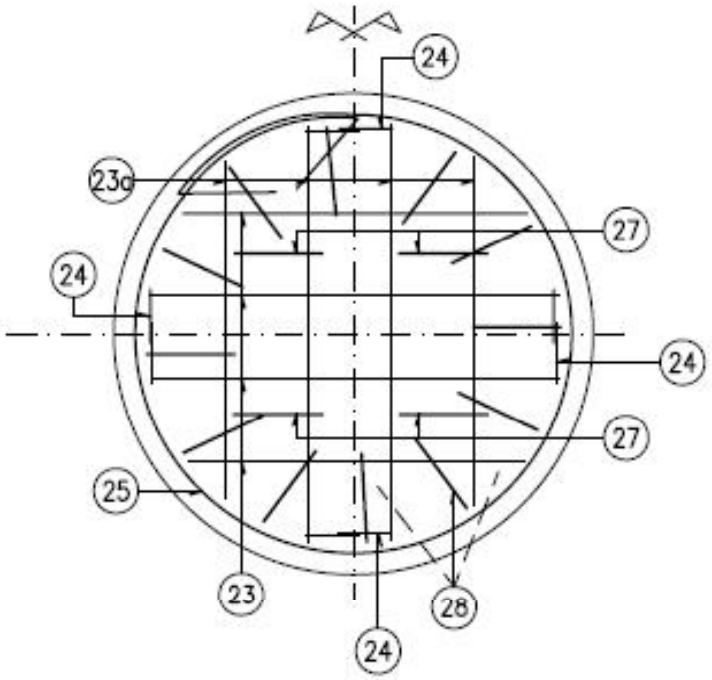
Pier reinforcement: base and top sections

Reinforcement under bearings

section

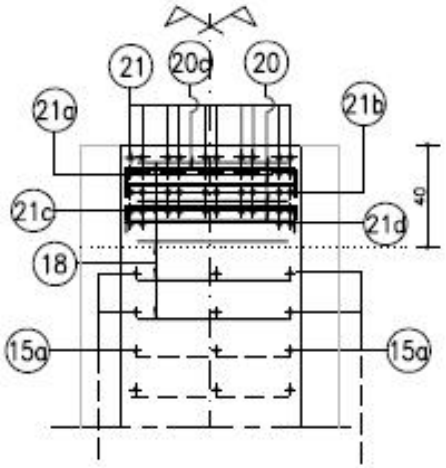


Top view

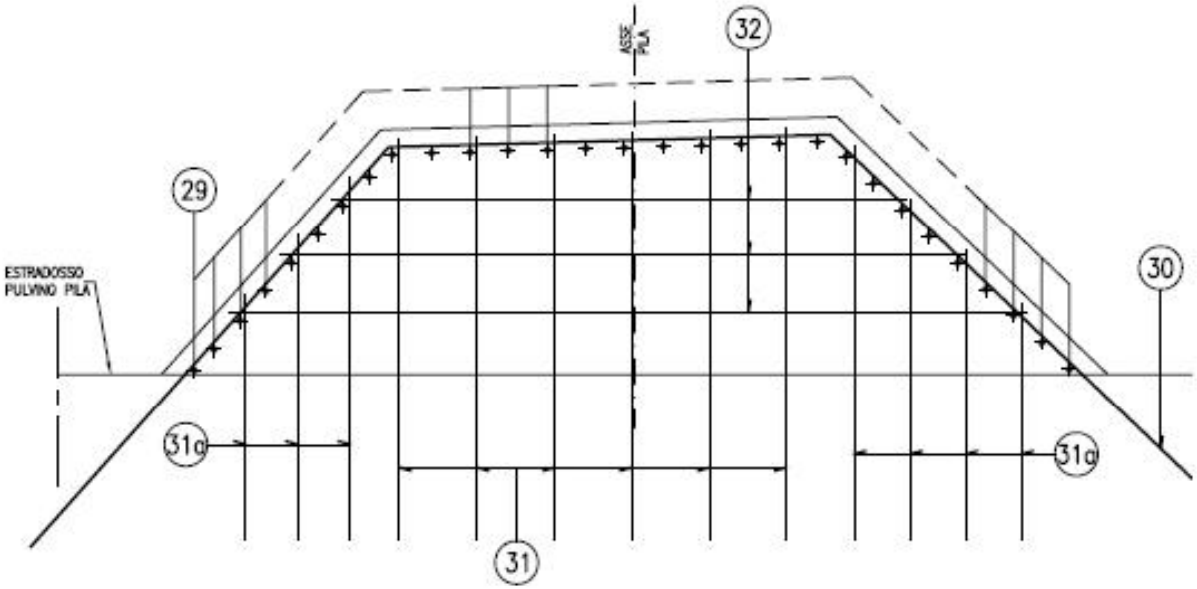


Reinforcement of seismic end of strokes

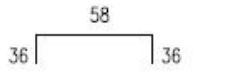
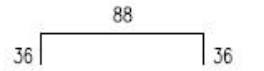
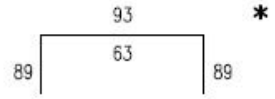
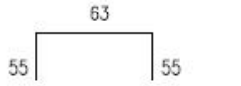
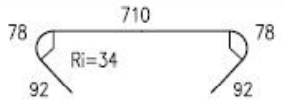
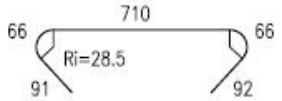
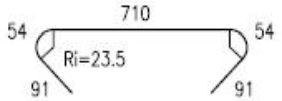
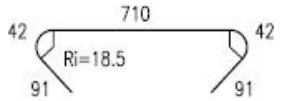
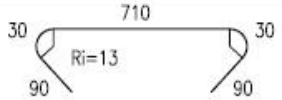
section

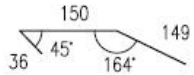
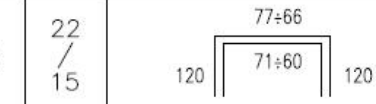
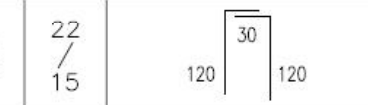
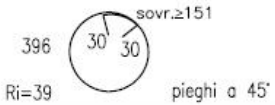
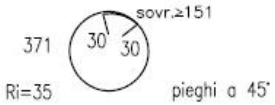
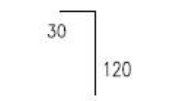
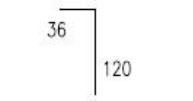


Front view

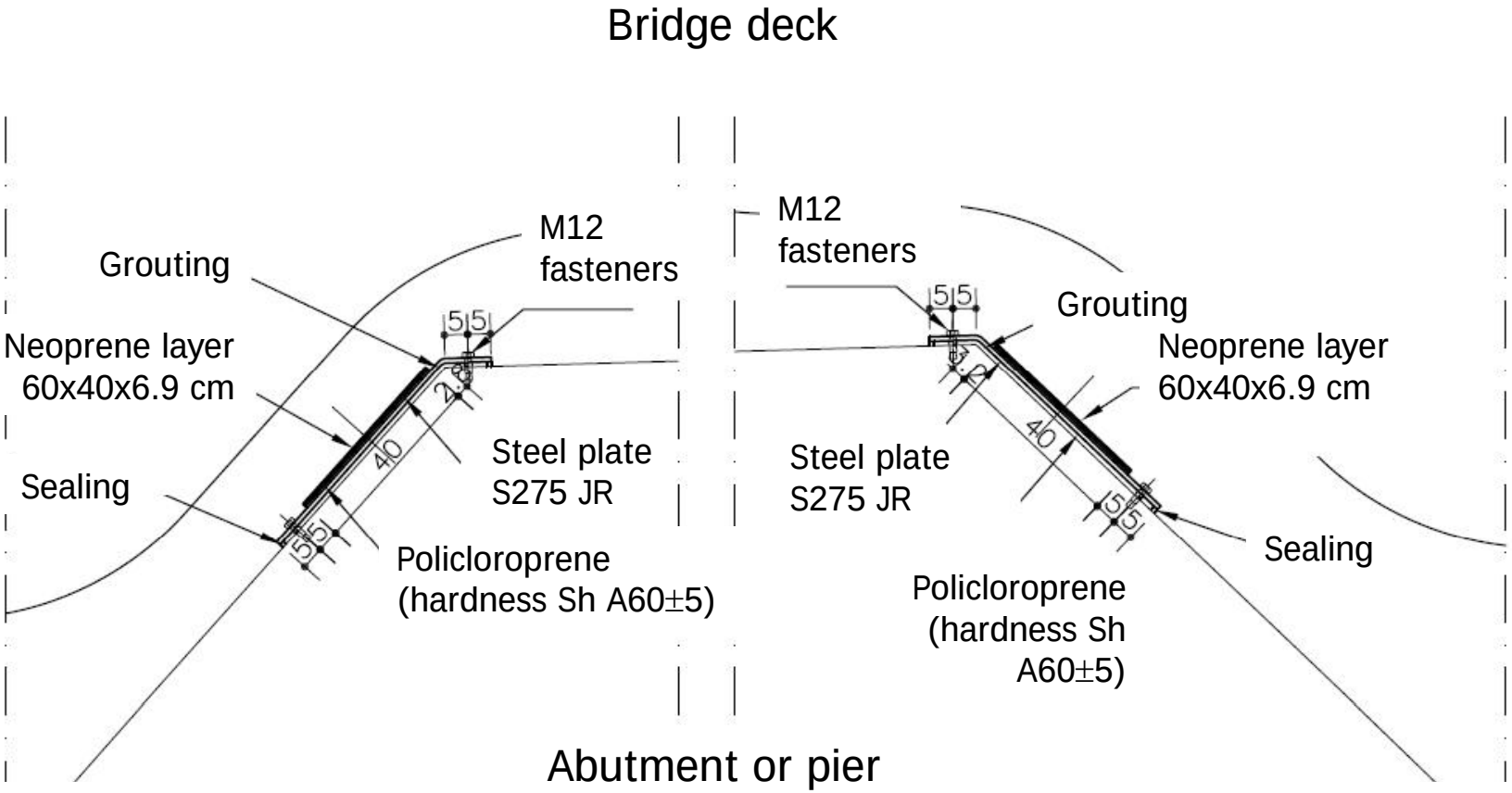


Reinforcement table

20	26 / 100		130	16	86.7
20a	26 / 30		160	(2x4) x 2	106.7
20b	26 / 15		271 241	9x2 3x2	263.6
20c	16 / 30		173	13	35.5
21	26		1050	10	437.6
21a	26		1025	10	427.2
21b	26		1000	10	416.8
21c	26		976	10	406.8
21d	26		950	2 + 2	158.4

22	26 / 15		335	(3+3) x 2	167.5
23	22 / 15		(317÷306) + (311÷300)	4 x 2	147.3
23a	22 / 15		(317÷306) + (311÷300)	4 x 2	147.3
24	22 / 15		150 + 150	4 x 2	71.6
25	22		426	3 x 2	76.3
26	22		431	3 x 2	77.2
27	22		150	4 x 2	35.8
28	26 / 20		156	12 x 2	156

Seismic end of stroke (on piers and abutments)



Reinforcement cage of the pier

Detail of reinforcement cage at the foot of the pier

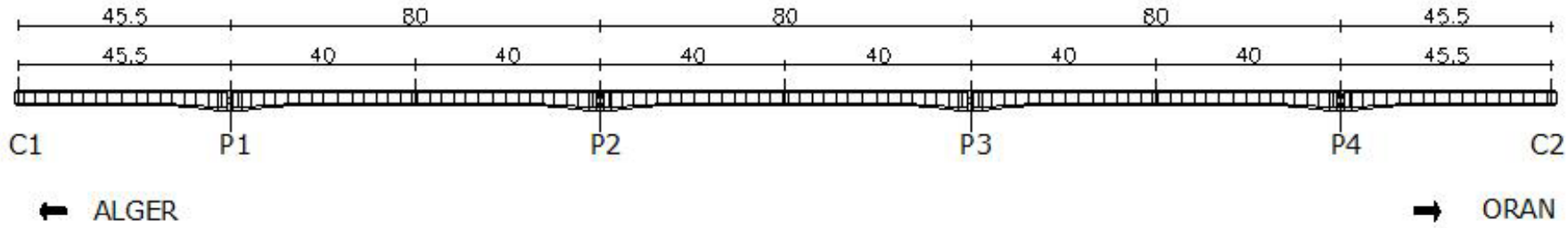
SEISMIC DESIGN OF BRIDGES

Hysteretic damping bearings application:

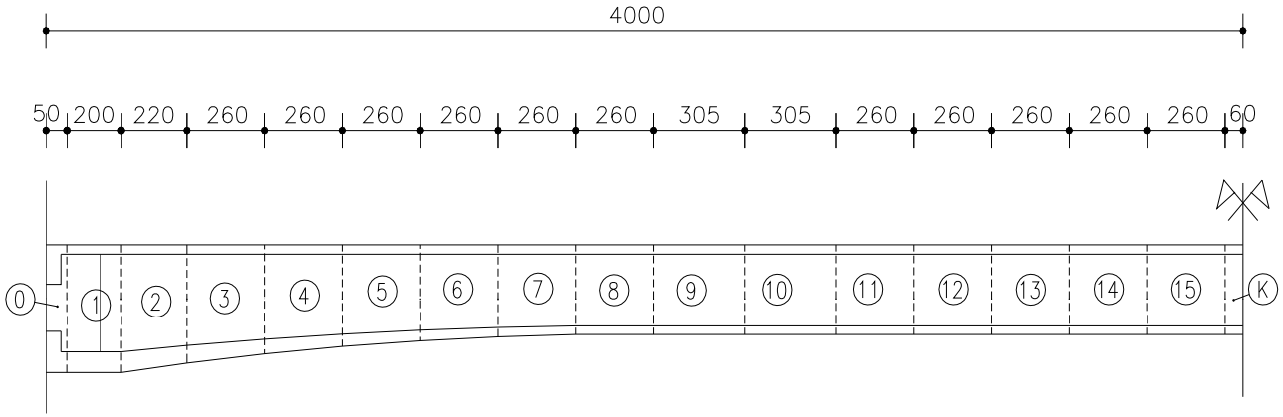
Highway in Algeria

General dimensions

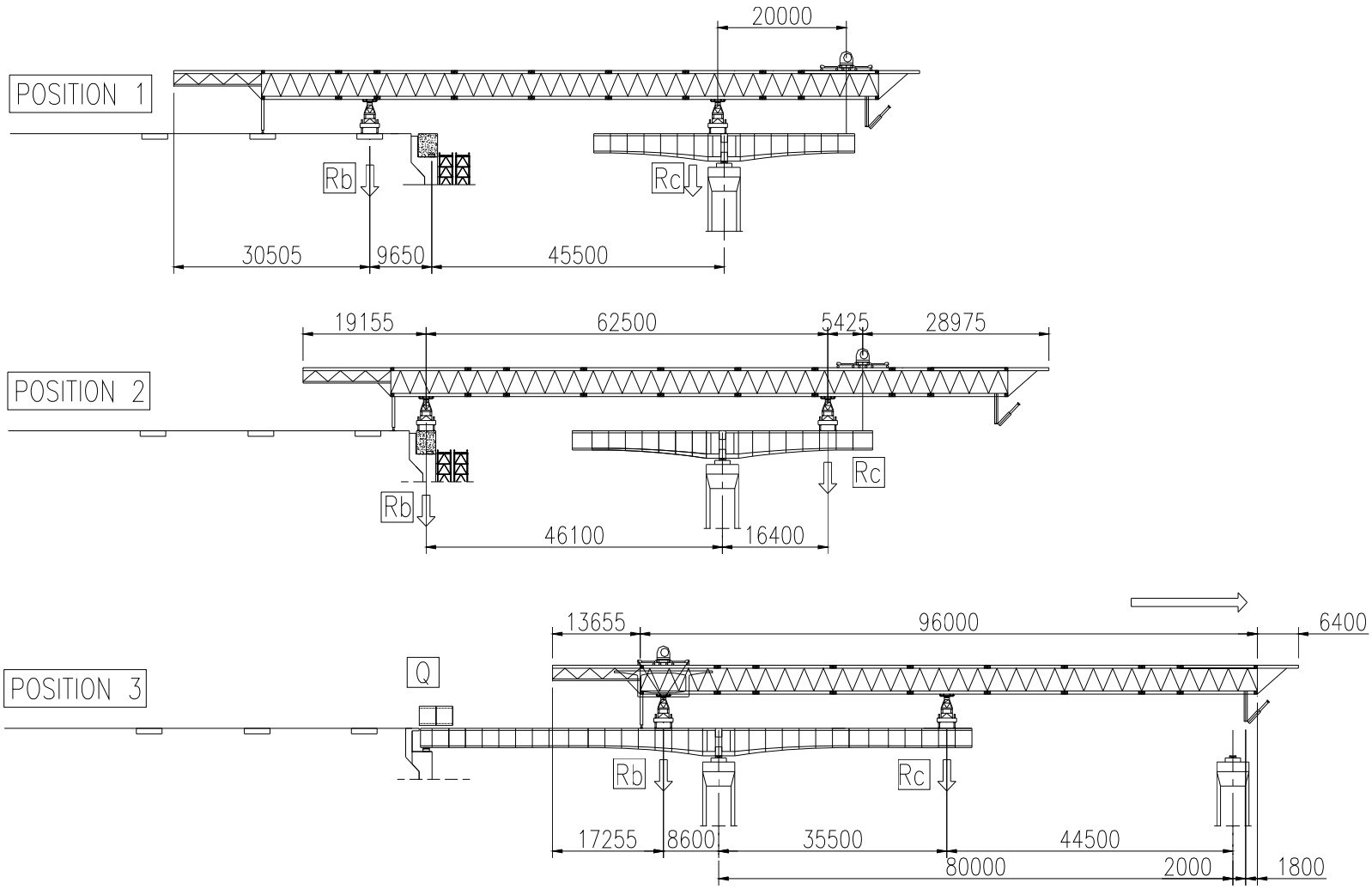
Carriageway in direction of Oran



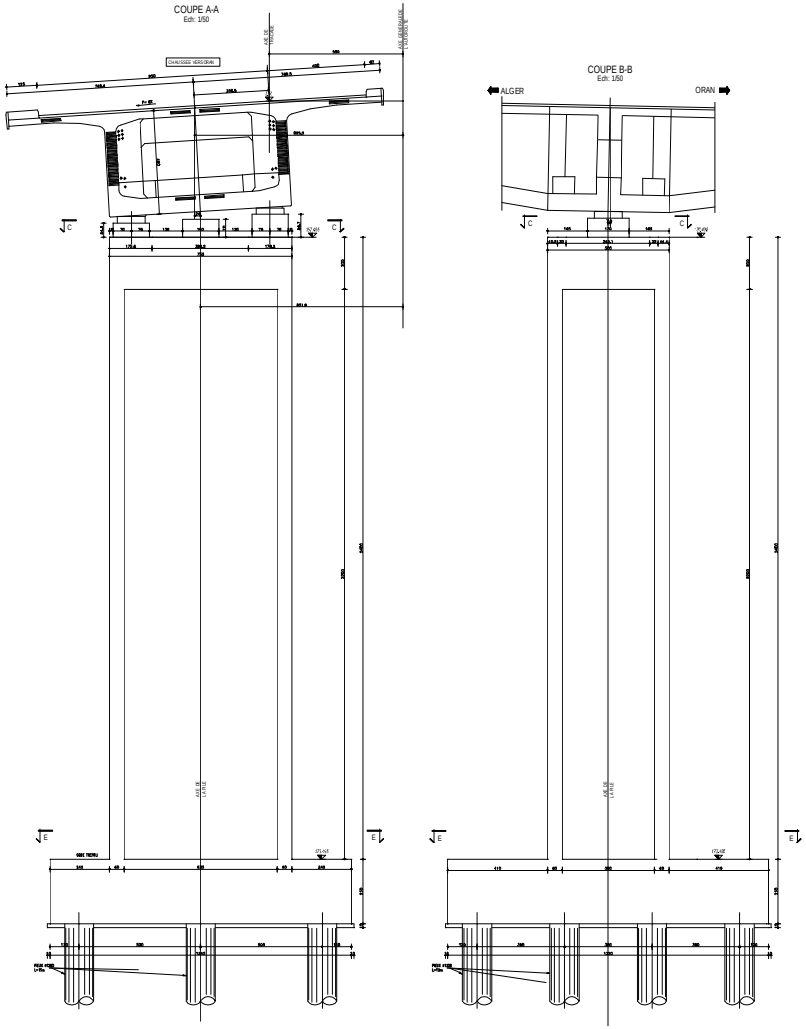
Segments for each half hammer



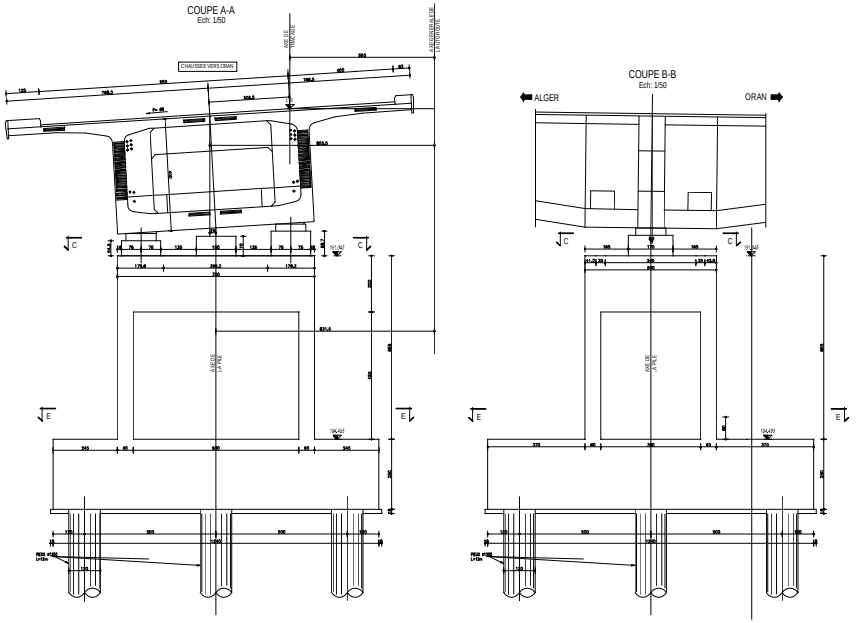
Construction by launching girder



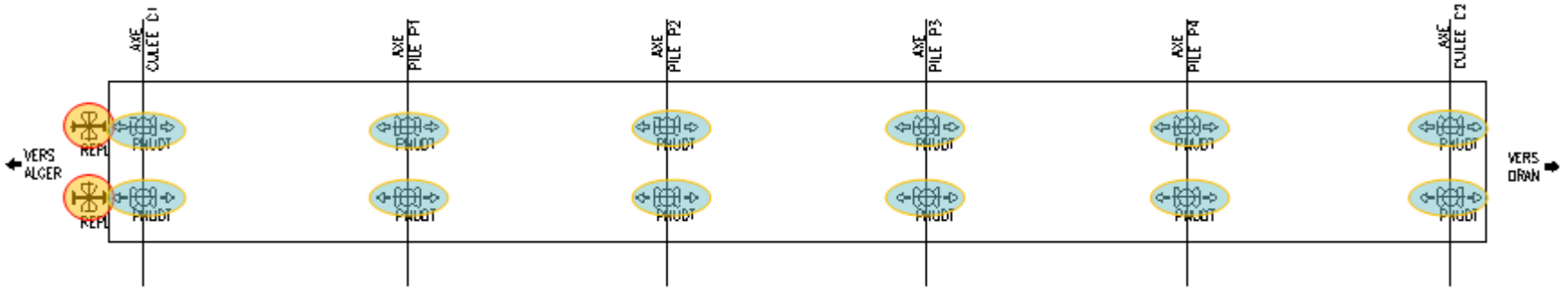
Tallest pier ~ 24 m



Shortest pier ~ 6.5 m

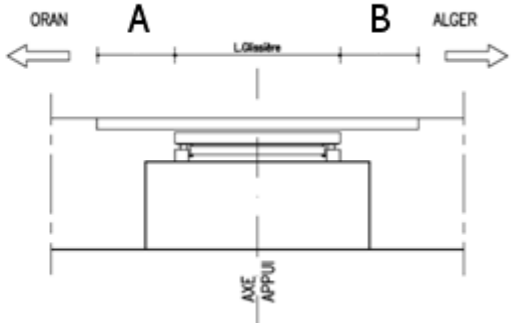


Hysteretic damping bearings scheme



Longitudinal damper

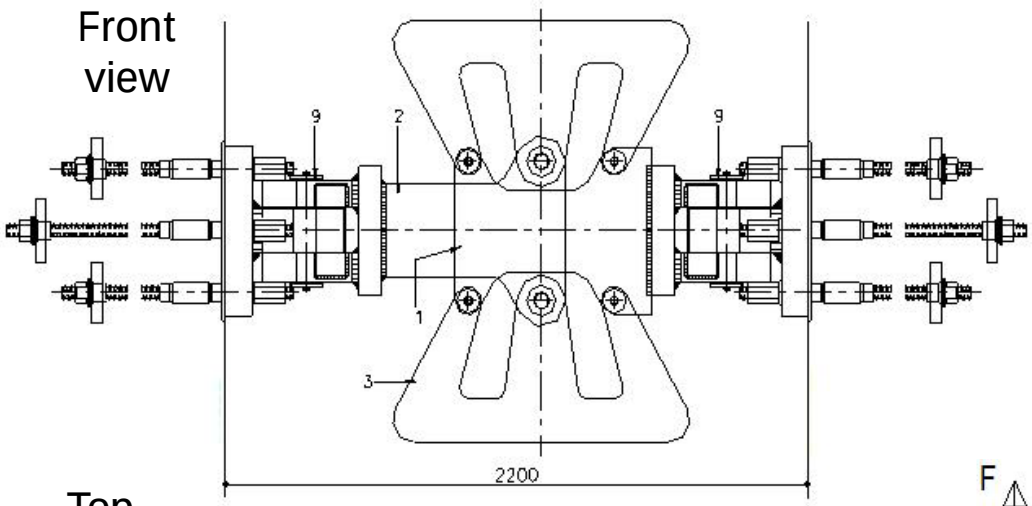
Transverse damper



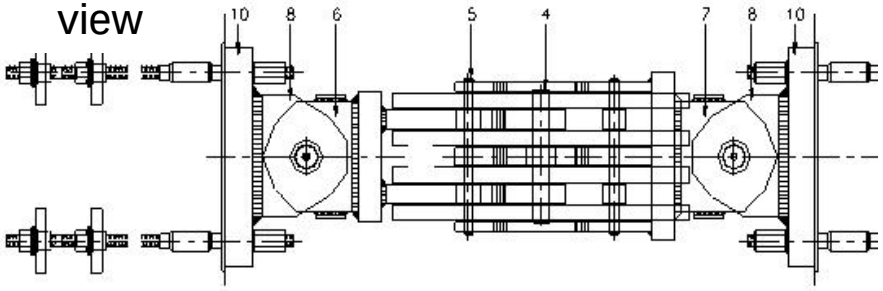
	Position	Rz [kN]	Rz [kN]	fy [kN]	fu = 1.15 fy [kN]	Long. sledge A [mm]	Long. sledge B [mm]	Trans. sledge C [mm]	inclination Transv. [%]	inclination Long. [%]
Type 1	P1	16700	17350	1150.00	1322.50	240	255	± 150	-6.00%	-1.98%
	P2	18400	18900	1150.00	1322.50	200	180	± 150	-6.00%	-3.05%
	P3	18400	18900	1150.00	1322.50	245	175	± 150	-6.00%	-3.05%
	P4	16700	17350	1150.00	1322.50	285	190	± 150	-6.00%	-1.27%
Type 2	C1	4700	5250	500.00	575.00	185	195	± 150	-4.63%	-1.29%
	C2	4700	5250	500.00	575.00	315	190	± 150	-6.00%	0.08%
Type 3	C1	-	-	4500.00	5175.00	150	150	± 150	-	-
Type 4	C2	-	2500	-	-	315	190	± 150	-	-
	C1	-	5000	-	-	150	150	± 150	-	-

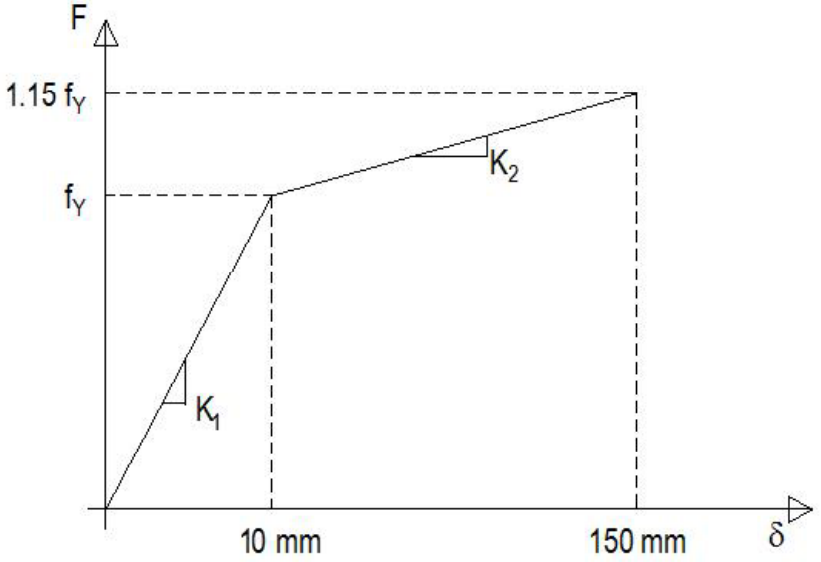
Longitudinal damper

Front view



Top view

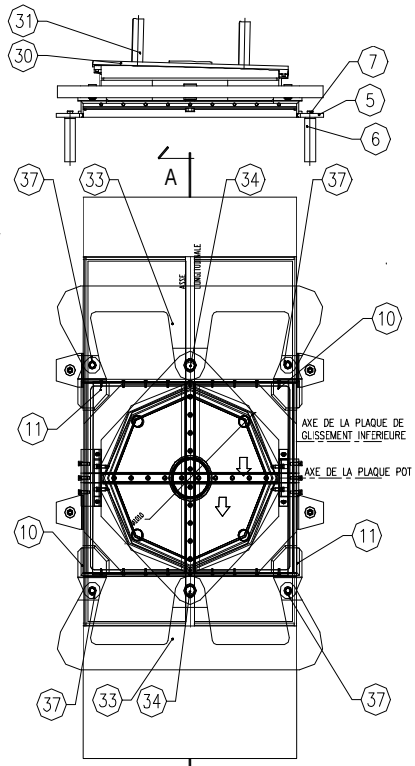




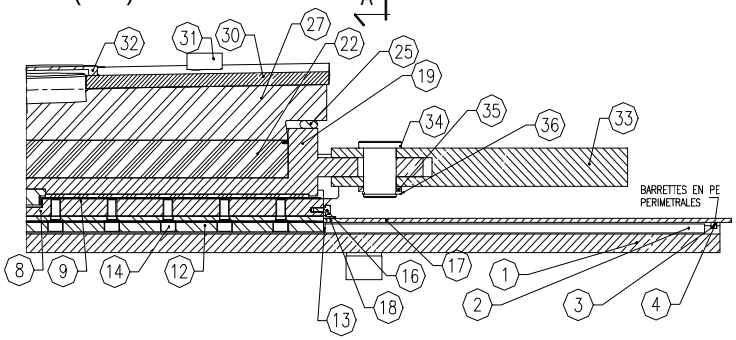
Transverse damper

Front view

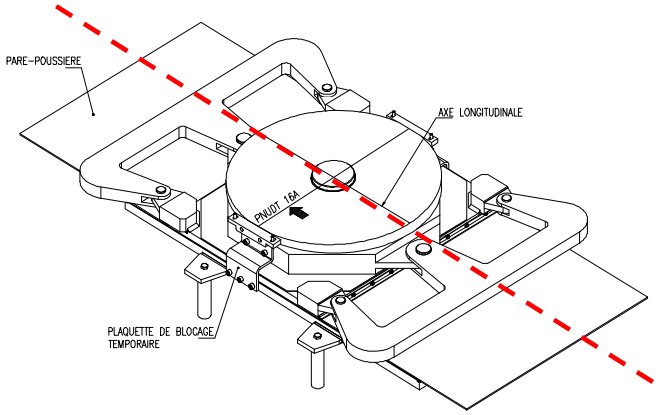
Top view



A-A (1 : 3)

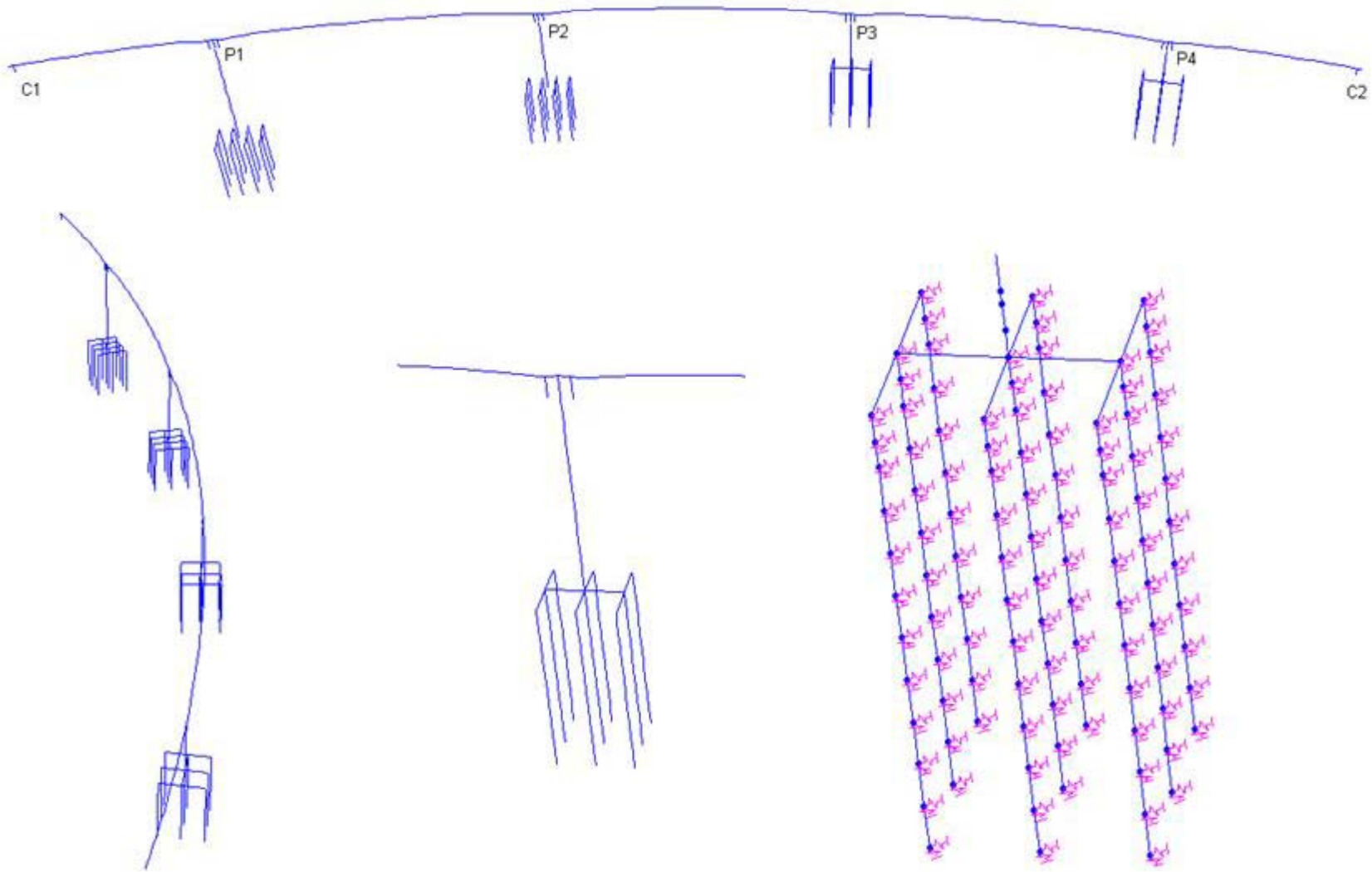


Assonometric view

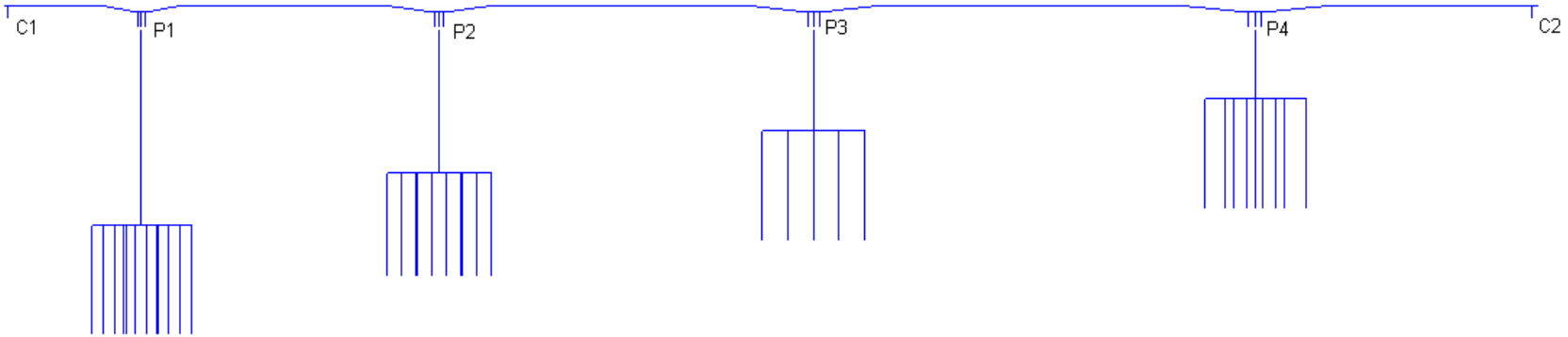


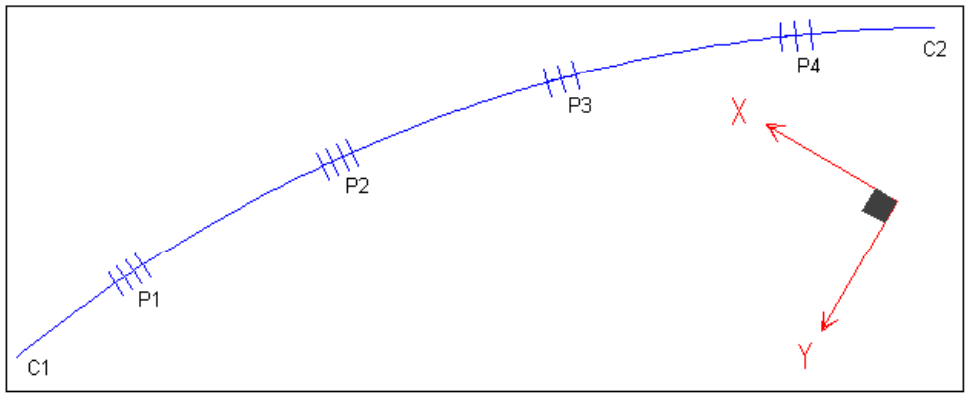
Longitudinal axis of the bridge

Finite element model – non linear analysis



Finite element model – non linear analysis

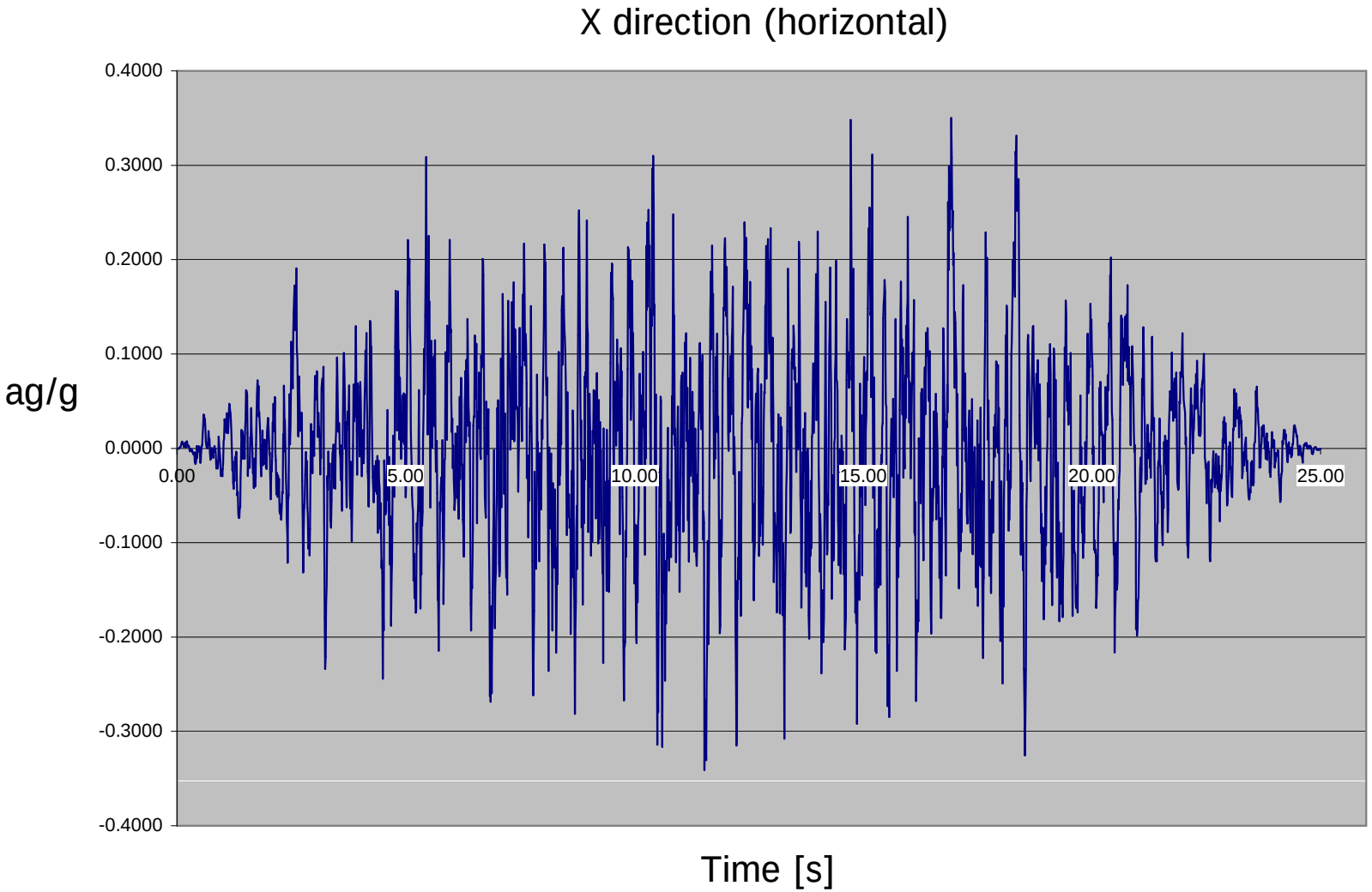




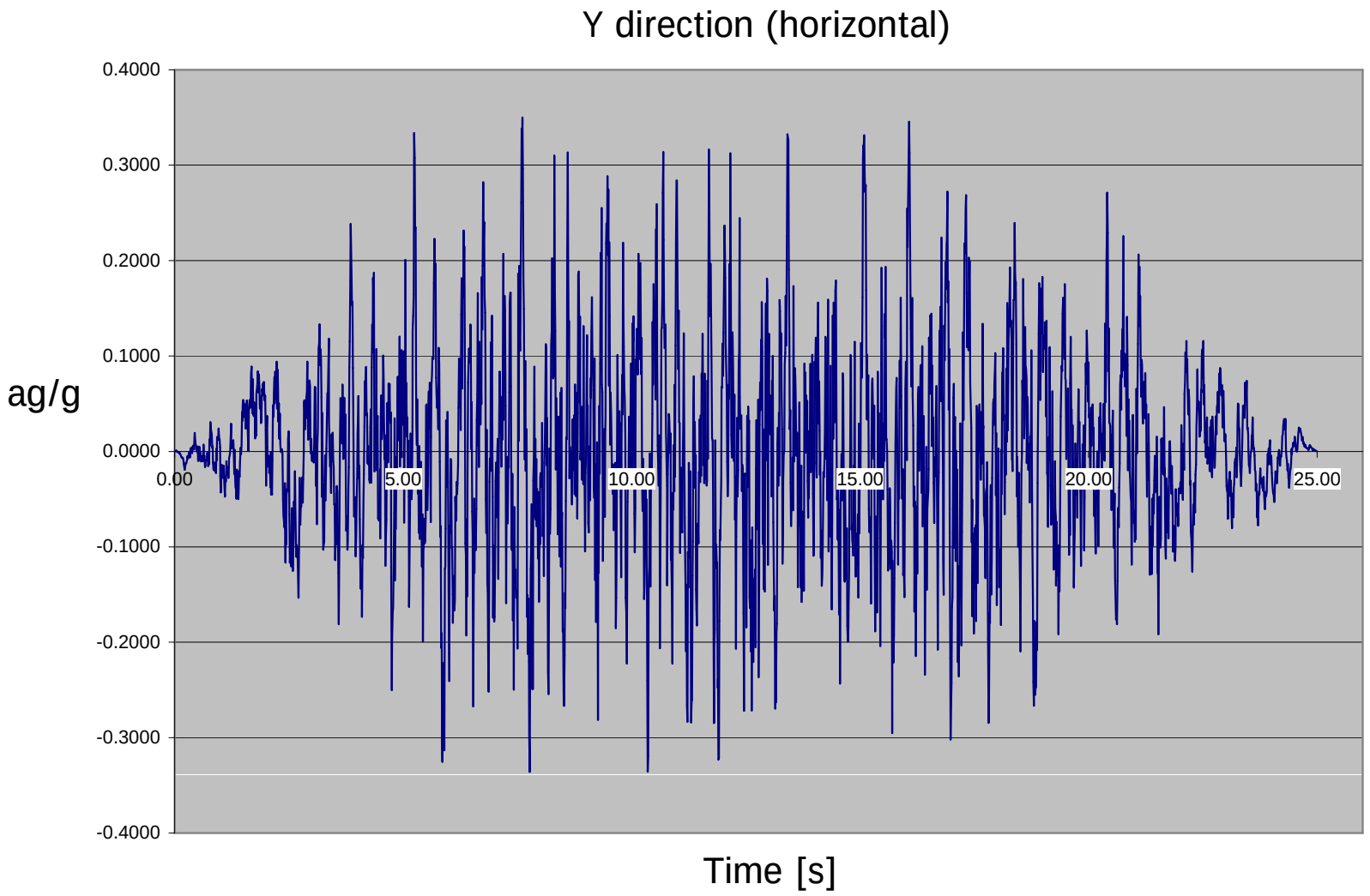
X axis = East – West direction

Y axis = North – South direction

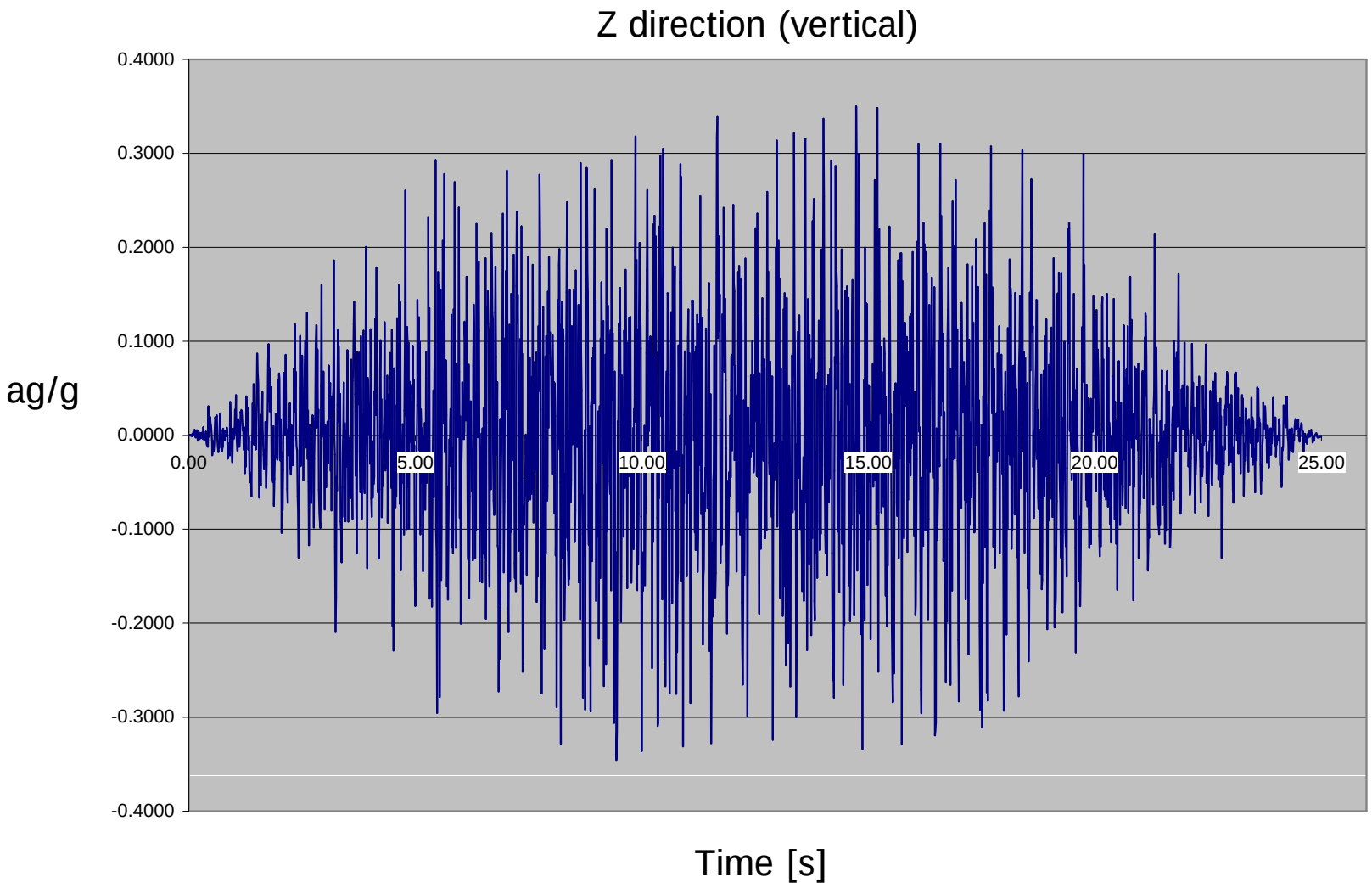
1st Accelerograms



1st Accelerograms

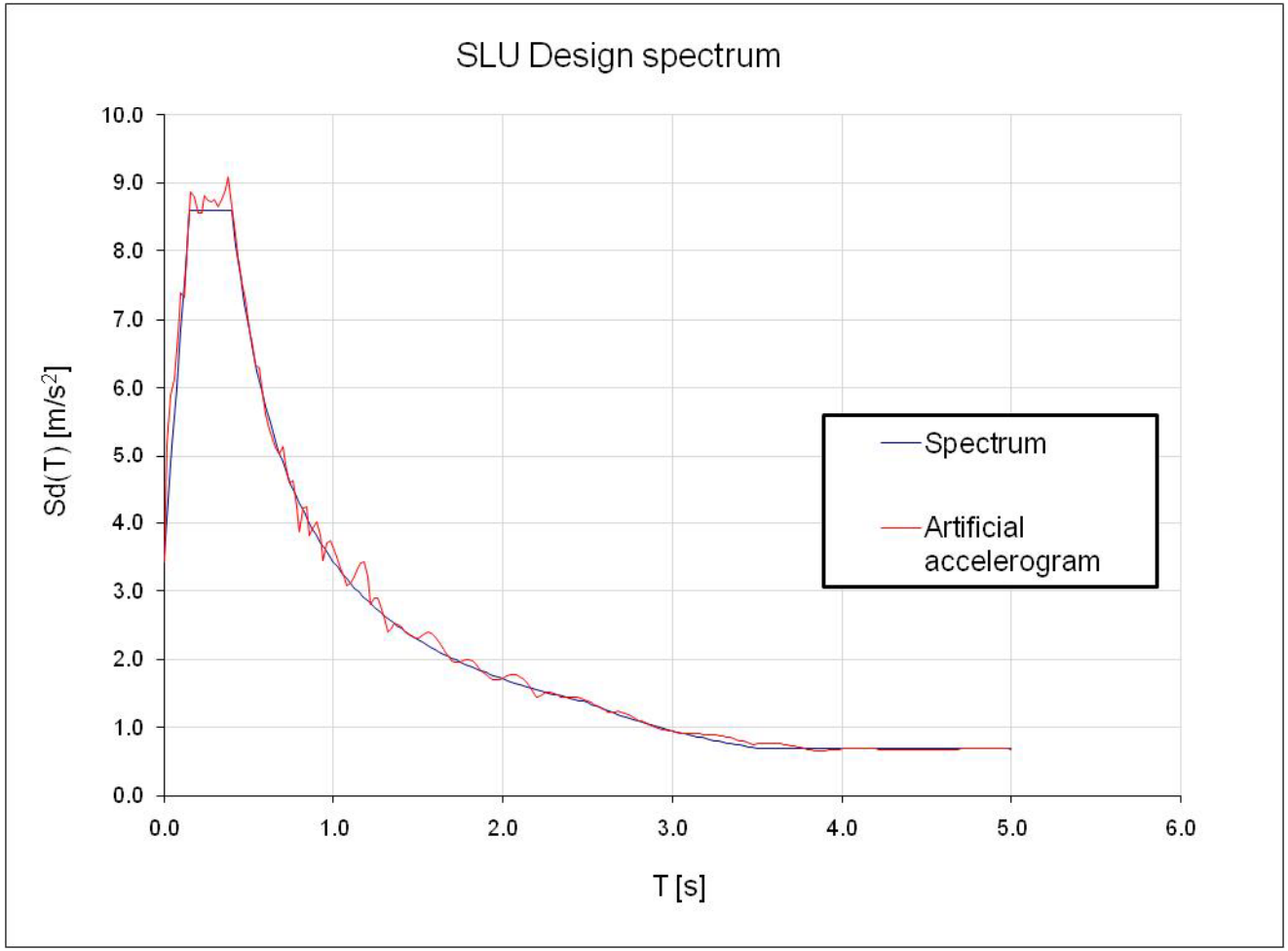


1st Accelerograms



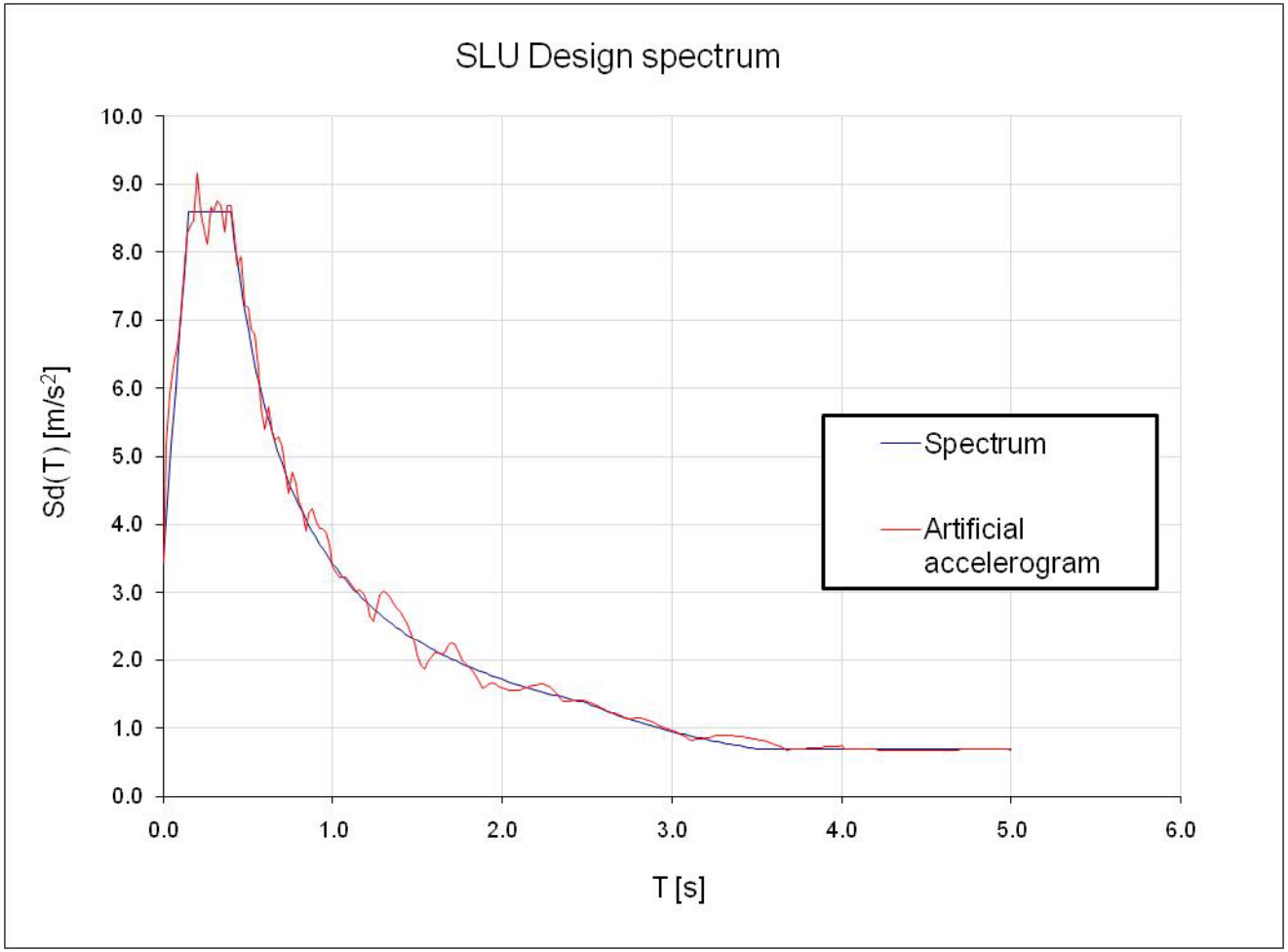
1st Accelerograms spectrum

X direction (horizontal)



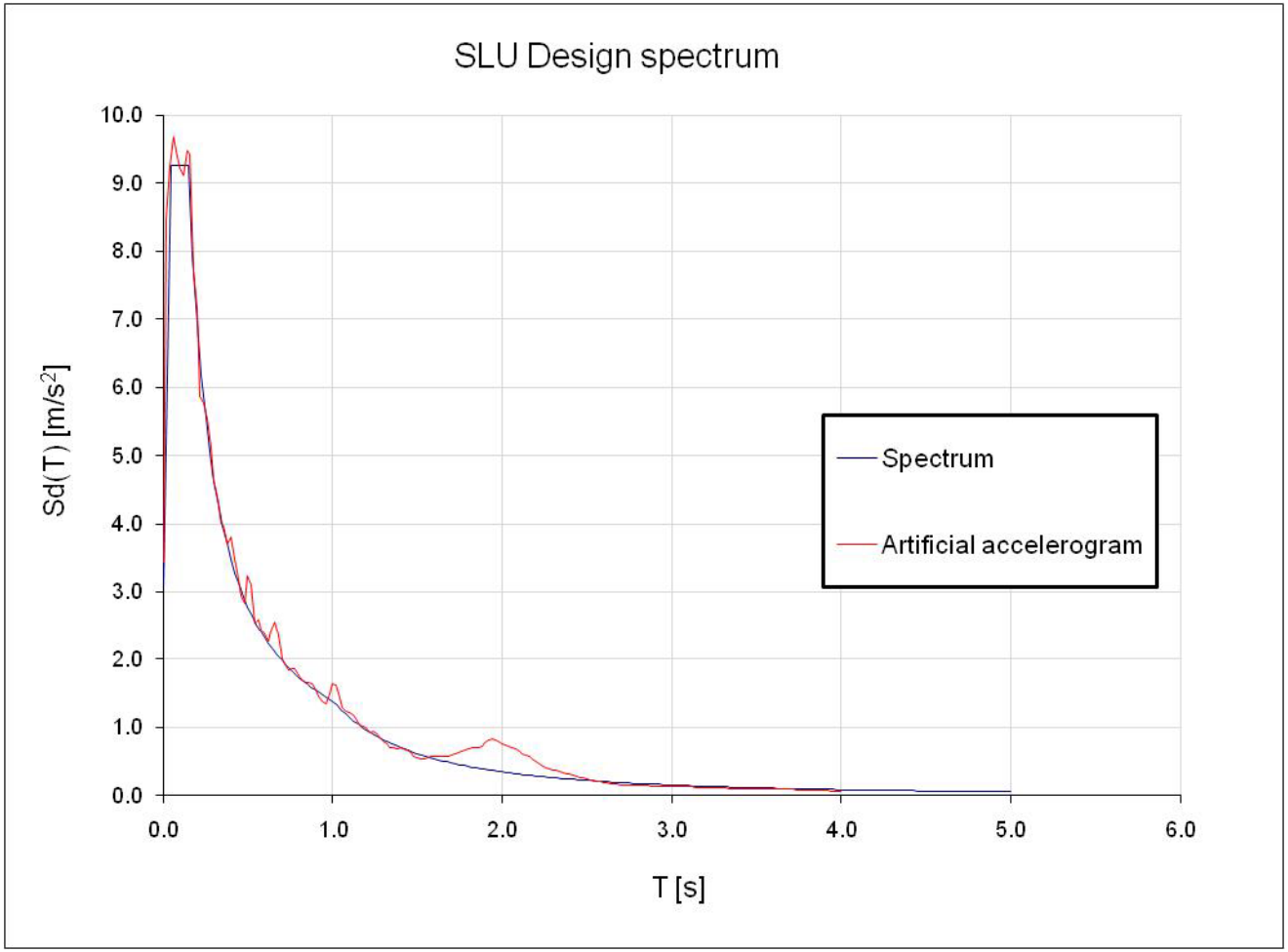
1st Accelerograms spectrum

Y direction (horizontal)



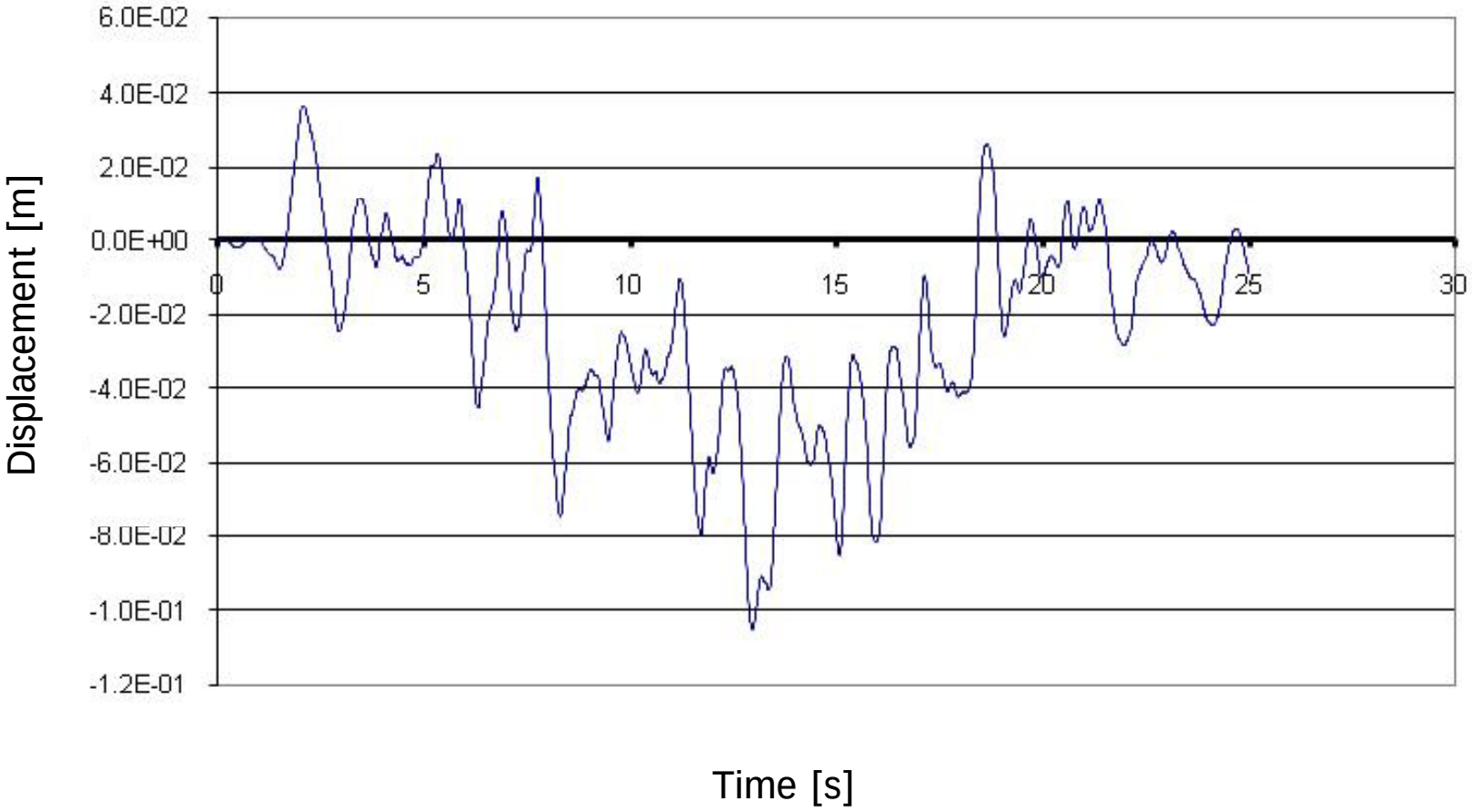
1st Accelerograms spectrum

Z direction (vertical)



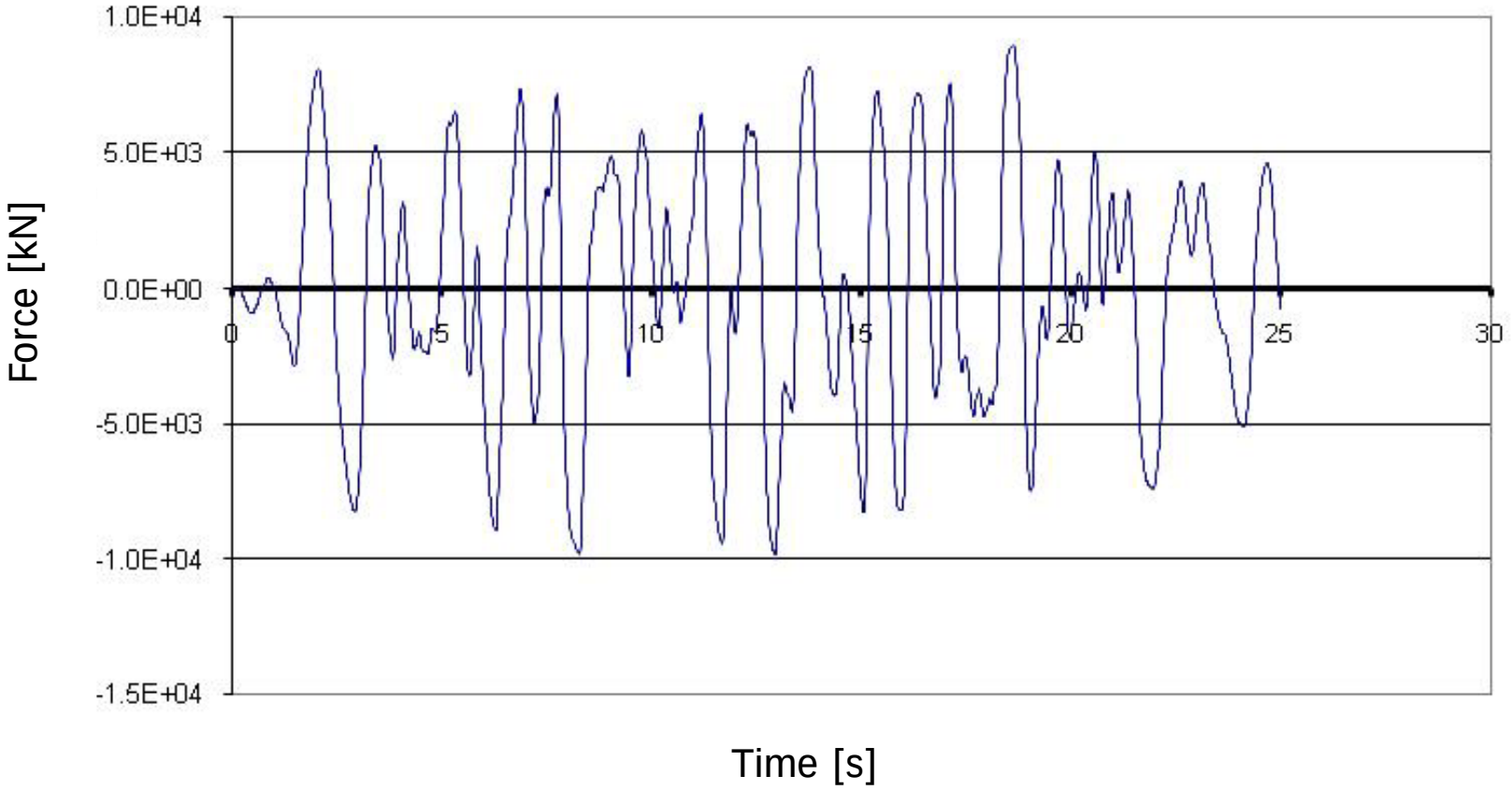
1st Accelerograms

Longitudinal (abutment C1) damper displacements



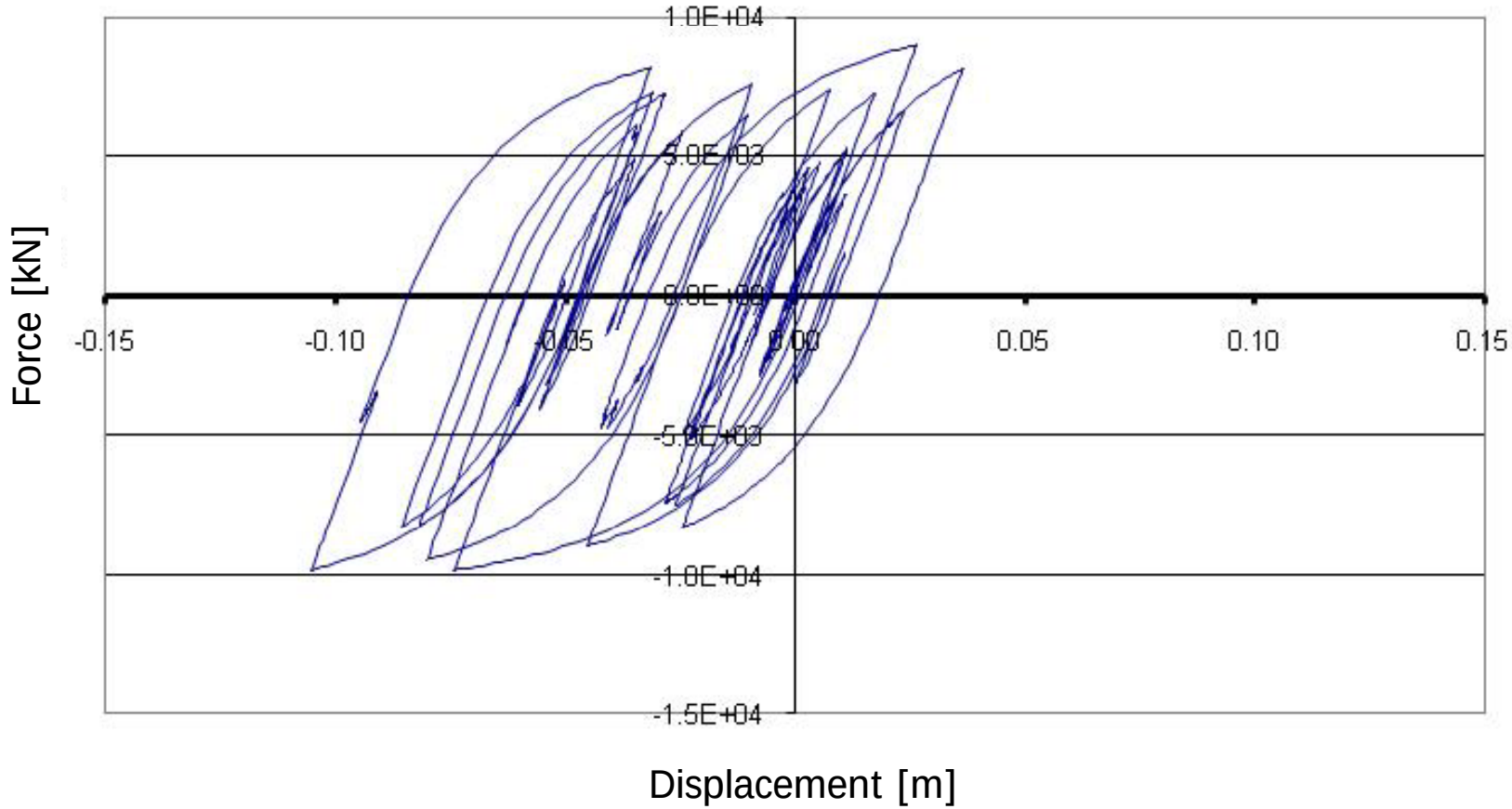
1st Accelerograms

Longitudinal (abutment C1) damper reaction



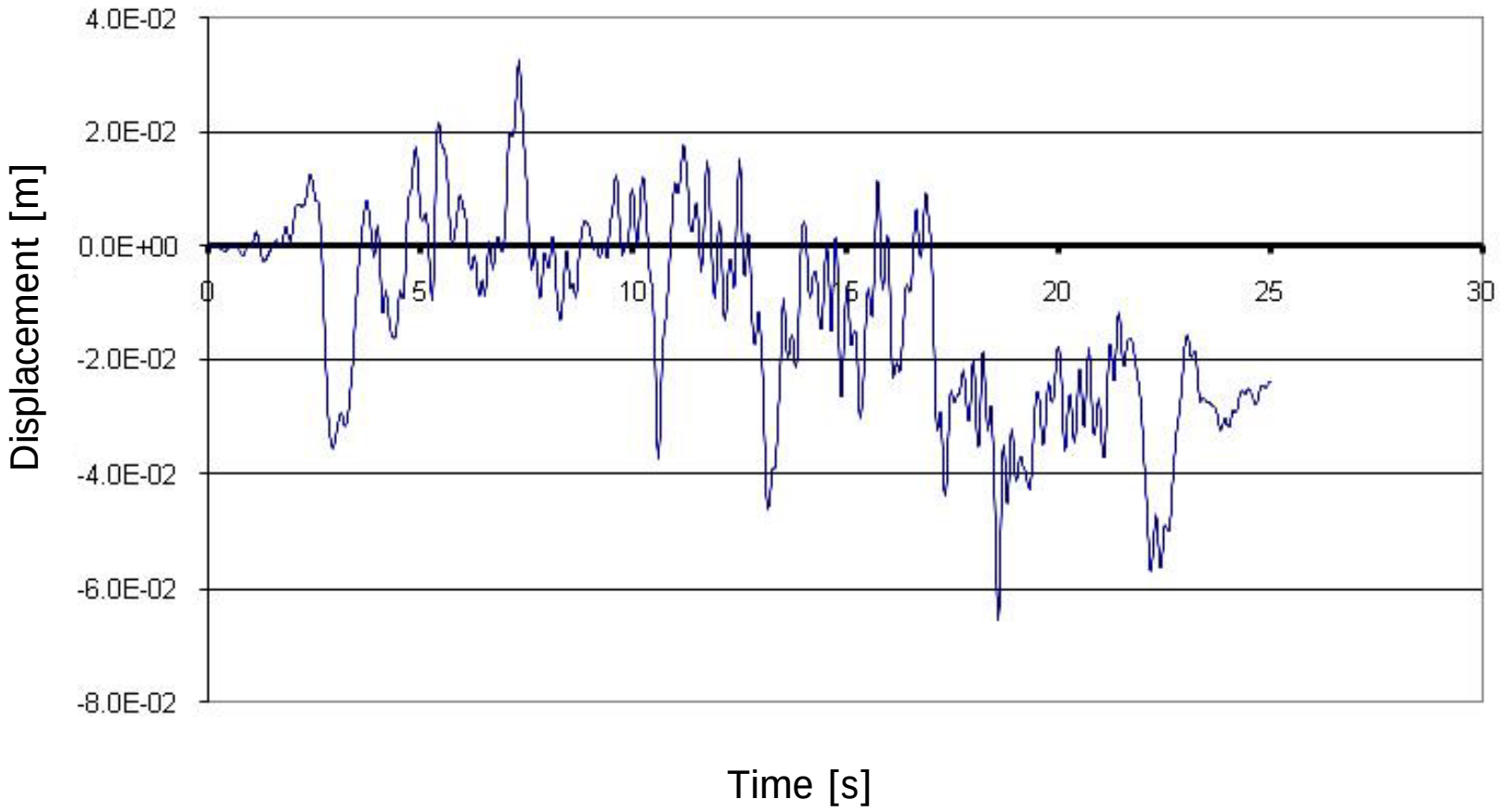
1st Accelerograms

Longitudinal (abutment C1) damper reaction vs. displacement



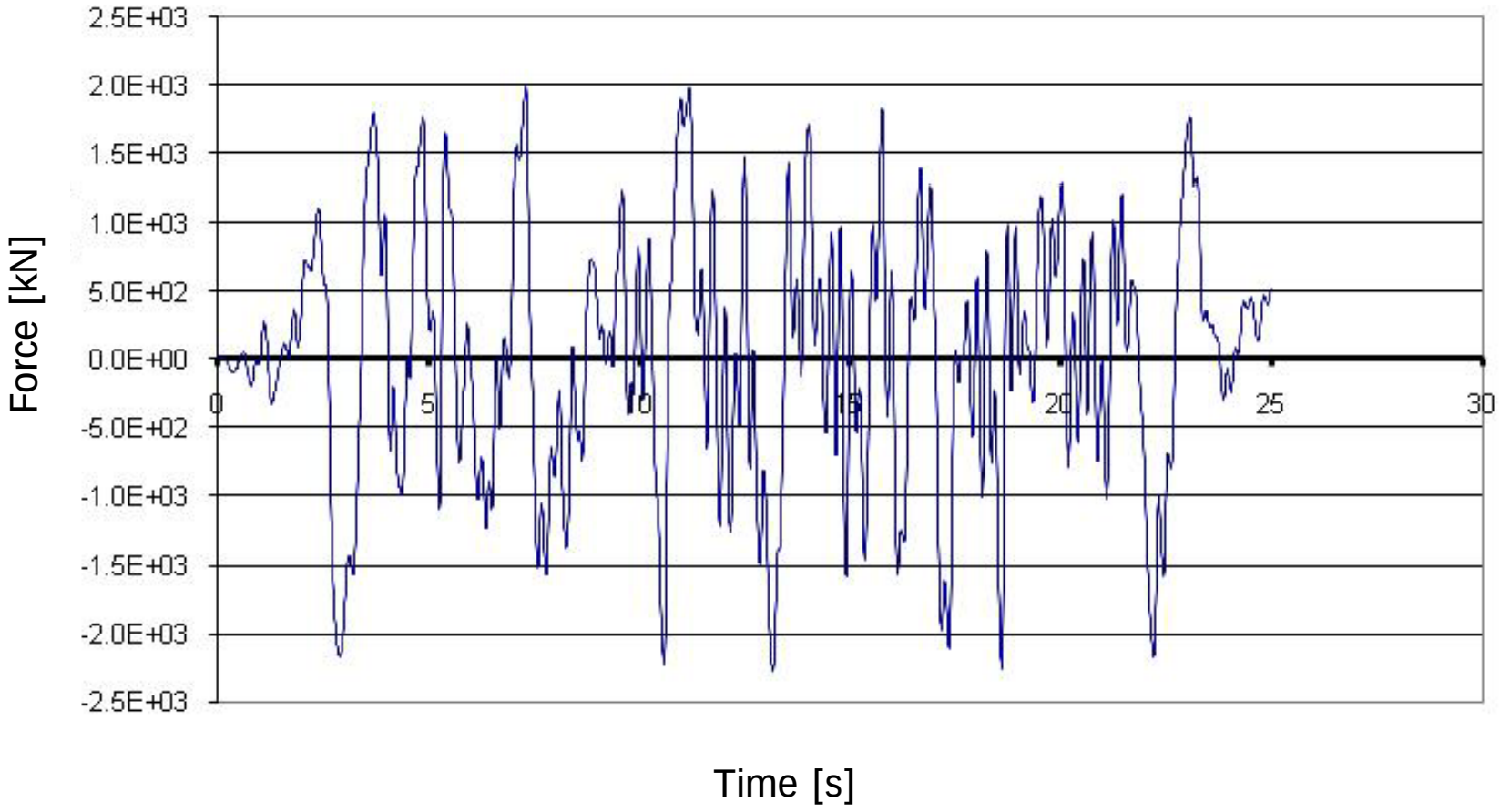
1st Accelerograms

Transverse Pier P1 damper displacements



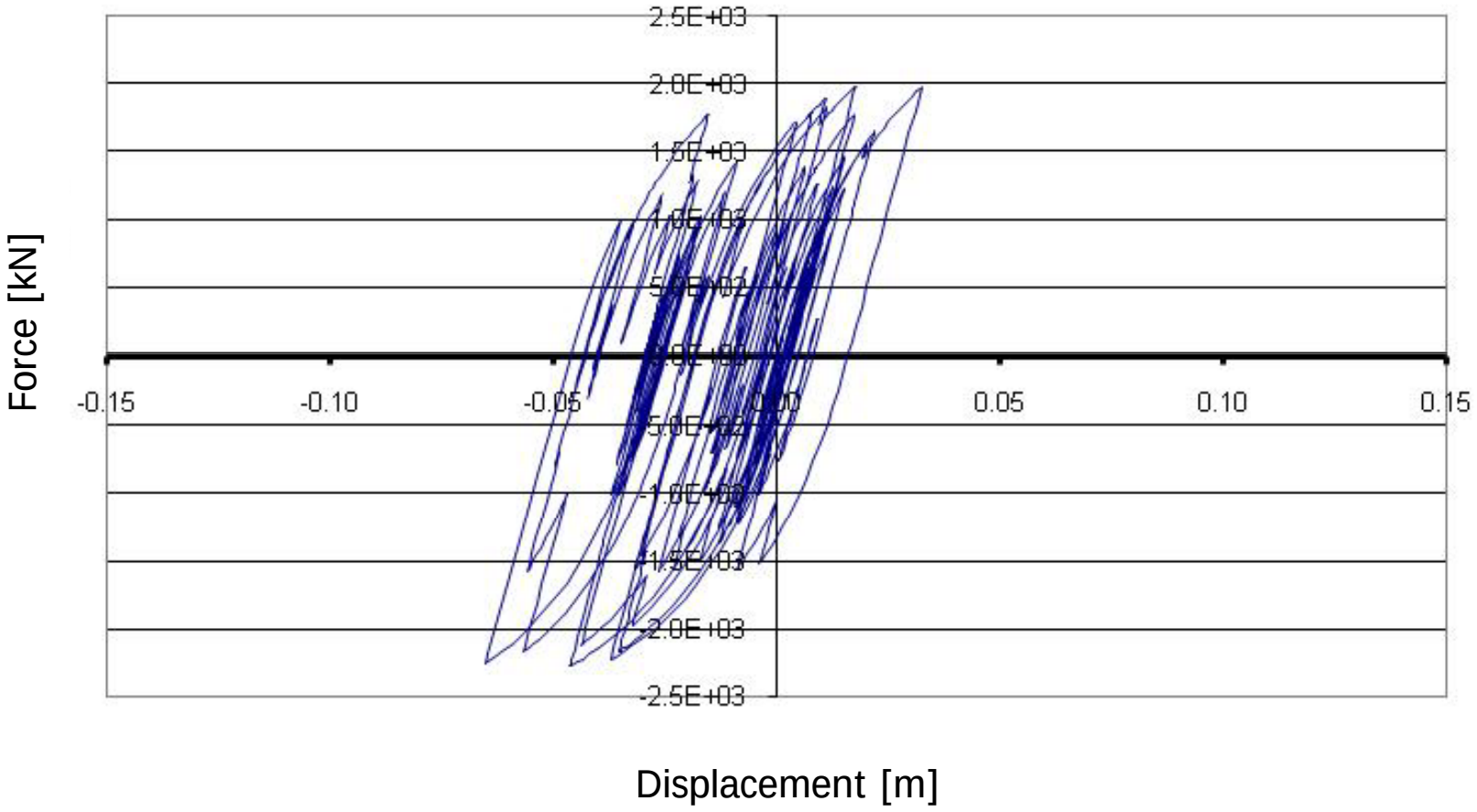
1st Accelerograms

Transverse Pier P1 damper reaction

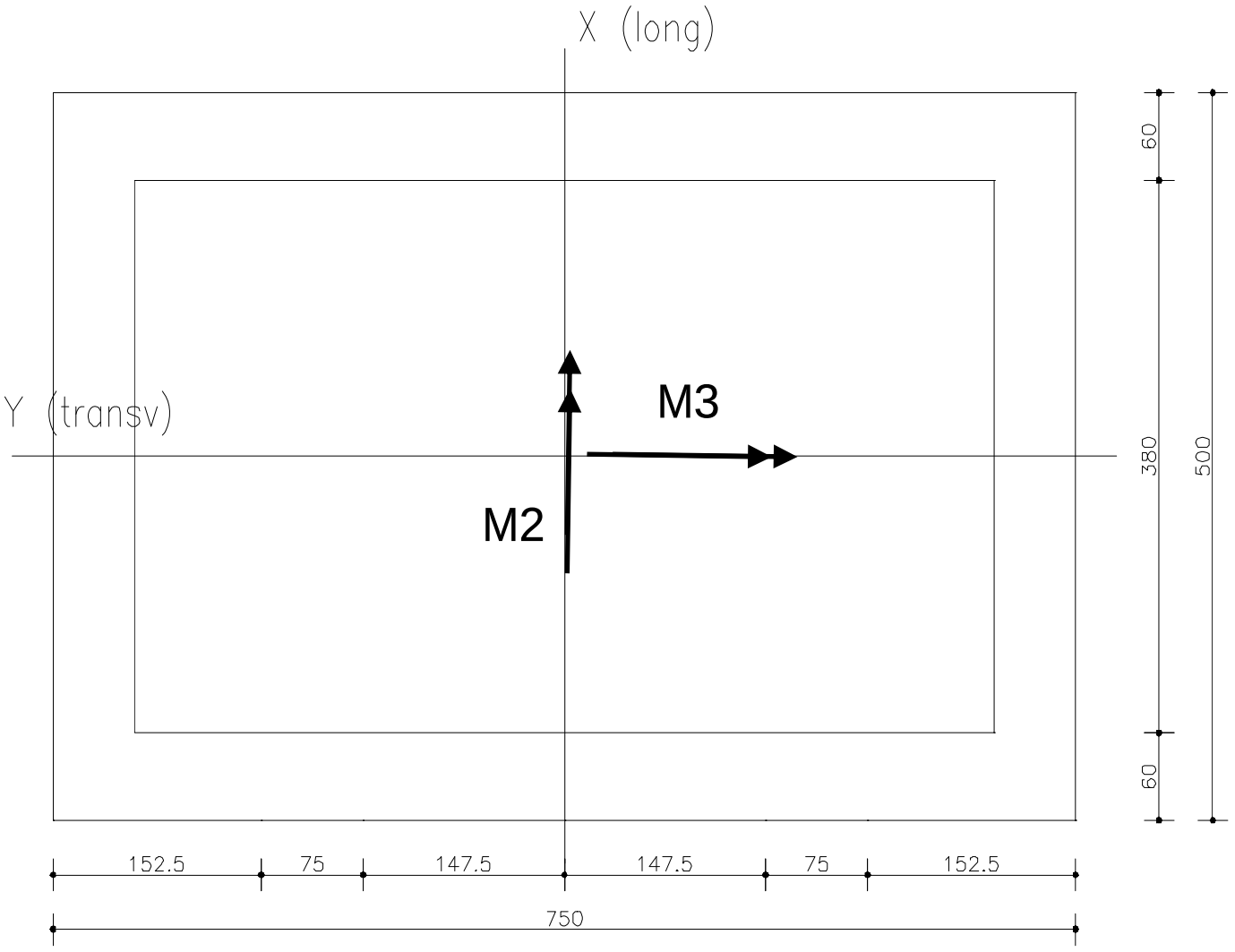


1st Accelerograms

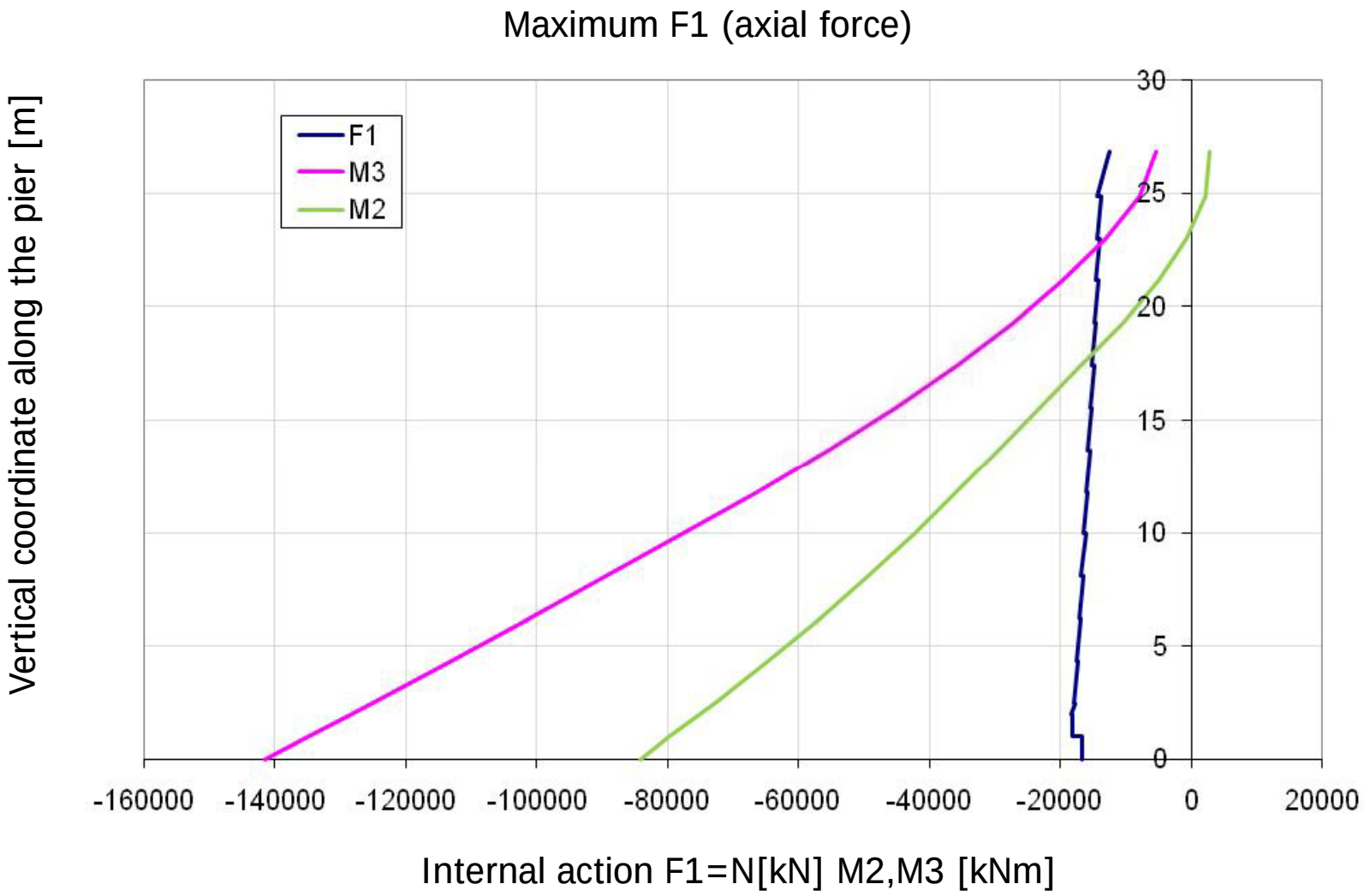
Transverse Pier P1 damper reaction vs. displacement



Piers dimensions and orientation of the internal actions

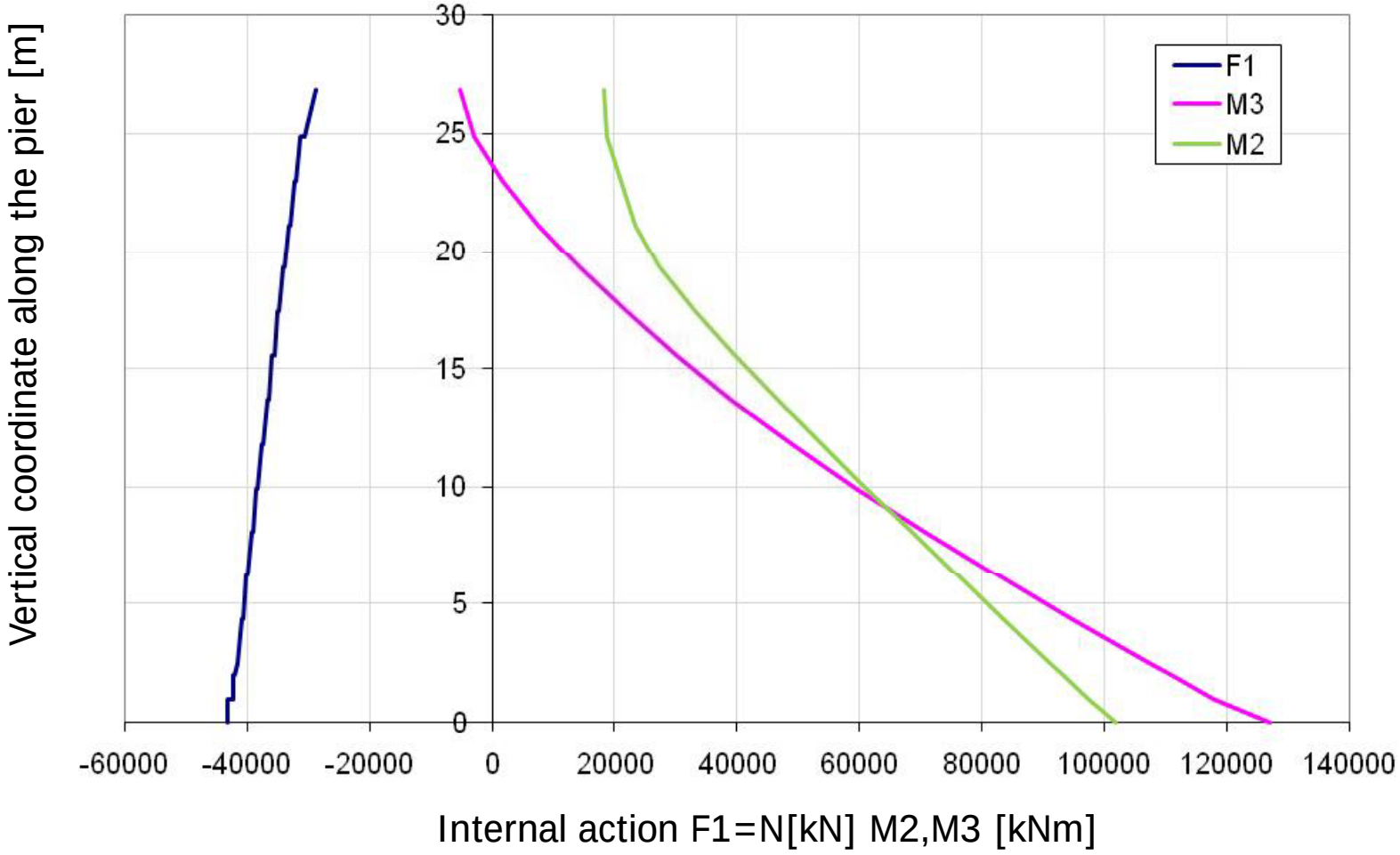


Pier P1 design internal actions – Seismic combination



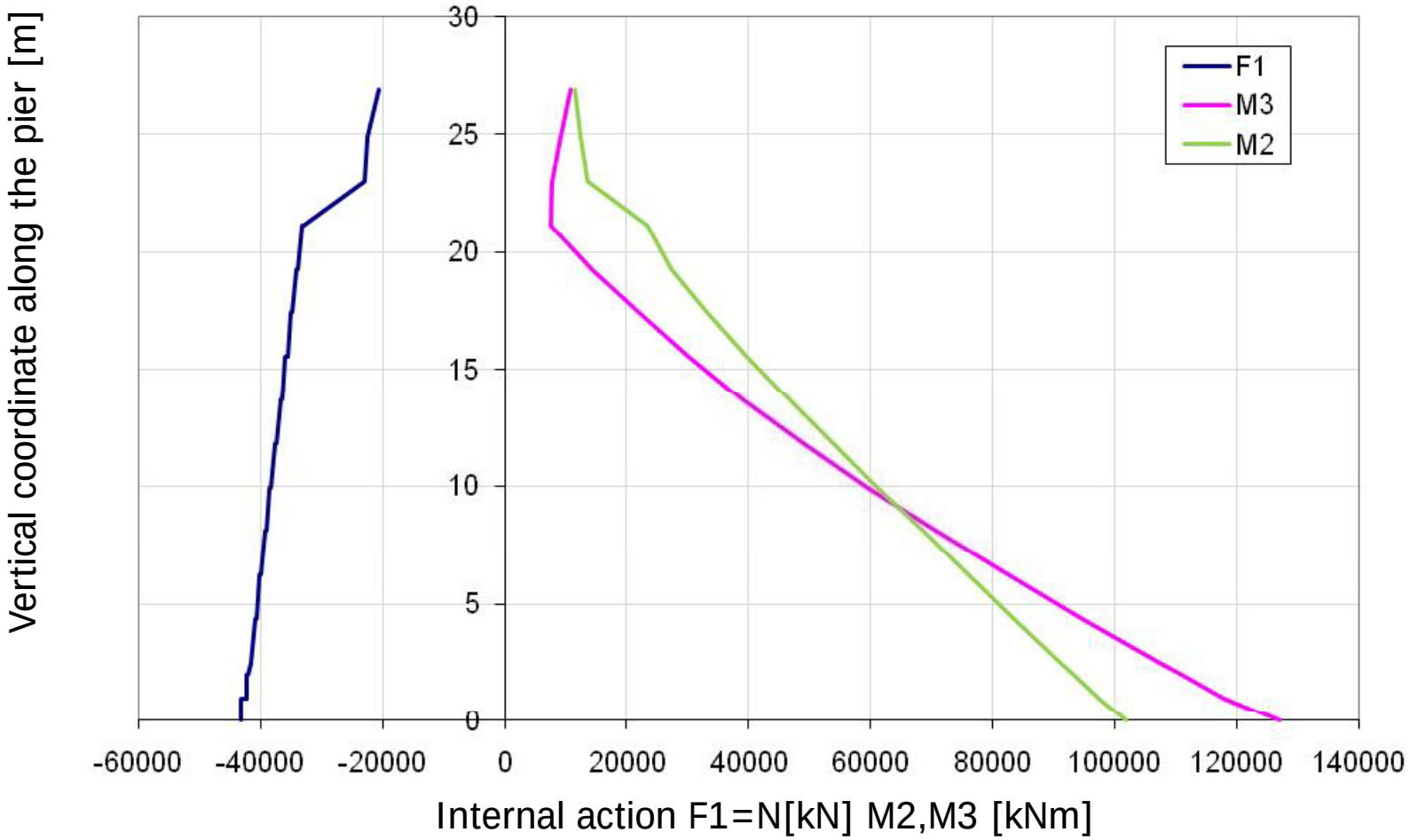
Pier P1 design internal actions – Seismic combination

Maximum M2 (transverse bending moment)

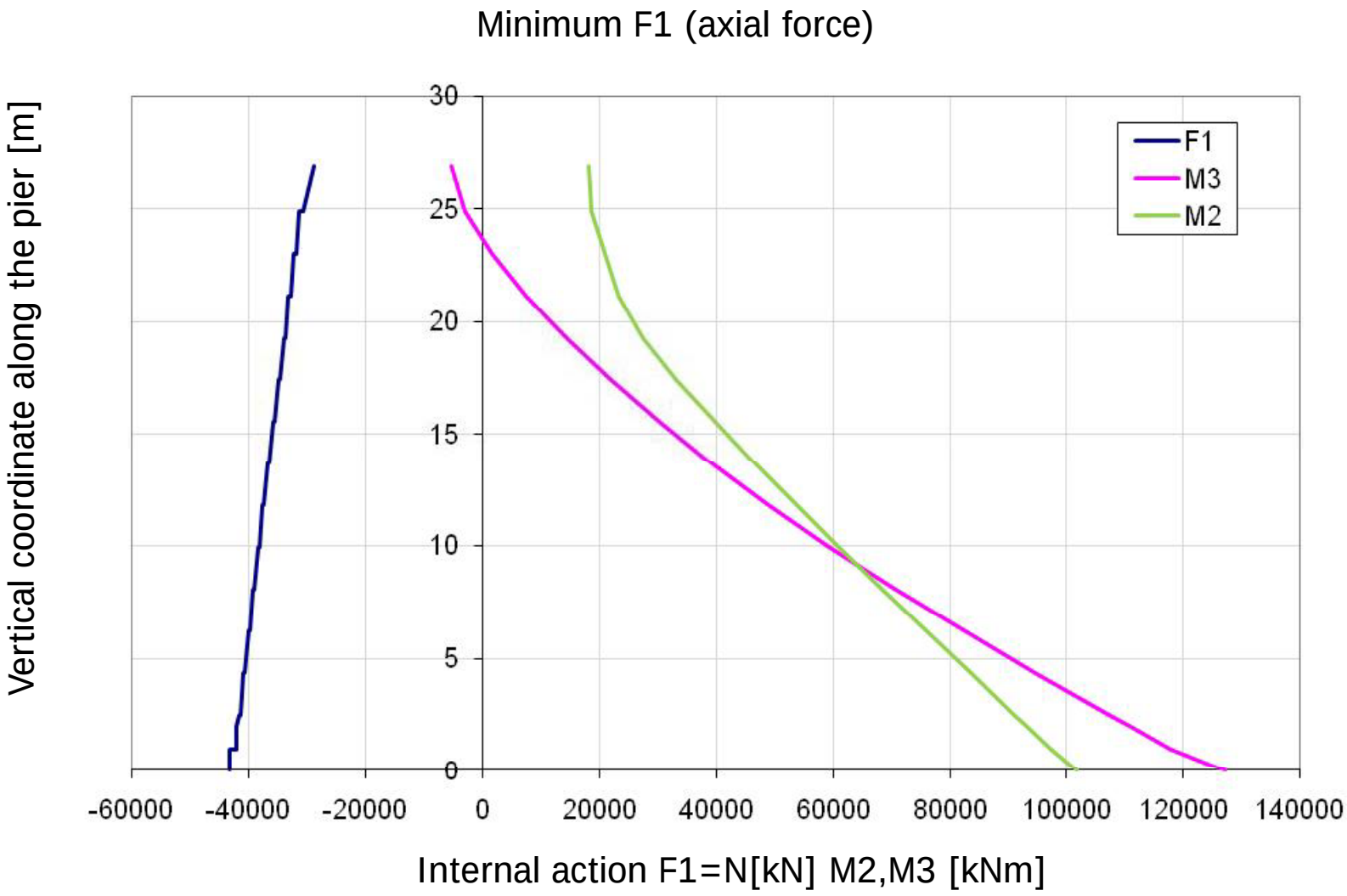


Pier P1 design internal actions – Seismic combination

Maximum M3 (longitudinal bending moment)

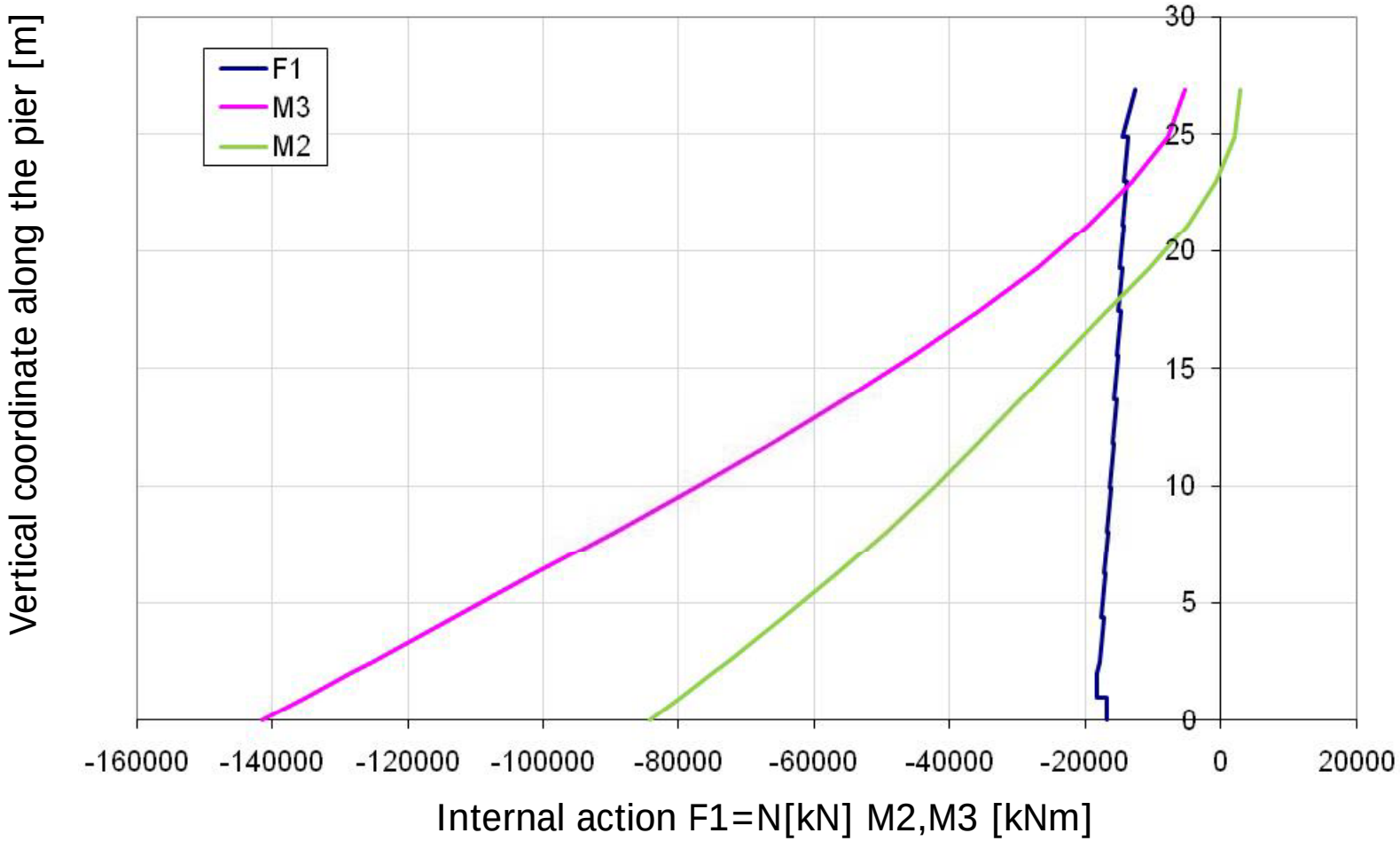


Pier P1 design internal actions – Seismic combination



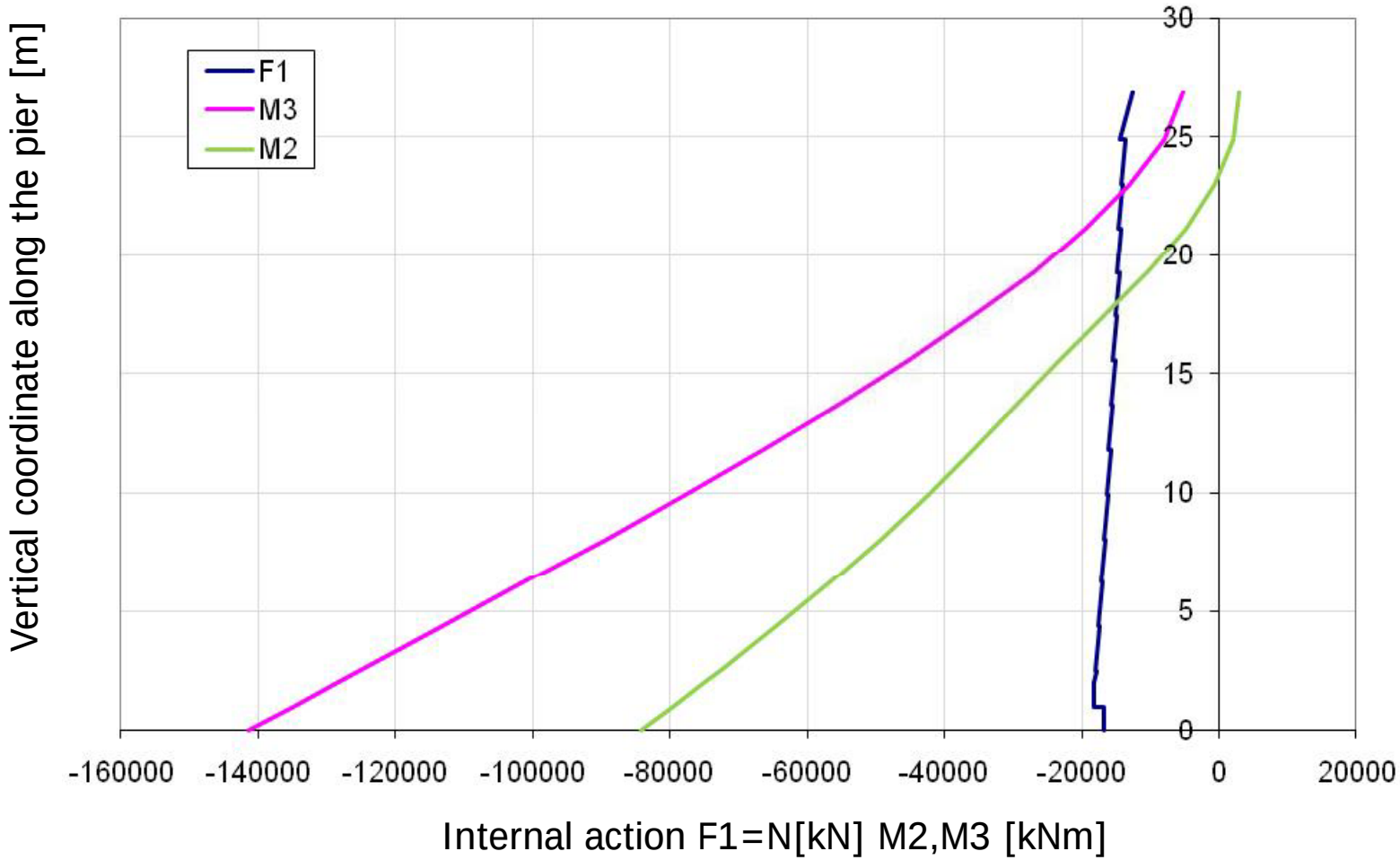
Pier P1 design internal actions – Seismic combination

Minimum M2 (transverse bending moment)

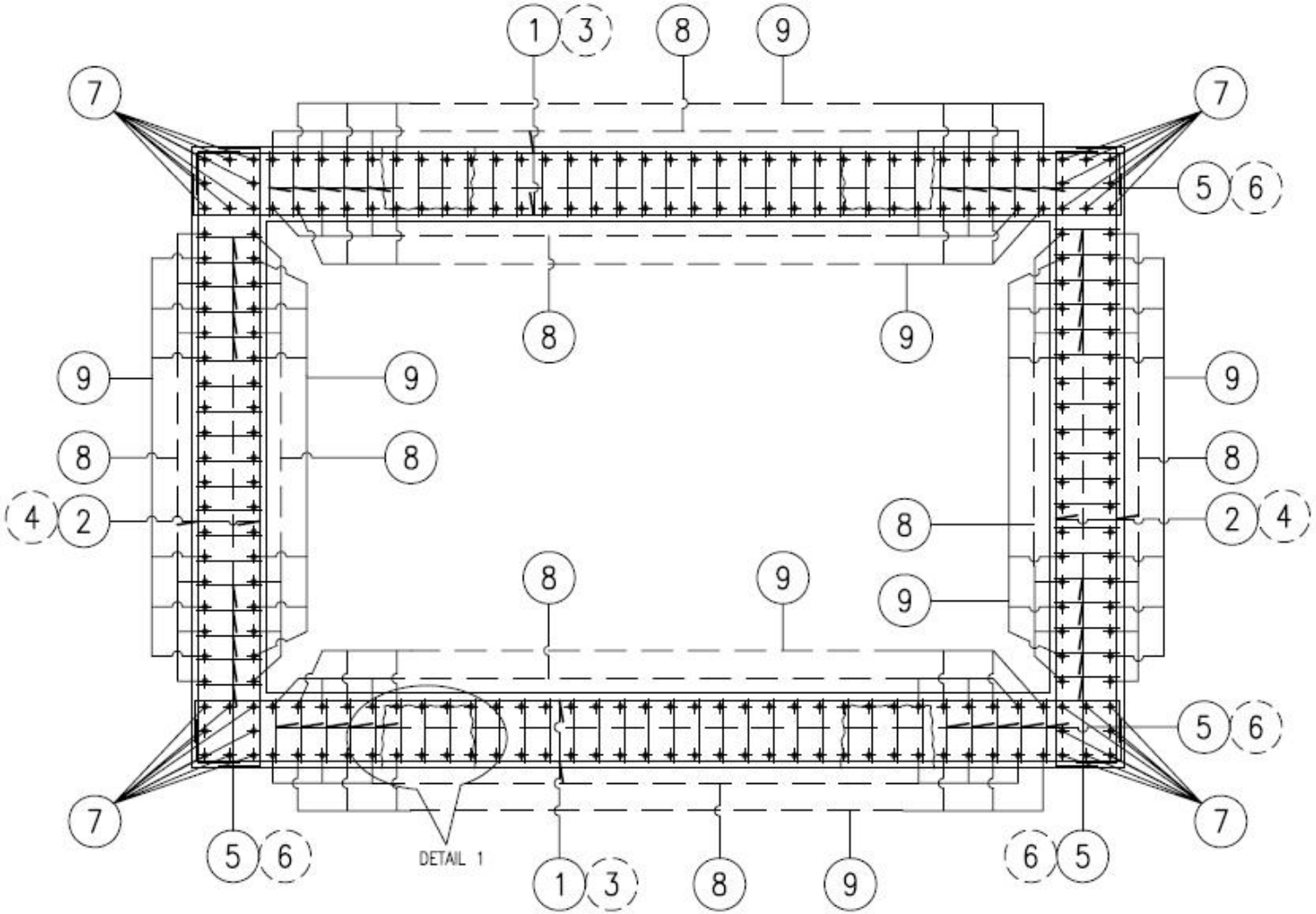


Pier P1 design internal actions – Seismic combination

Minimum M3 (longitudinal bending moment)



Pier P1 (25m tall) reinforcement (base section)



Pier P1 reinforcement table

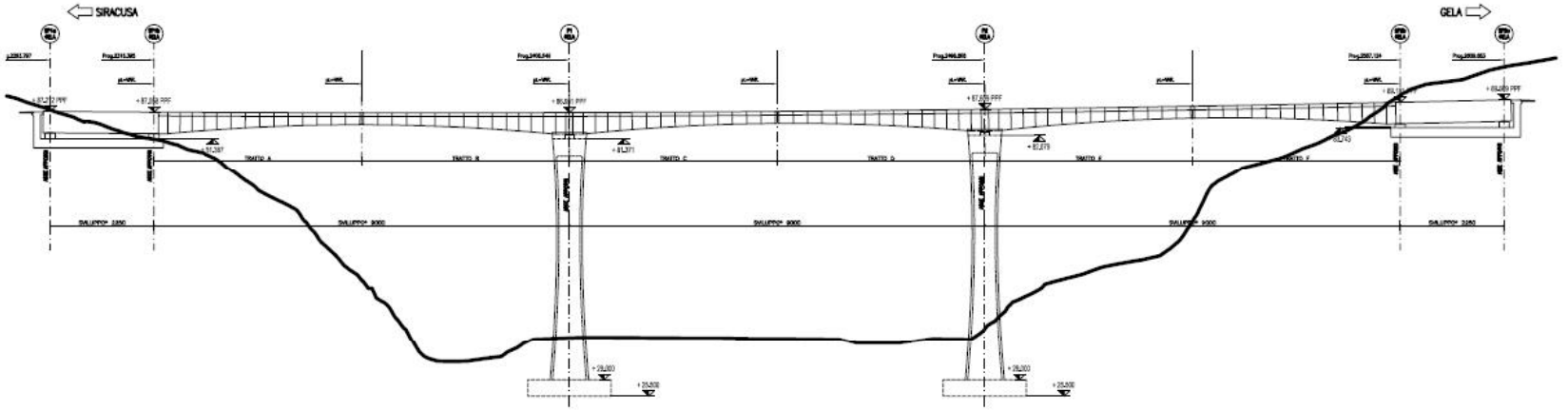
Pos	Ø (mm)	Shape	L (cm)	N°	W (Kg)
1	24 / 20	33 — 742 — 33	808	35 x 4	4017.18
2	24 / 20	33 — 492 — 33	558	35 x 4	2774.24
3	20 / 20	27 — 742 — 27	796	75 x 4	5889.17
4	20 / 20	27 — 492 — 27	546	75 x 4	4039.55
5	14 / 20x20	17 — 52 — 17	86	120x2 + 665x2	3710.07
6	14 / 40x40	17 — 52 — 17, décalés	86	608x2 + 380x2	2053.53
7	26	530 / 650, 650 / 800, recouvr.≥188	530+ 650x2+ 800	8 x 4	3507.62
8	20 / 40	600 / 715, 600, recouvr.≥145	715 + 600x2	20x2 + 32x2	4911.58
9	20 / 40	530 / 600, 600 / 750, recouvr.≥145	530+ 600x2+ 750	18x2 + 32x2	6116.05
Total weight					37019 kg

SEISMIC DESIGN OF BRIDGES

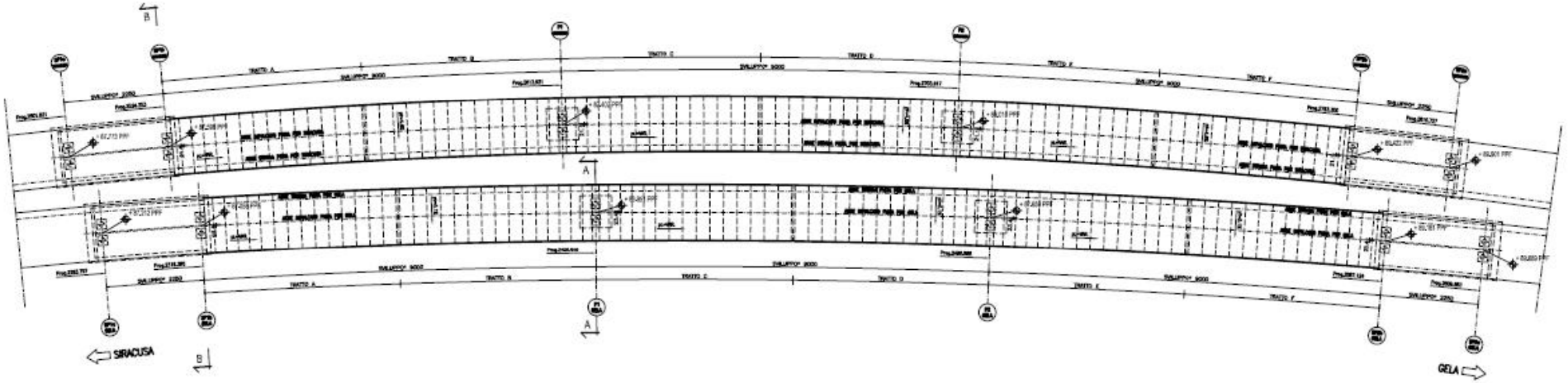
Lead-rubber bearings application:

Highway in Sicily

General dimensions

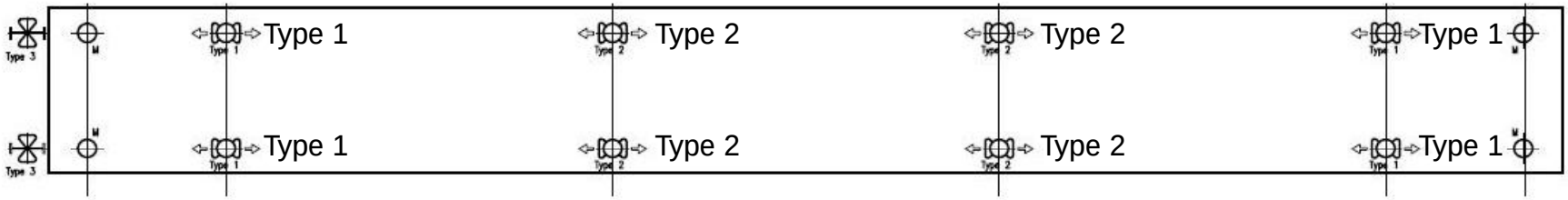


2 decks made of three 90m spans each with 53m tall piers



Two solutions:

Hysteretic Damping Bearings (HDB)

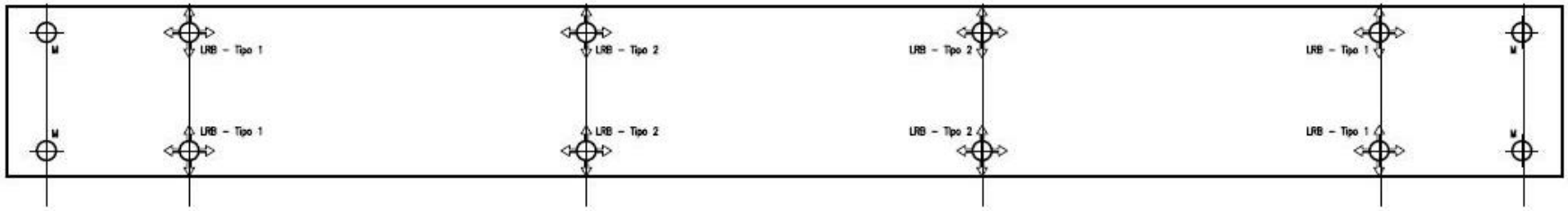


Transverse HDB

Longitudinal HDB

Two direction free bearing

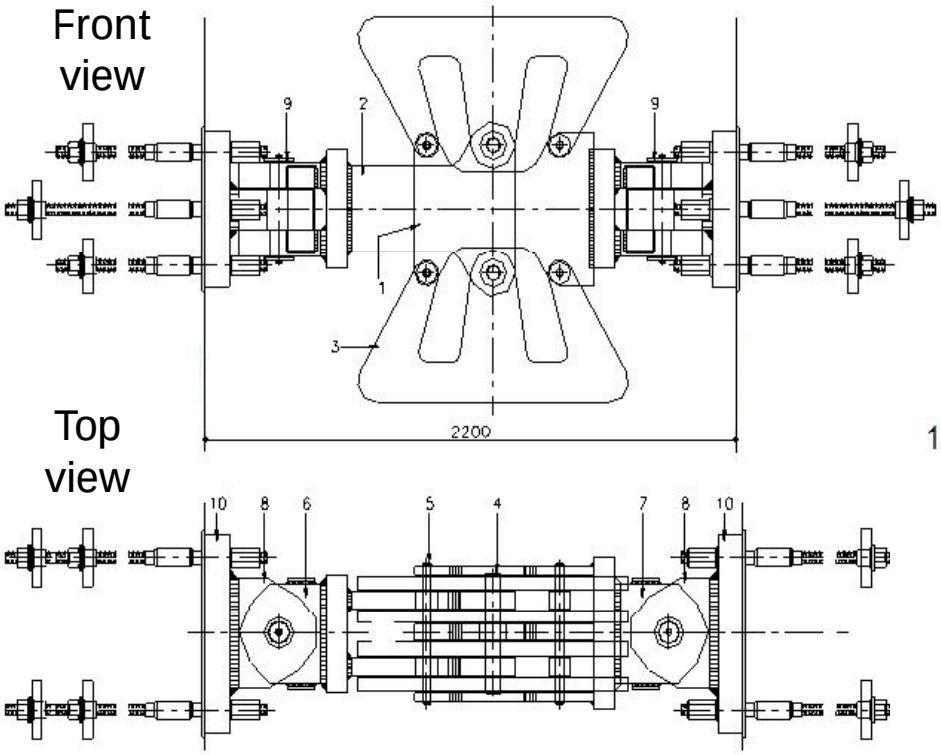
Lead rubber bearings (LRB)



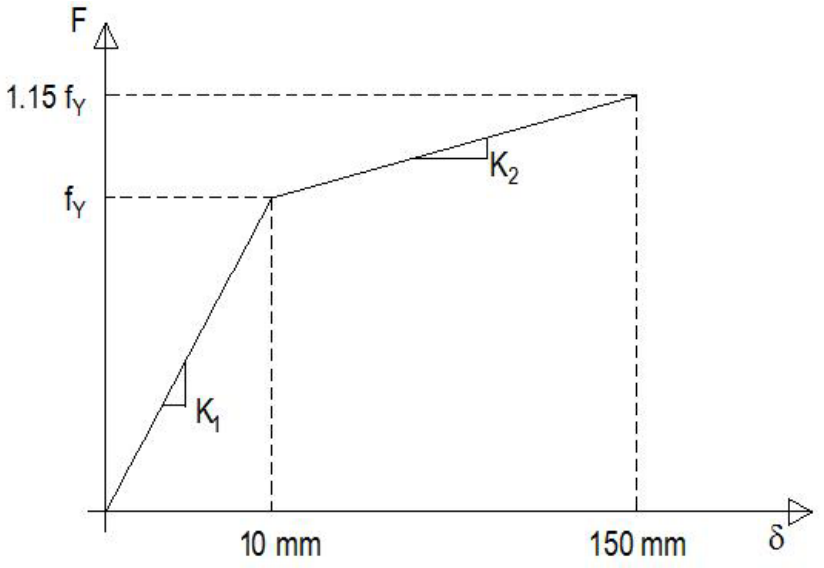
Lead rubber bearing LRB

Two direction free bearing

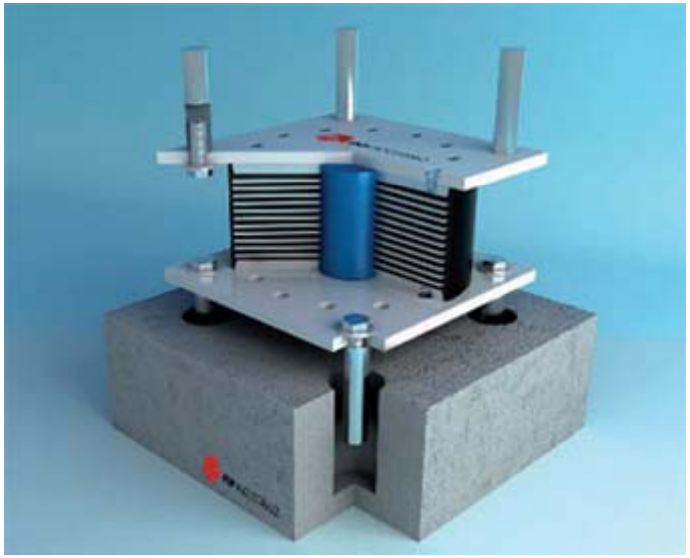
Hysteretic damping Bearings

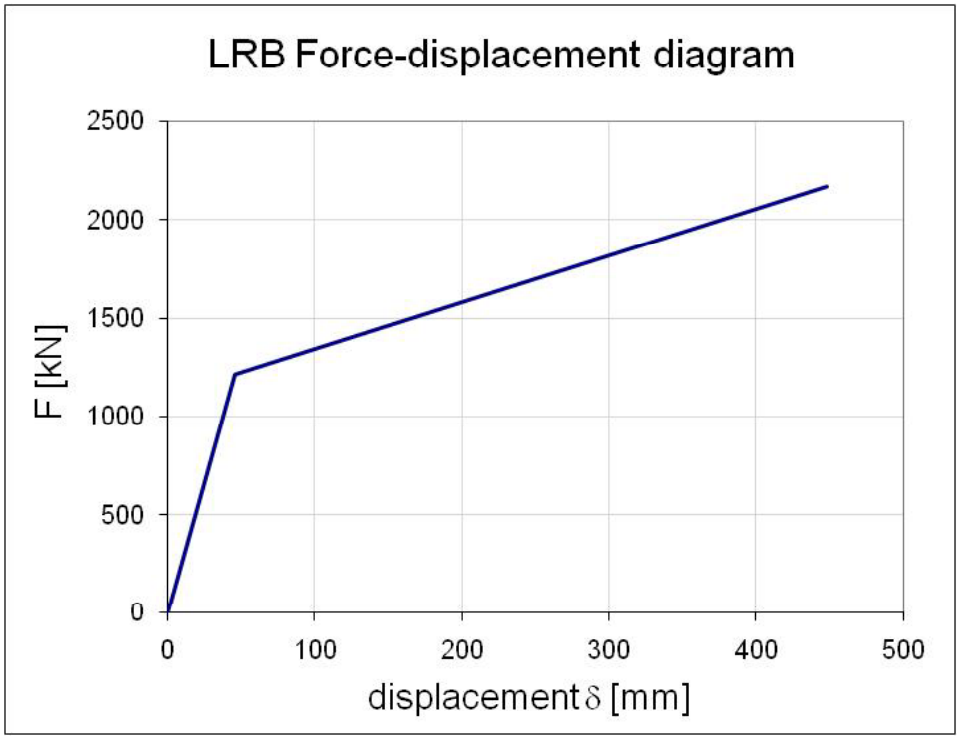


	Type1	Type2	Type3
f_y [kN]	1750	1950	7250
f_u [kN]	2012.5	2242.5	8337.5
δ_y [mm]	10	10	10
δ_u [mm]	150	150	150
K_1 [kN/m]	175000	195000	725000
K_2 [kN/m]	1875	2089.286	7767.857

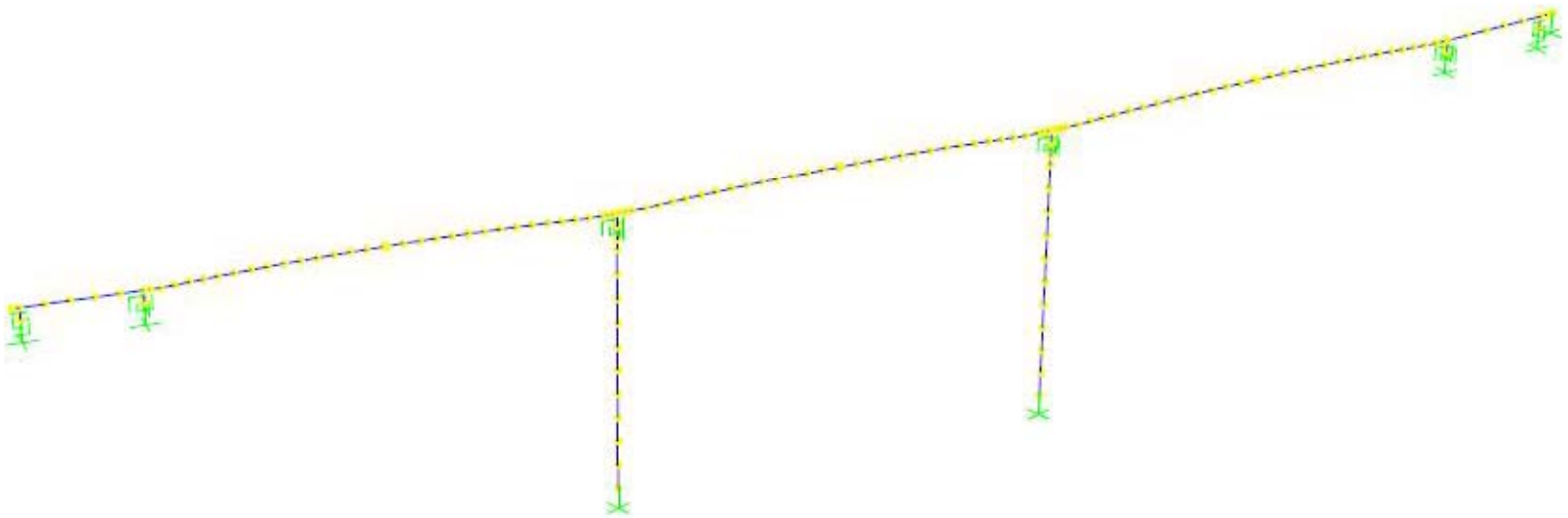


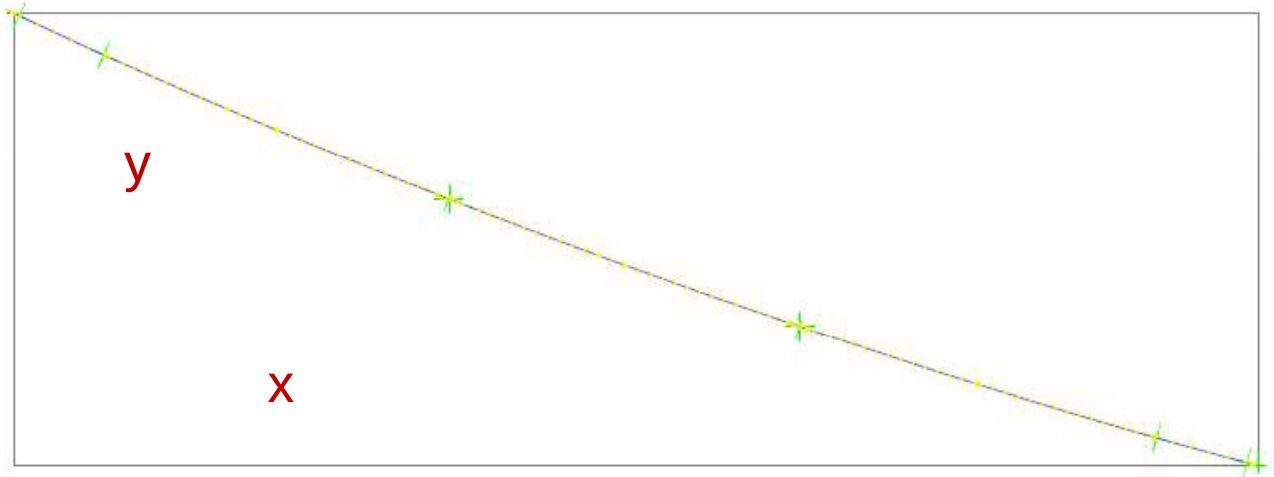
Lead rubber bearings





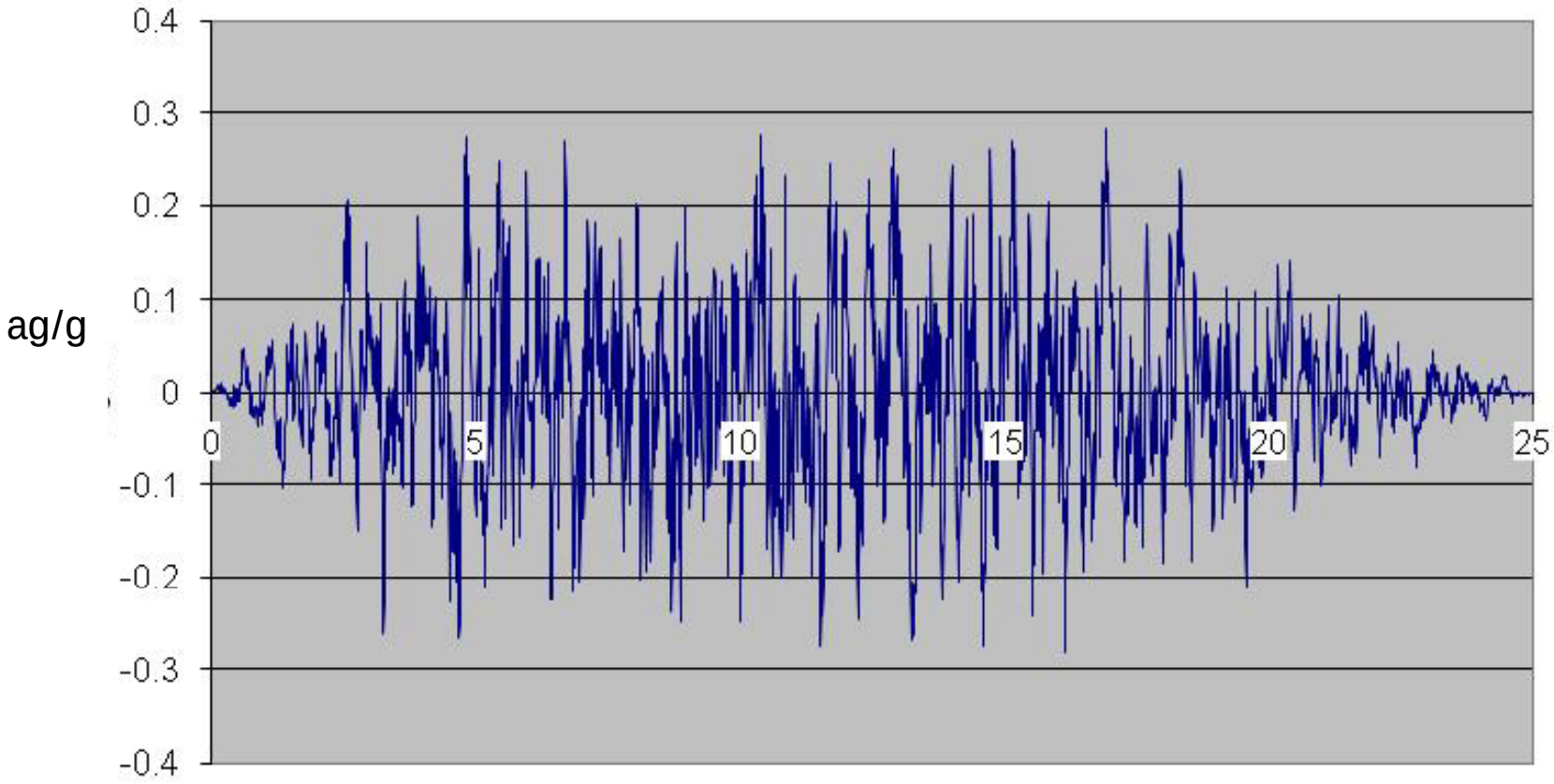
Finite element model – non linear analysis





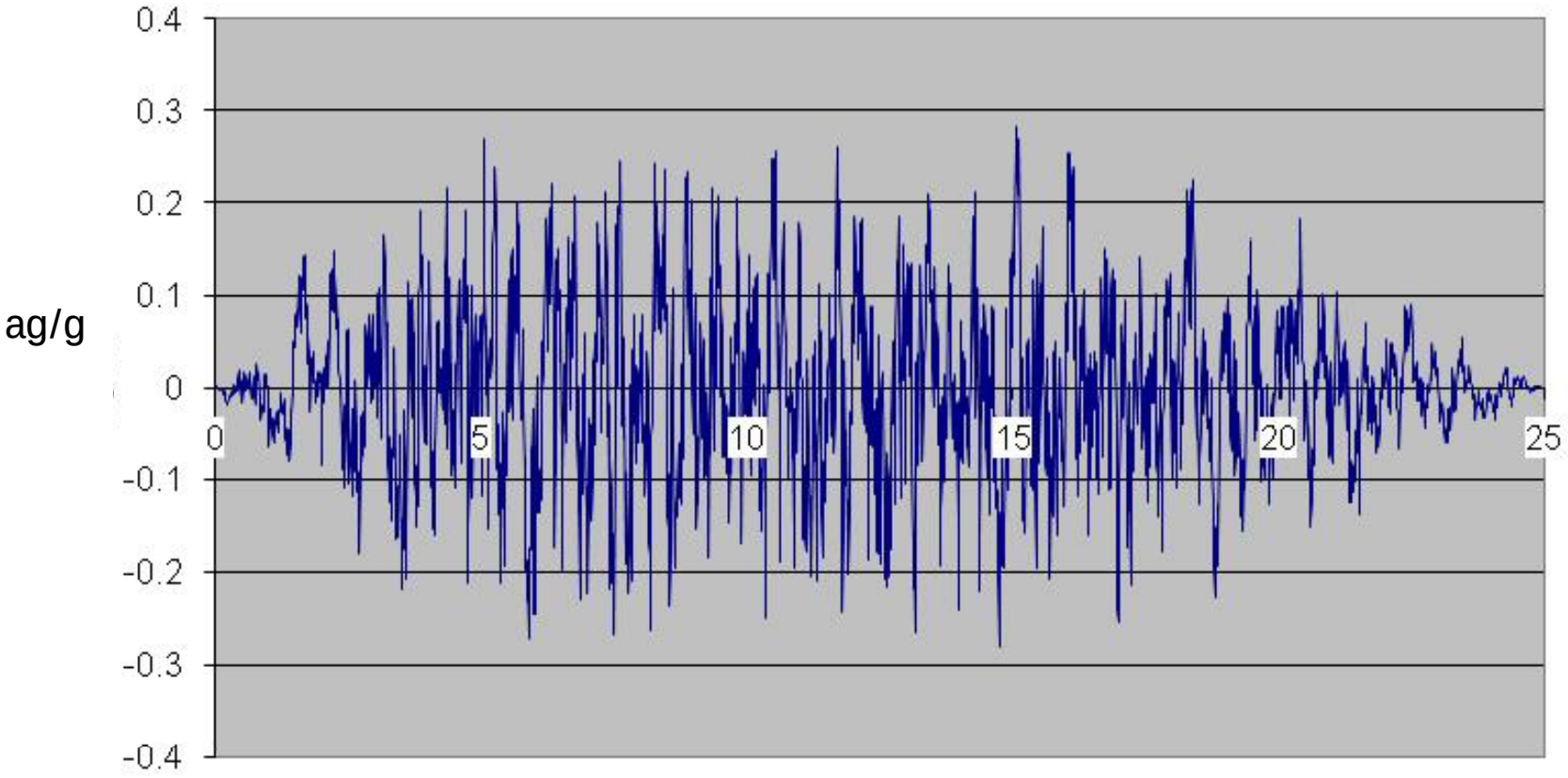
1st Accelerograms

X direction (horizontal)



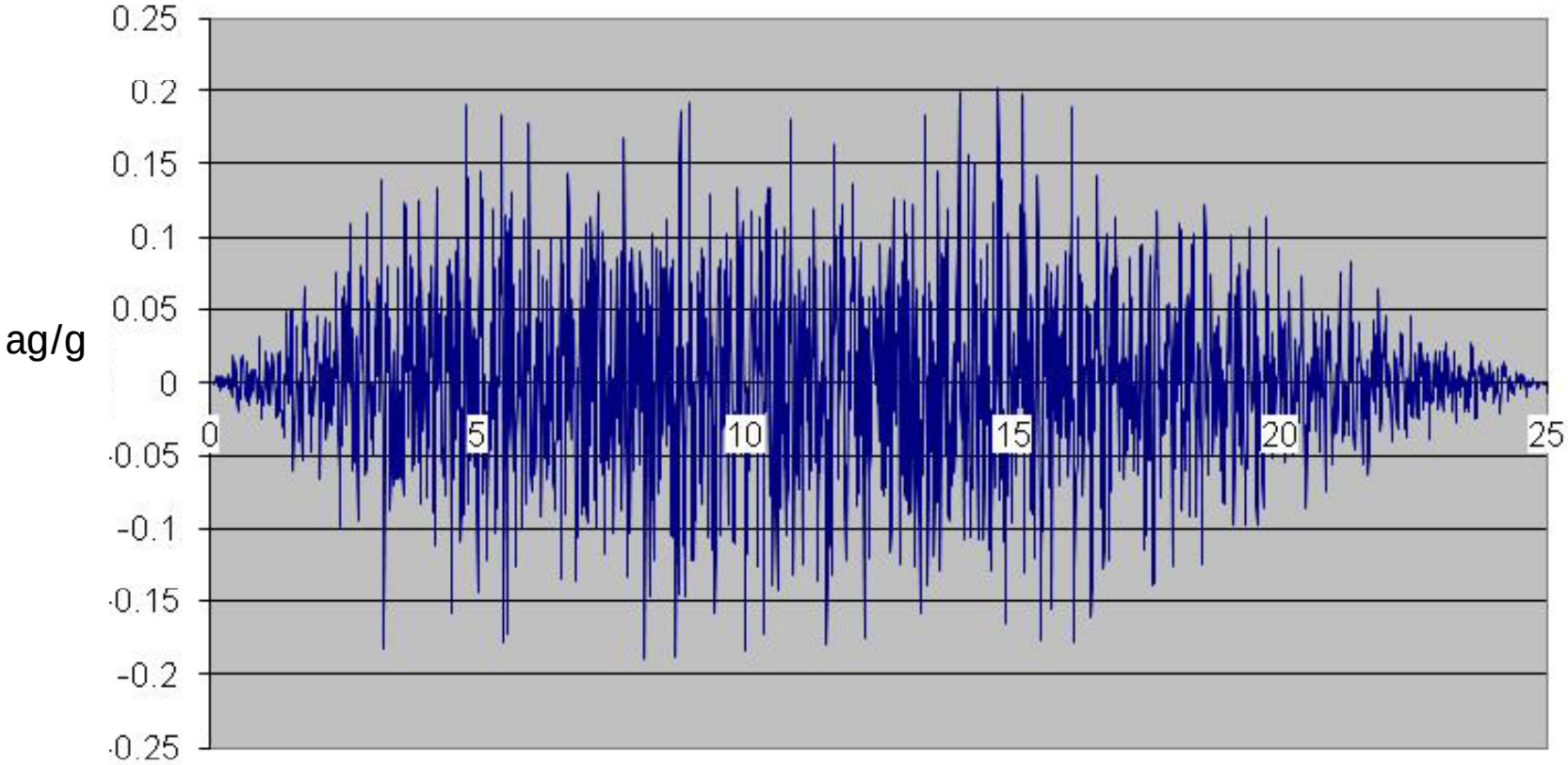
1st Accelerograms

Y direction (horizontal)



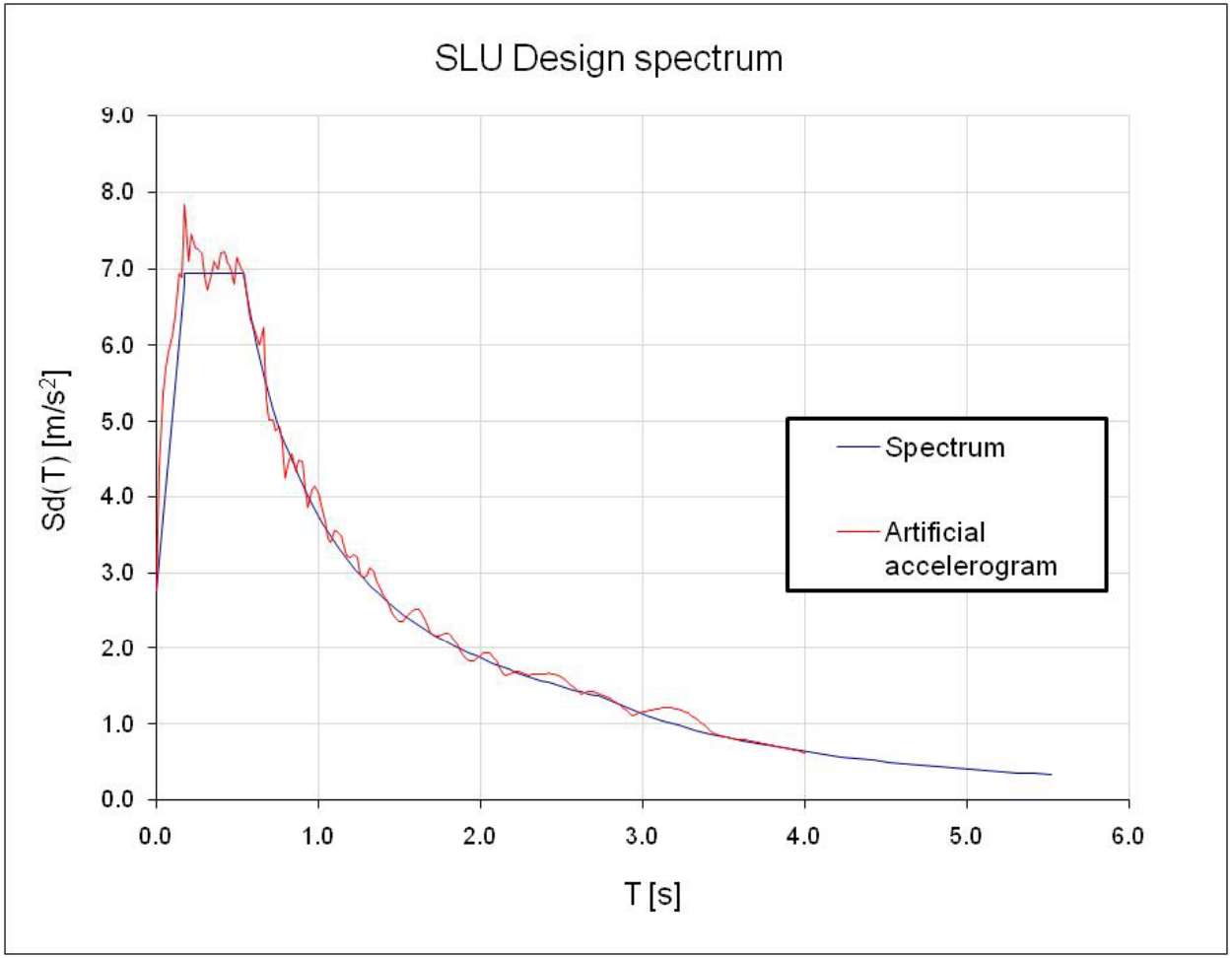
1st Accelerograms

Z direction (vertical)



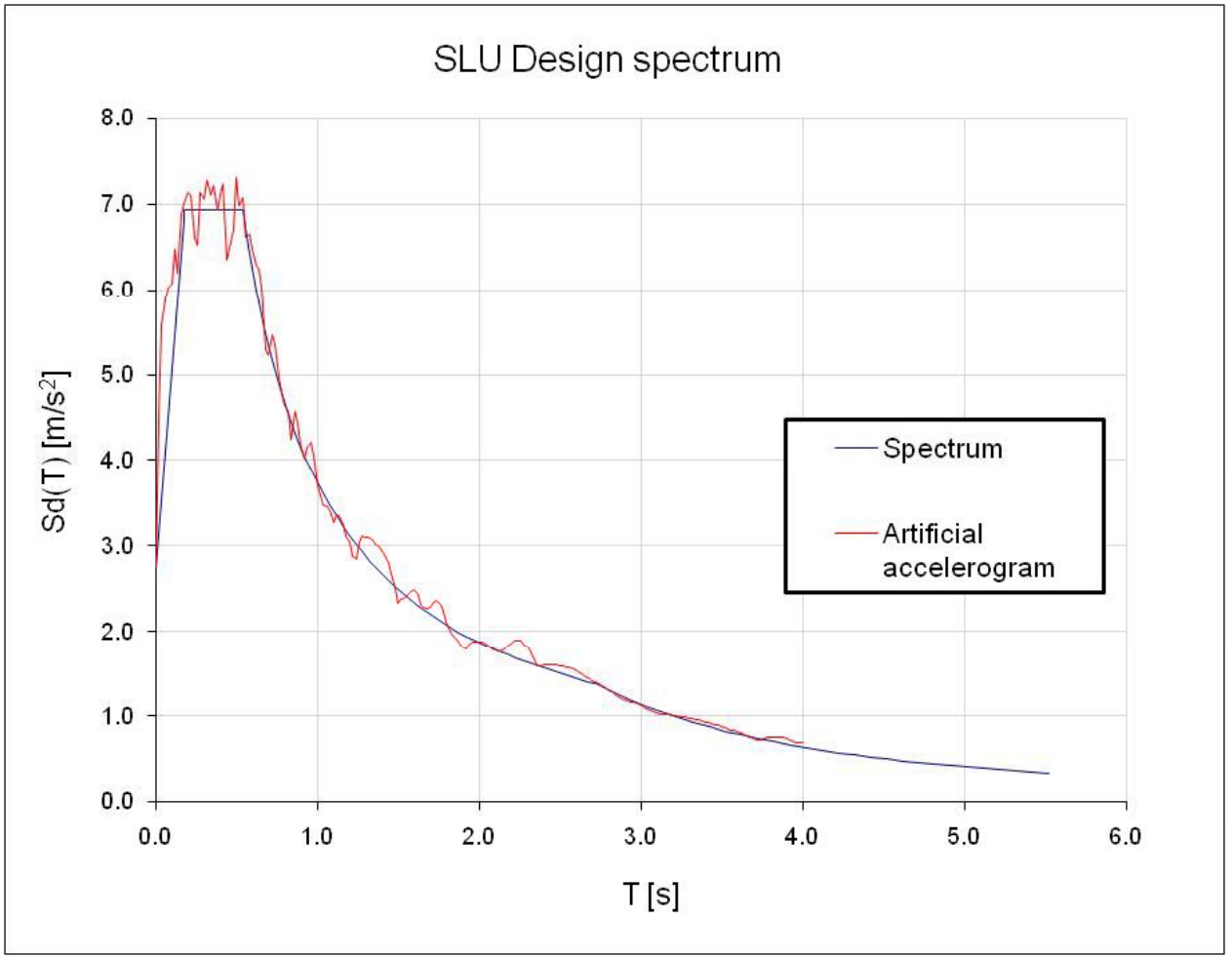
1st Accelerograms spectrum

X direction (horizontal)



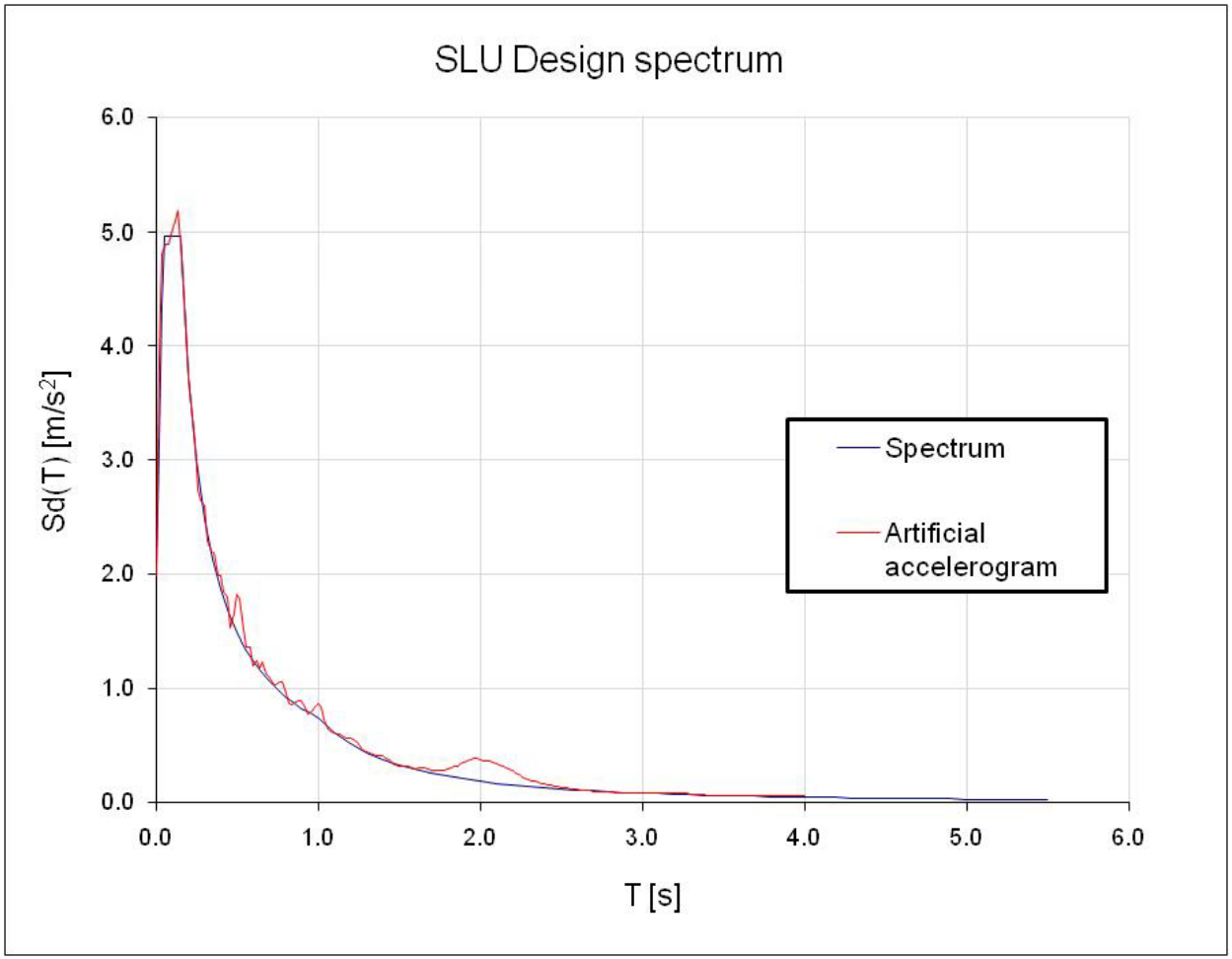
1st Accelerograms spectrum

Y direction (horizontal)



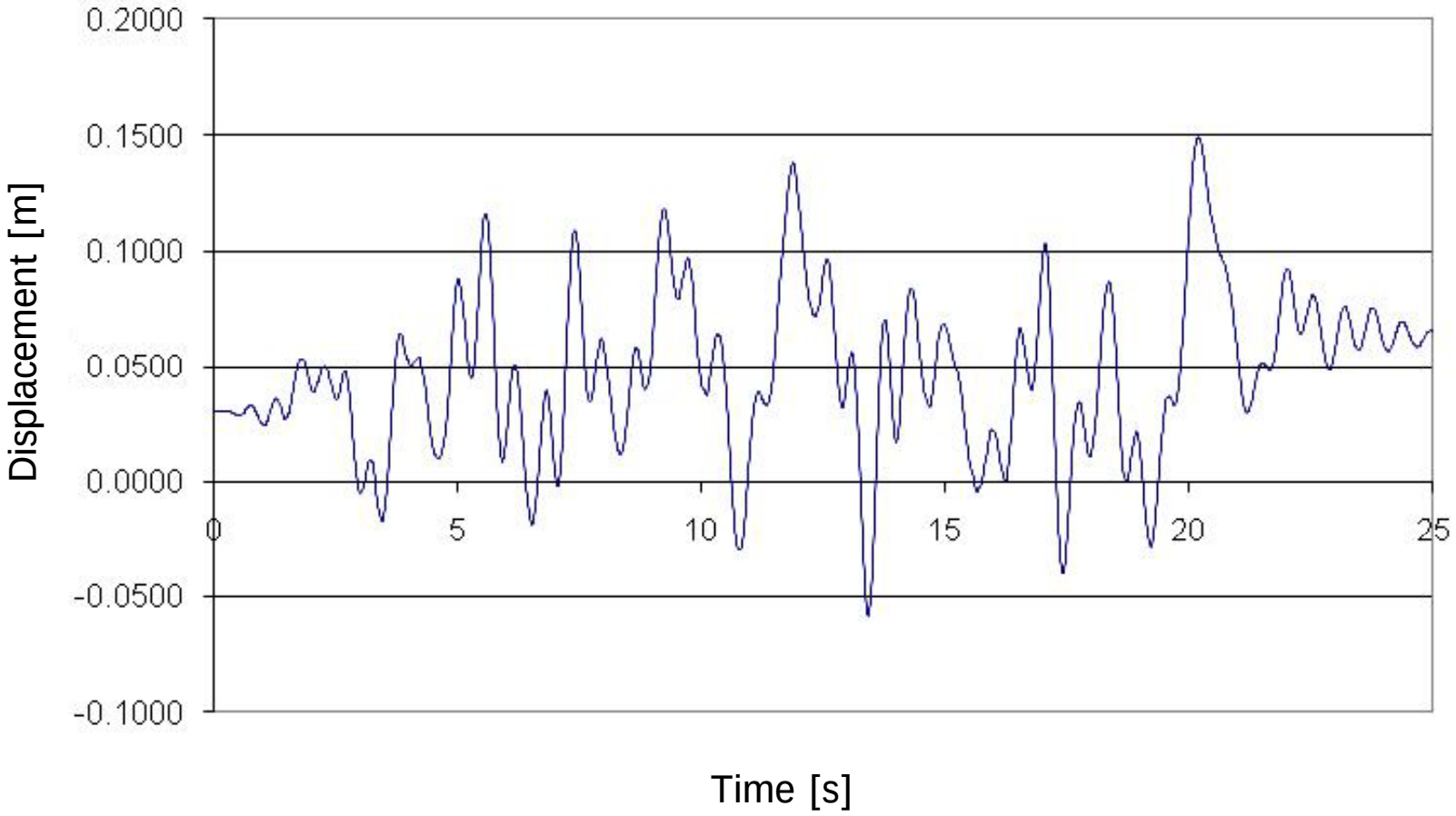
1st Accelerograms spectrum

Z direction (vertical)



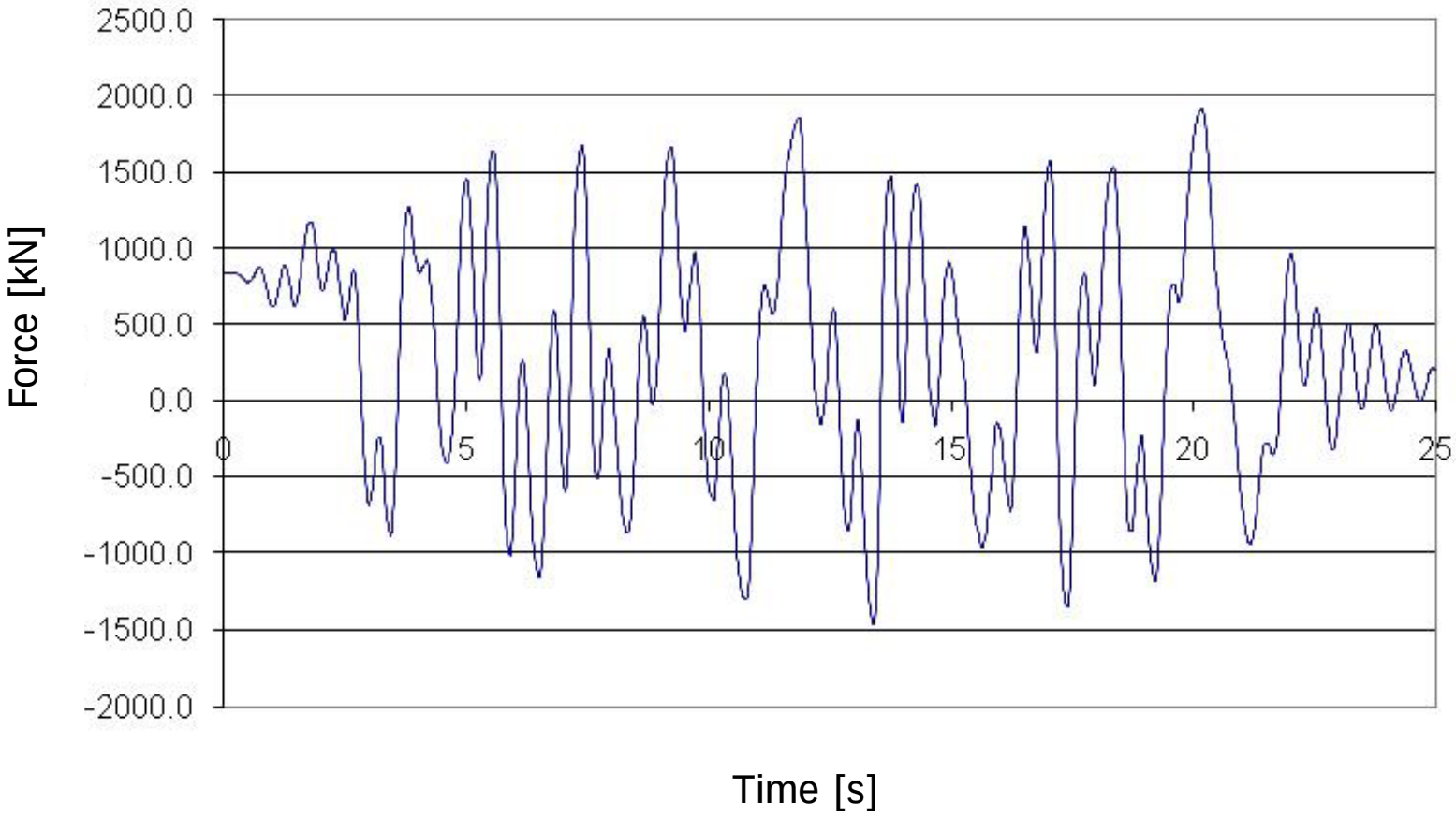
1st Accelerograms – Lead Rubber Bearings

Pier P2 longitudinal damper displacements



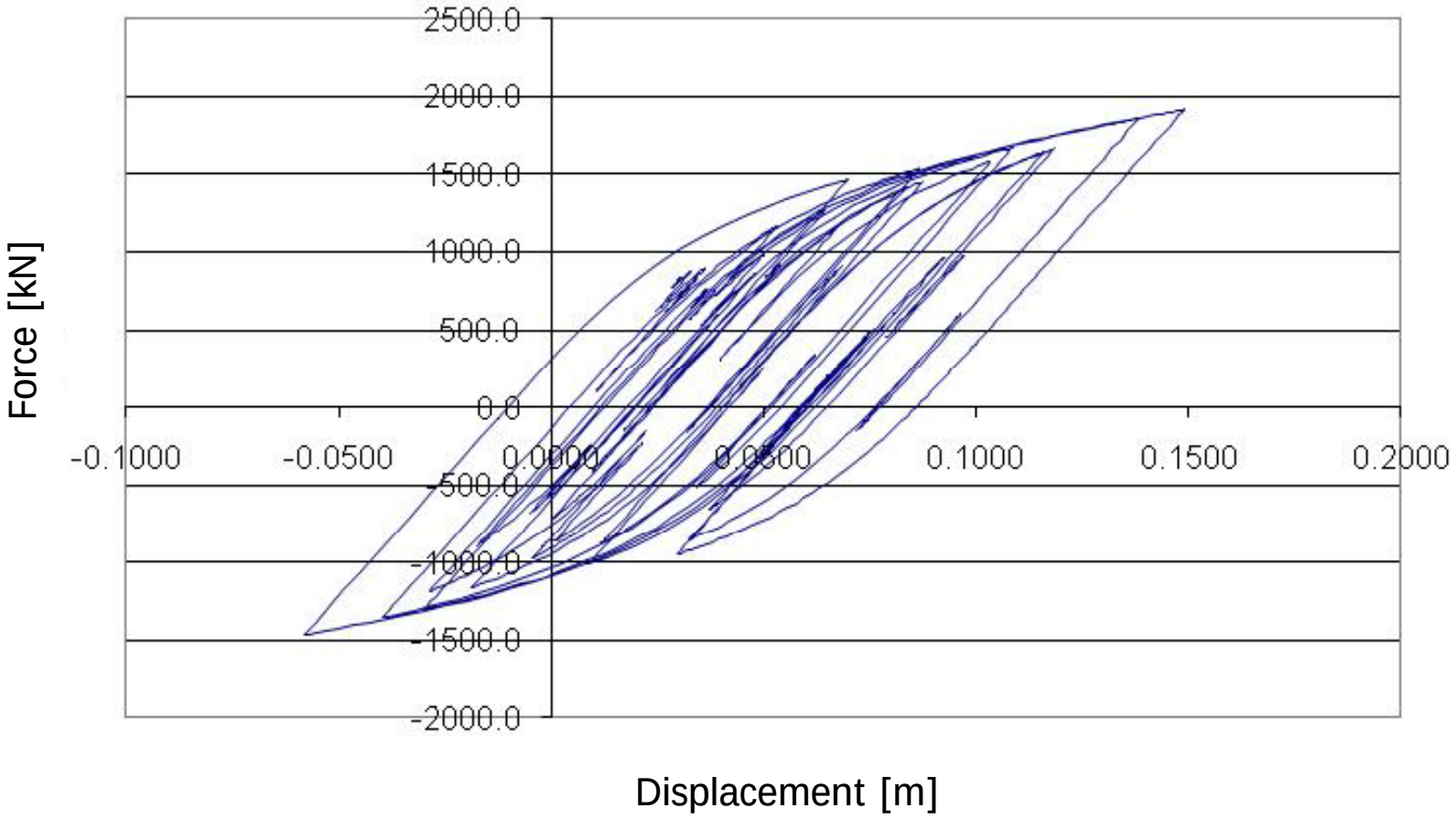
1st Accelerograms – Lead Rubber Bearings

Pier P2 longitudinal damper reaction



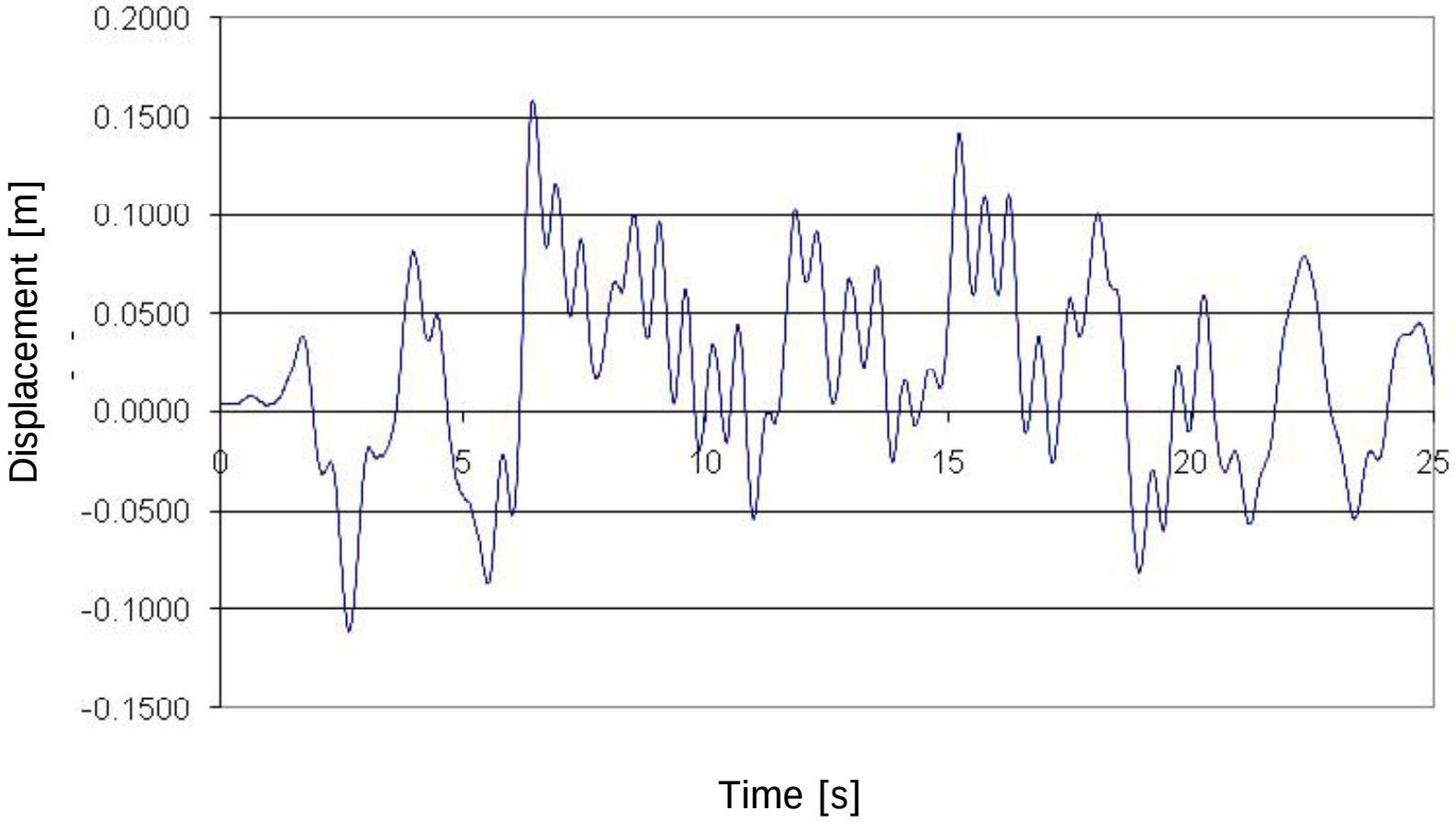
1st Accelerograms – Lead Rubber Bearings

Pier P2 longitudinal damper reaction vs. displacement



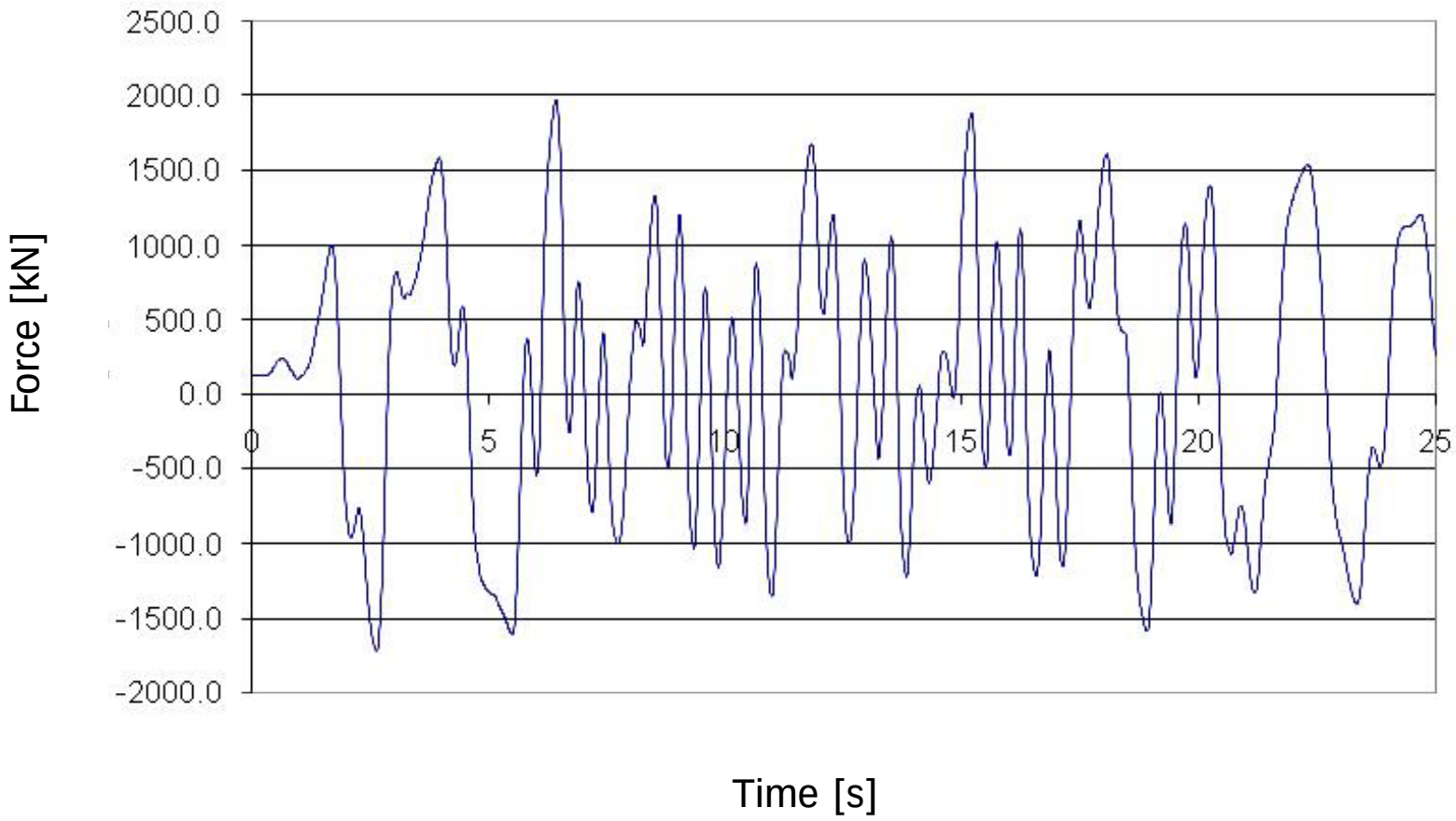
1st Accelerograms – Lead Rubber Bearings

Pier P2 transverse damper displacements



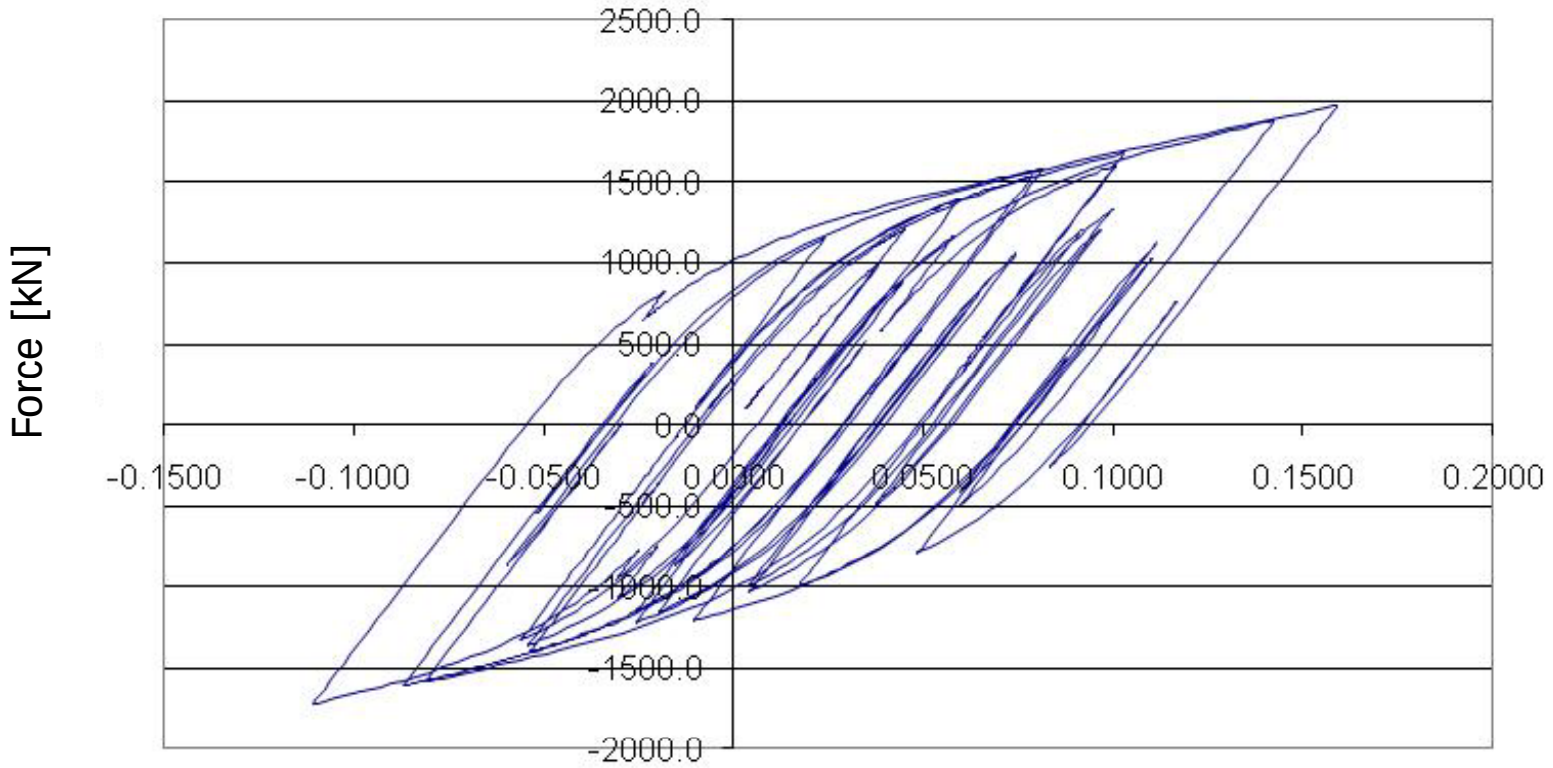
1st Accelerograms – Lead Rubber Bearings

Pier P2 transverse damper reaction



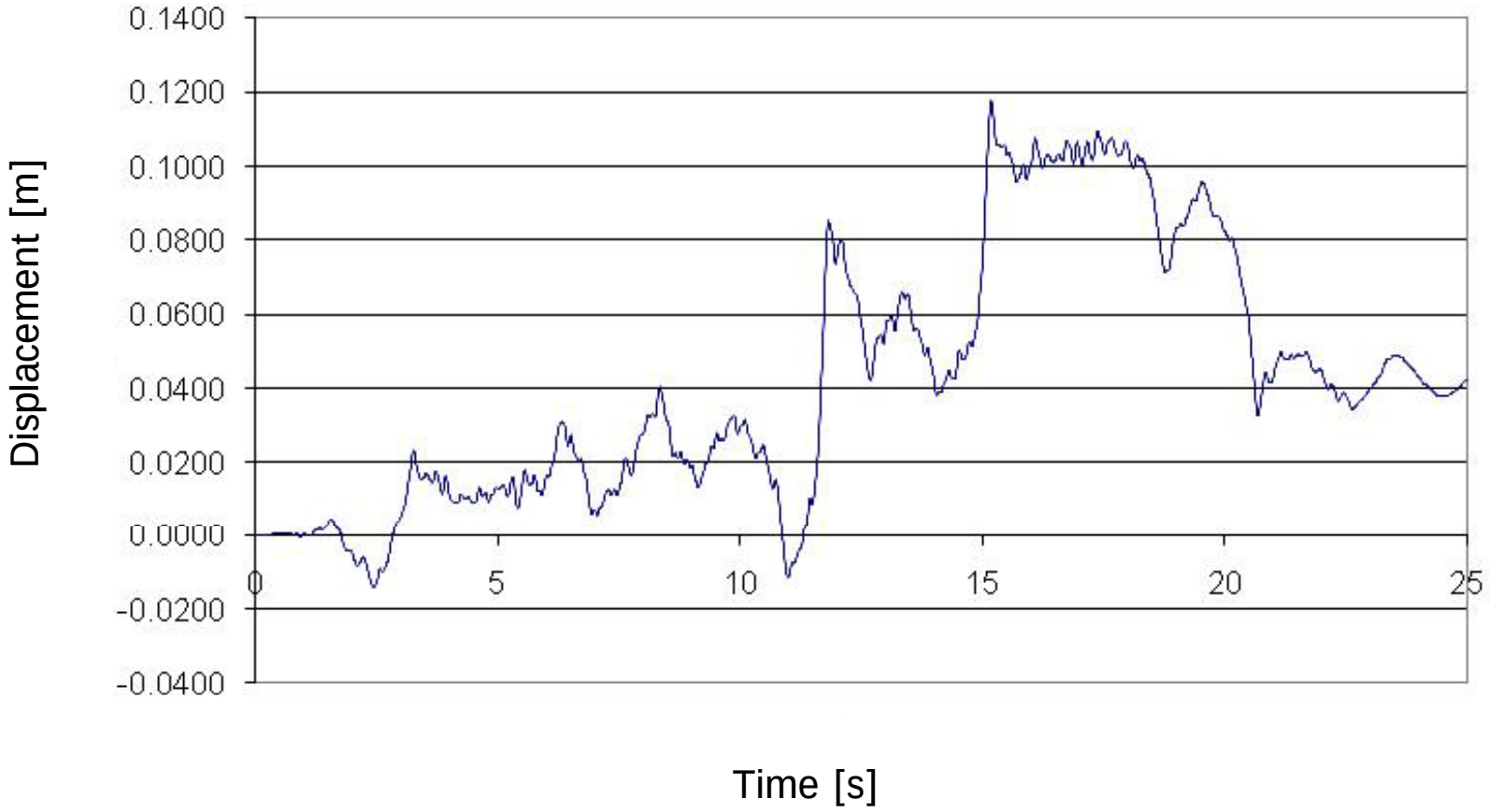
1st Accelerograms – Lead Rubber Bearings

Pier P2 transverse damper reaction vs. displacement



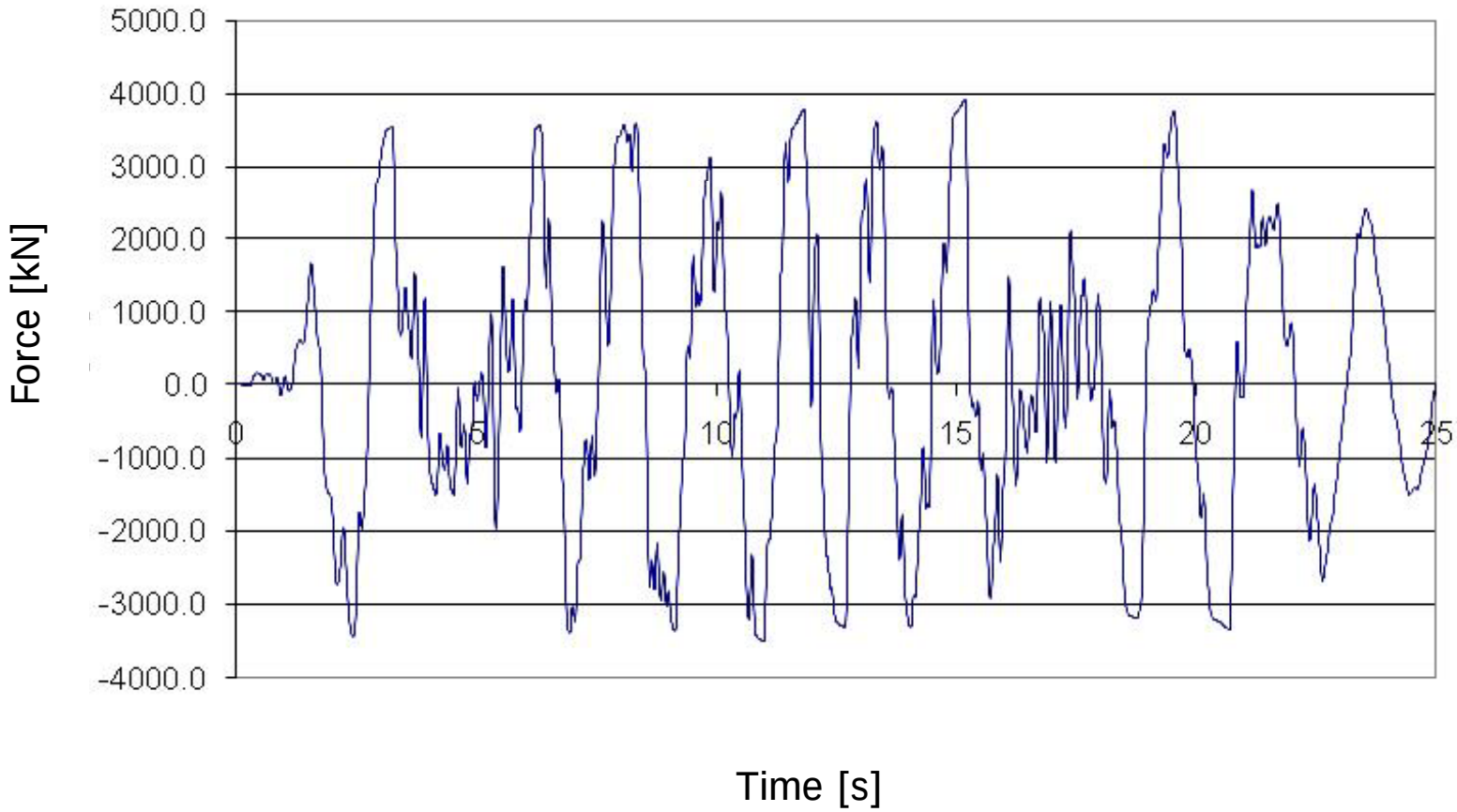
1st Accelerograms – Hysteretic Damper Bearings

Pier P2 transverse damper displacements



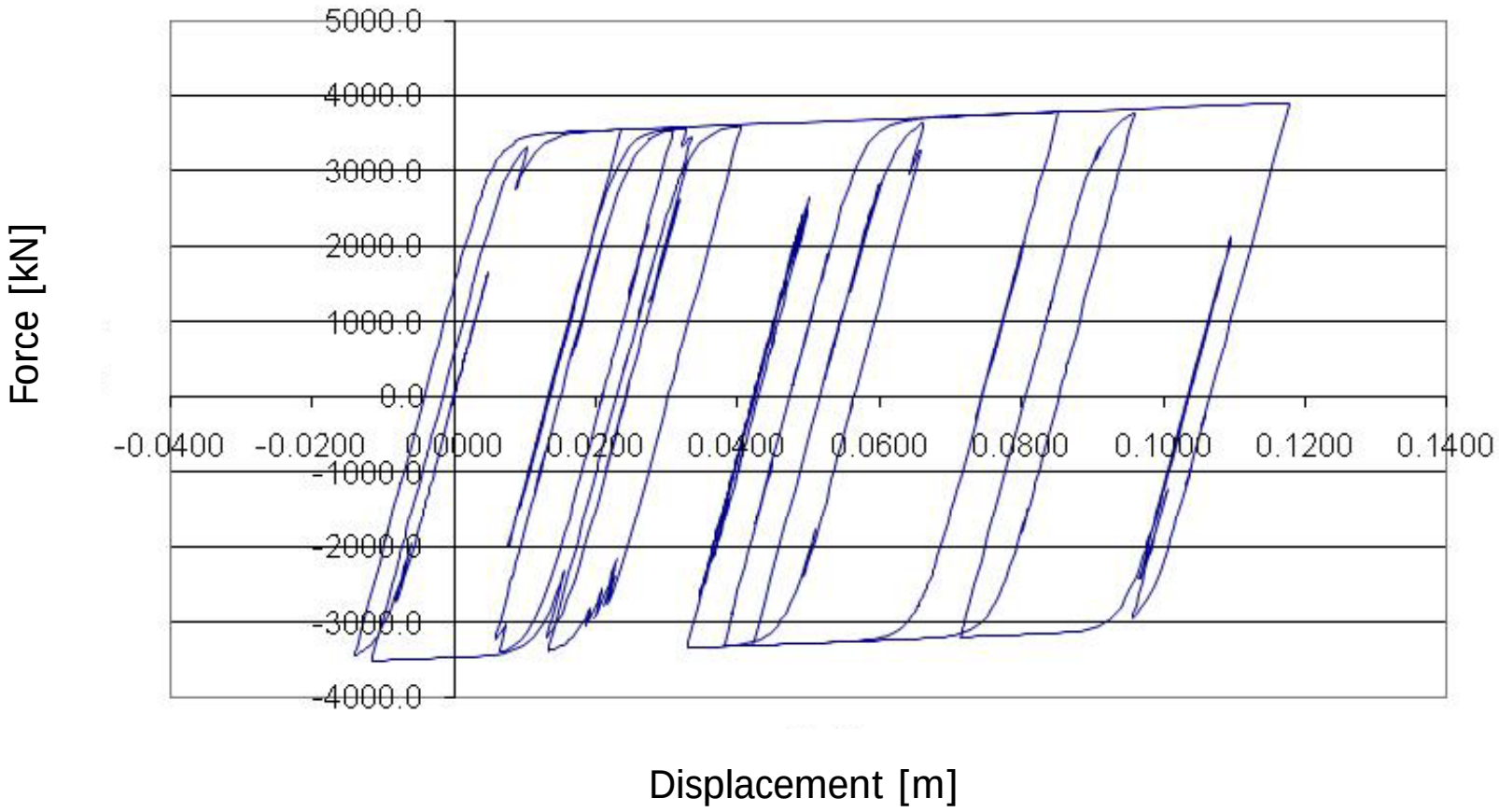
1st Accelerograms – Hysteretic Damper Bearings

Pier P2 transverse damper reaction



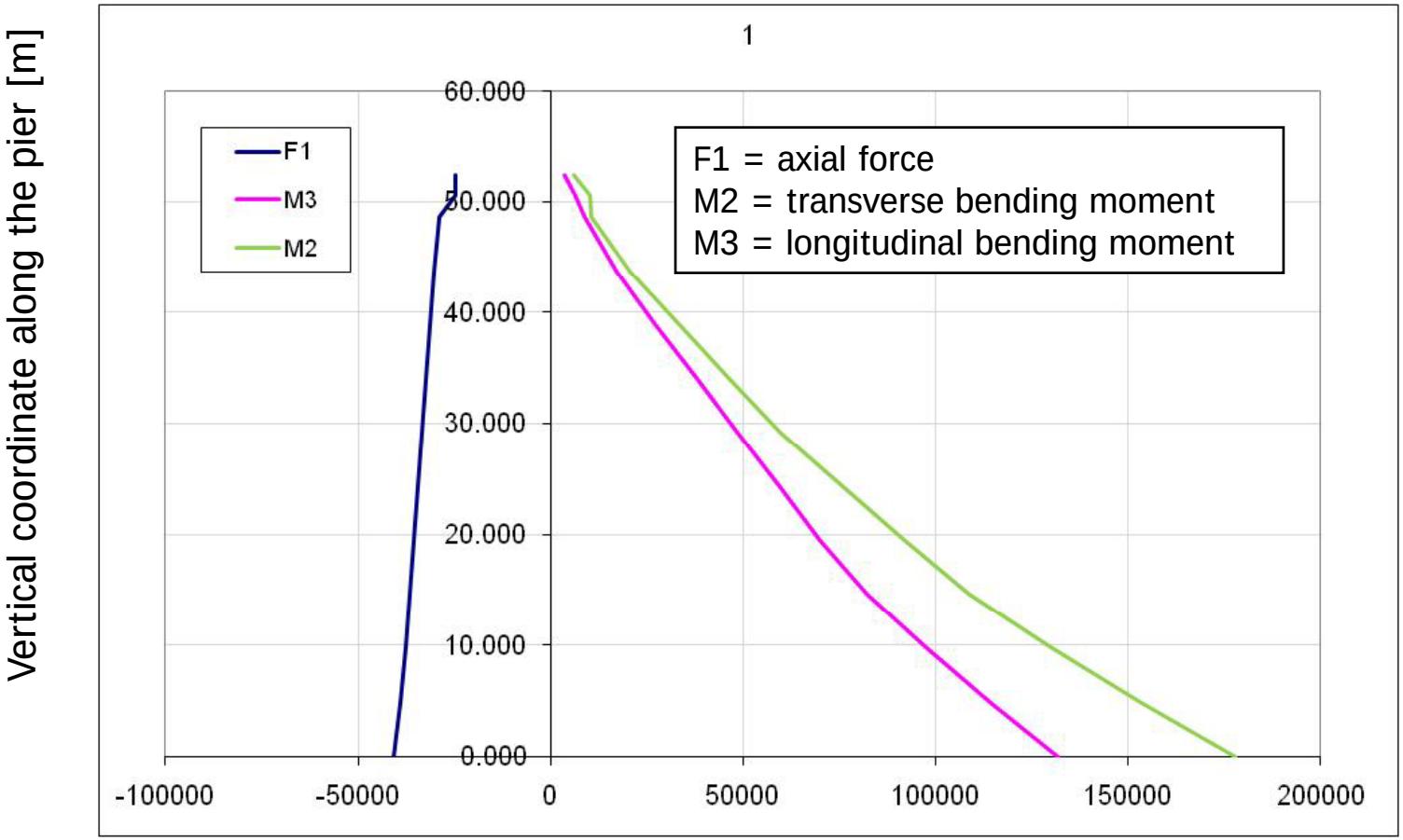
1st Accelerograms – Hysteretic Damper Bearings

Pier P2 transverse damper reaction vs. displacement



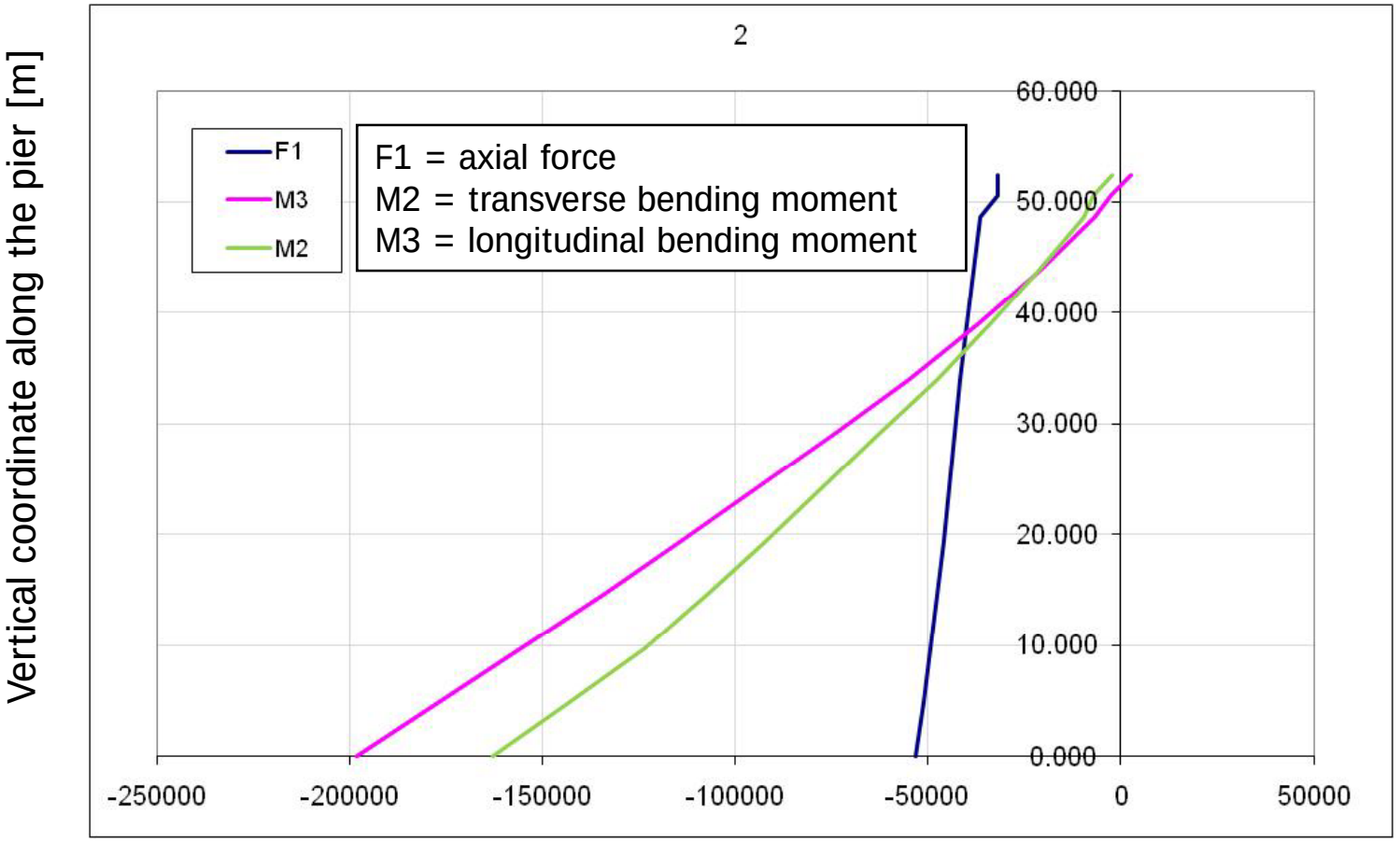
Pier P1 design internal actions – Seismic combination

$F1_{max}$ $M2_{max}$ $M3_{max}$



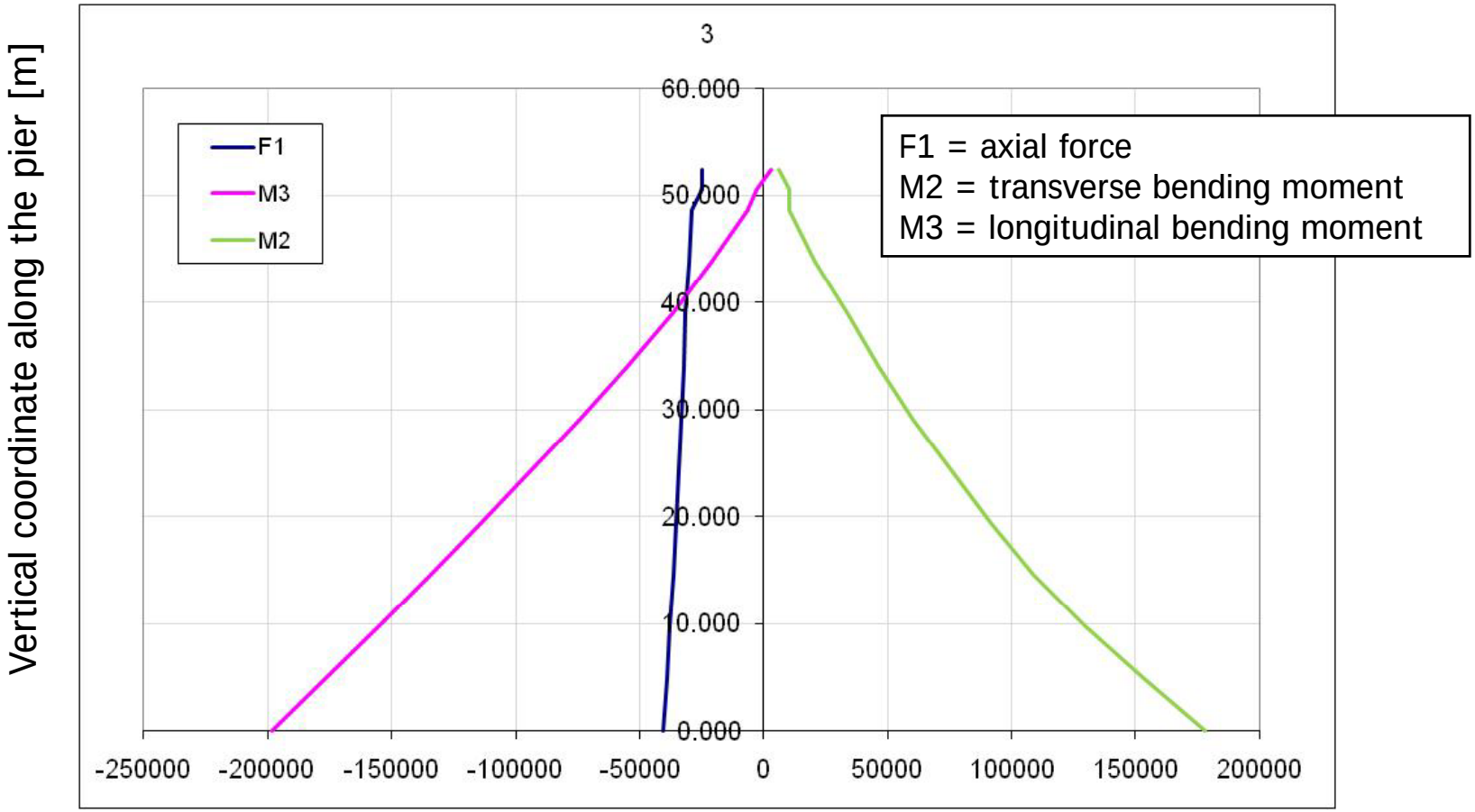
Pier P1 design internal actions – Seismic combination

$F1_{min}$ $M2_{min}$ $M3_{min}$



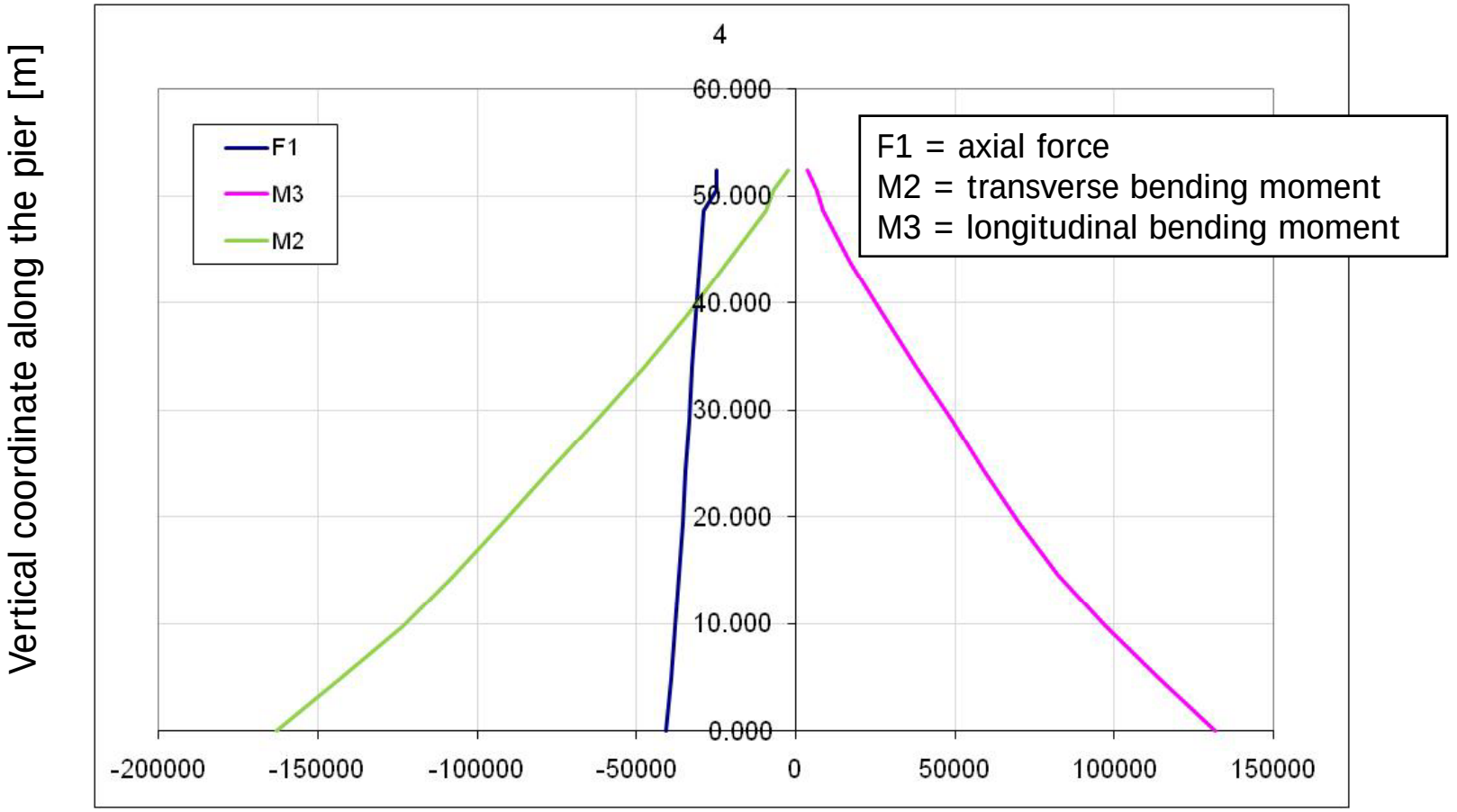
Pier P1 design internal actions – Seismic combination

$F1_{max}$ $M2_{max}$ $M3_{min}$



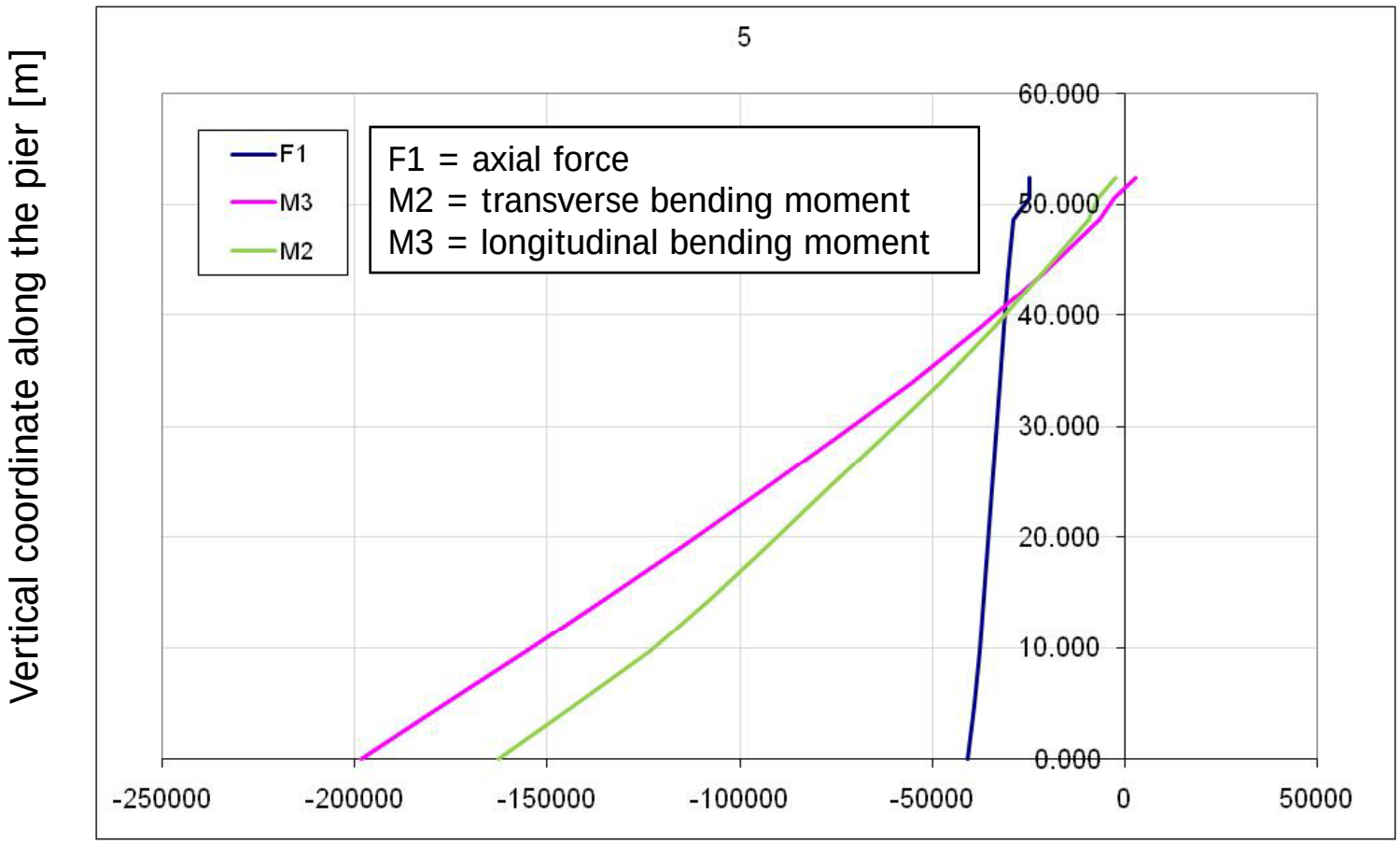
Pier P1 design internal actions – Seismic combination

$F1_{max}$ $M2_{min}$ $M3_{max}$



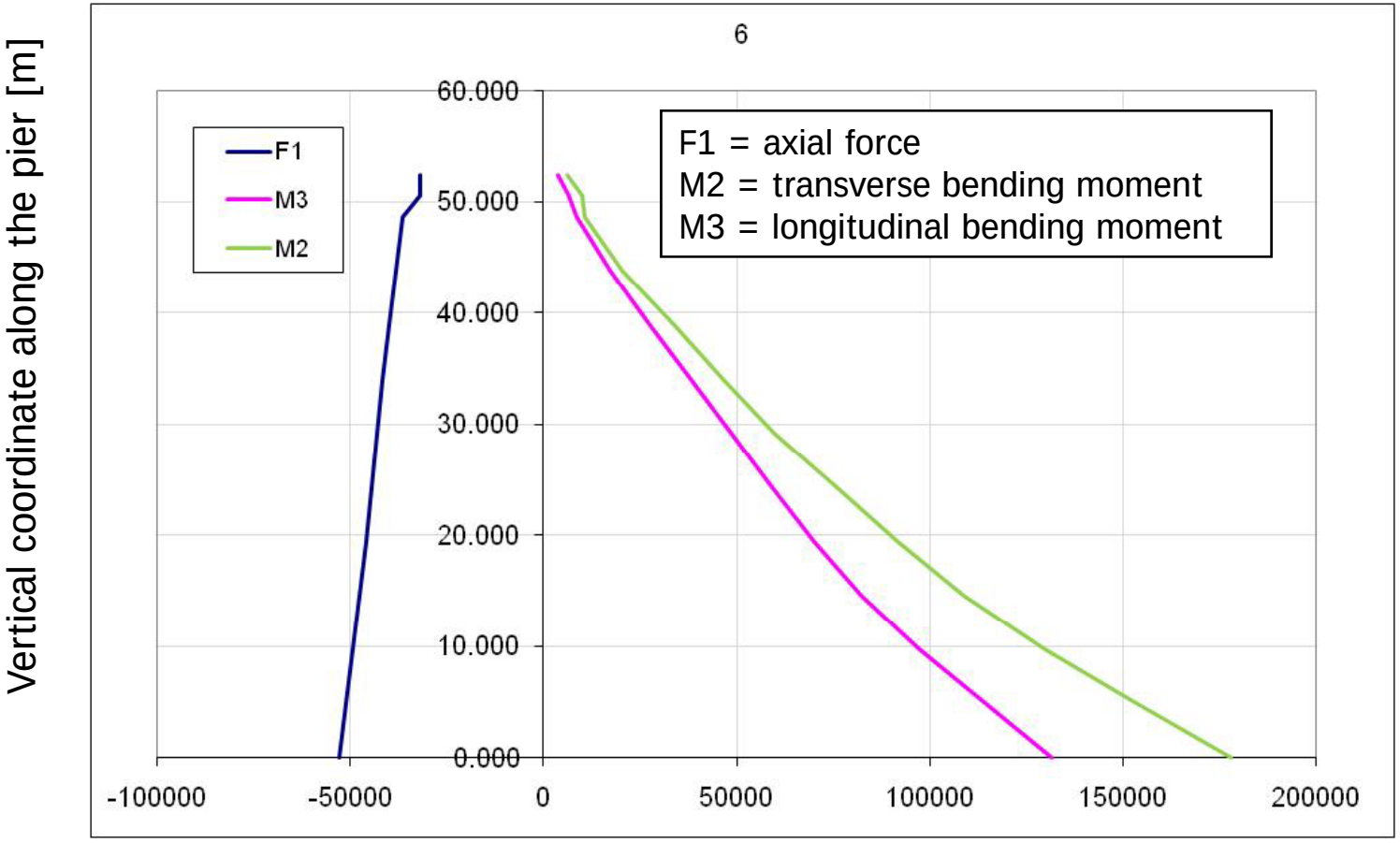
Pier P1 design internal actions – Seismic combination

$F1_{max}$ $M2_{min}$ $M3_{min}$



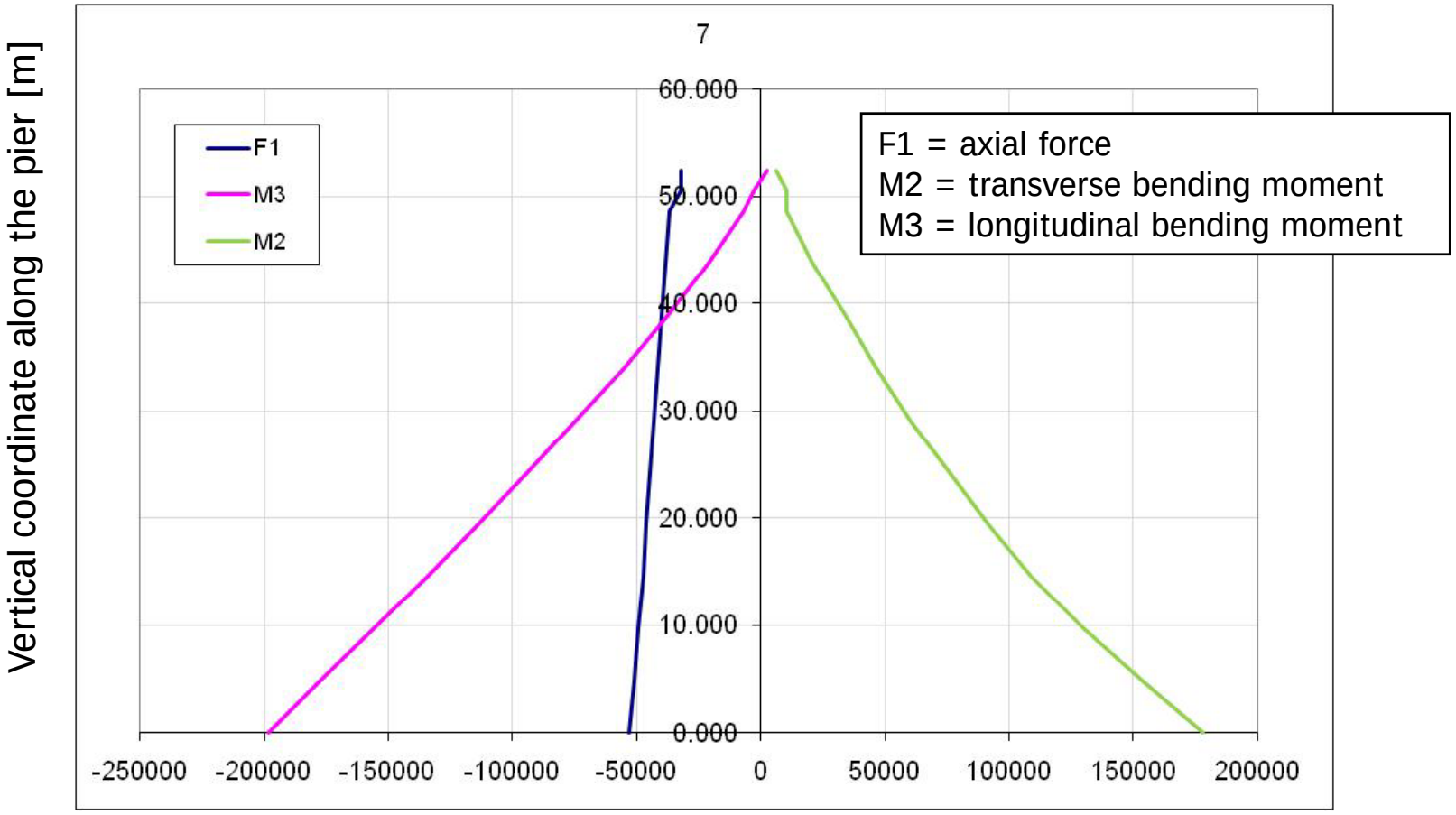
Pier P1 design internal actions – Seismic combination

$F1_{min}$ $M2_{max}$ $M3_{max}$



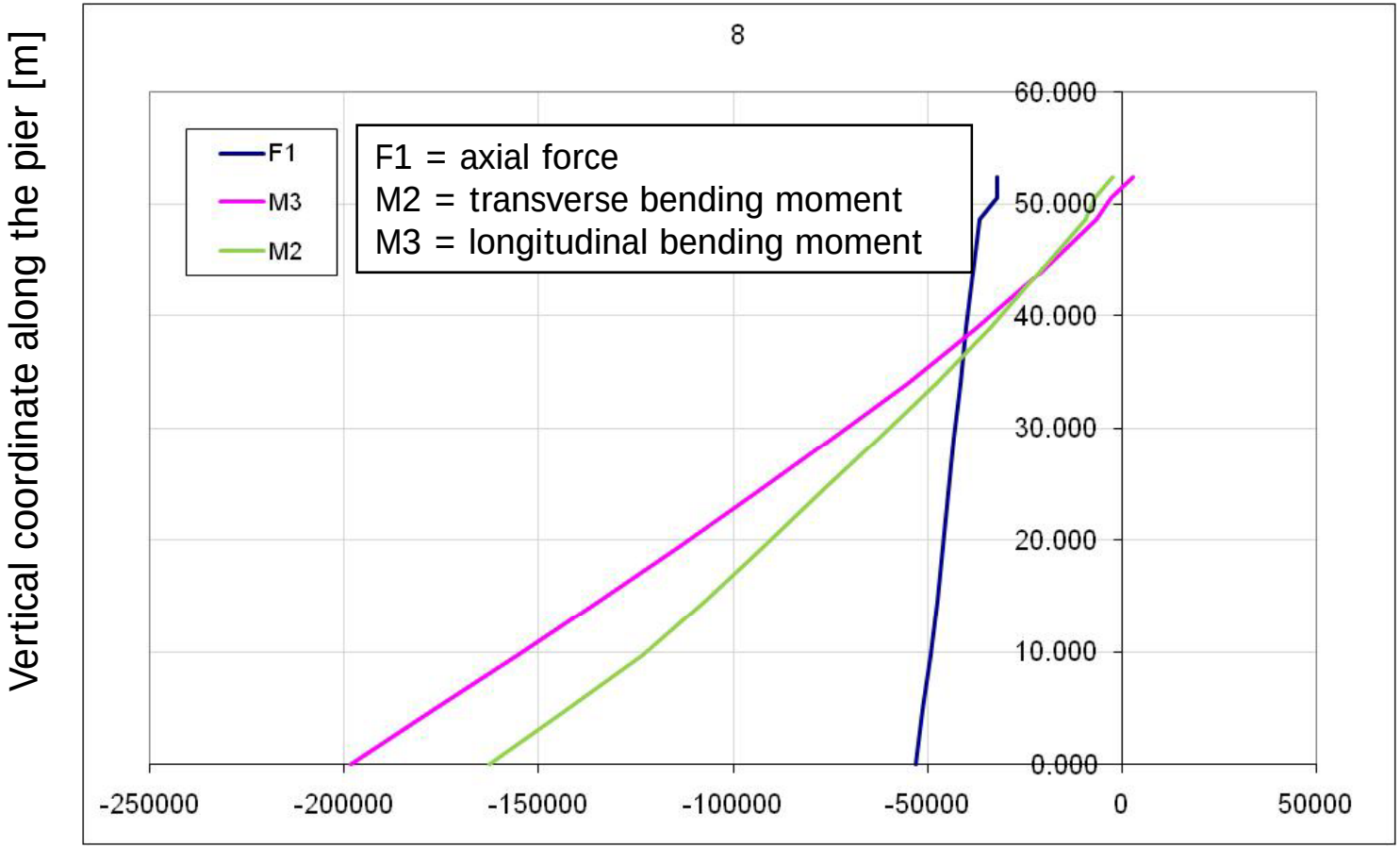
Pier P1 design internal actions – Seismic combination

$F1_{min}$ $M2_{max}$ $M3_{min}$



Pier P1 design internal actions – Seismic combination

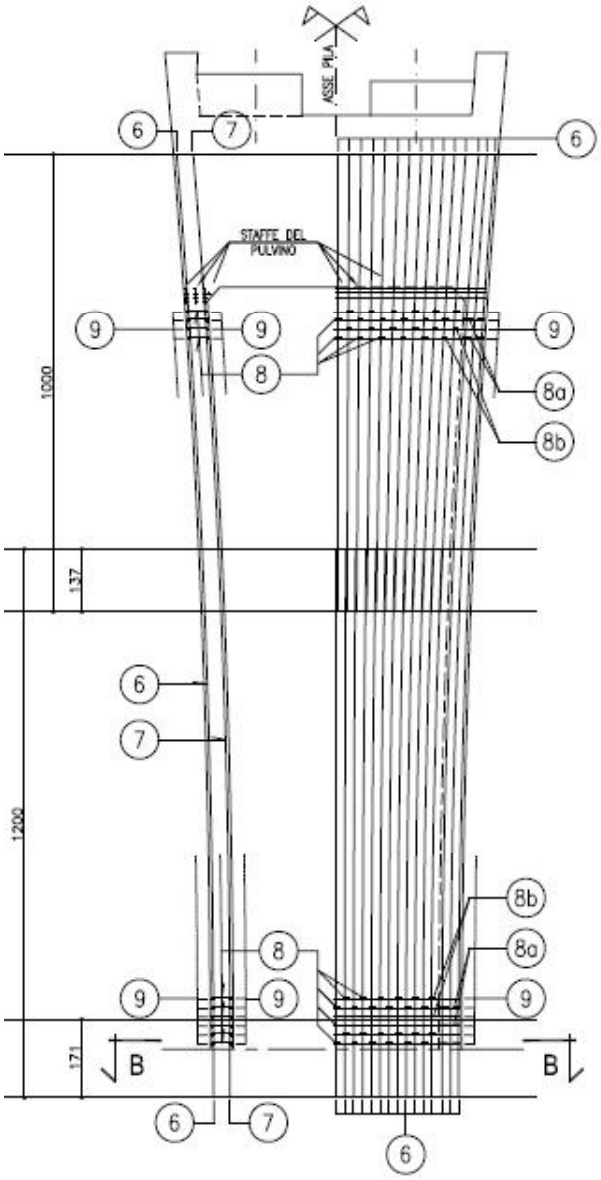
$F1_{min}$ $M2_{min}$ $M3_{max}$



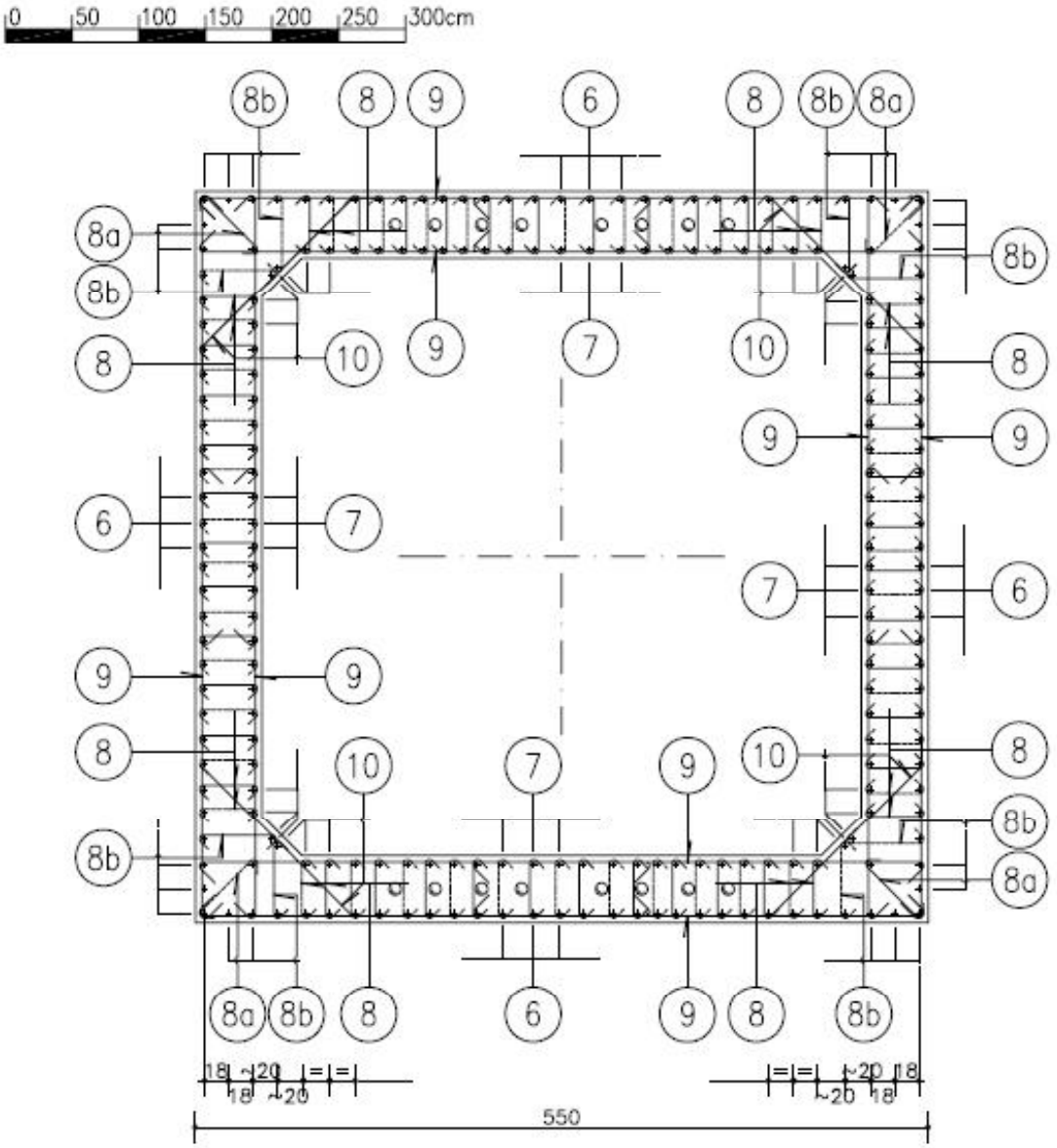
Pier P1 (53m tall) reinforcement

Upper half

(front view and vertical section)



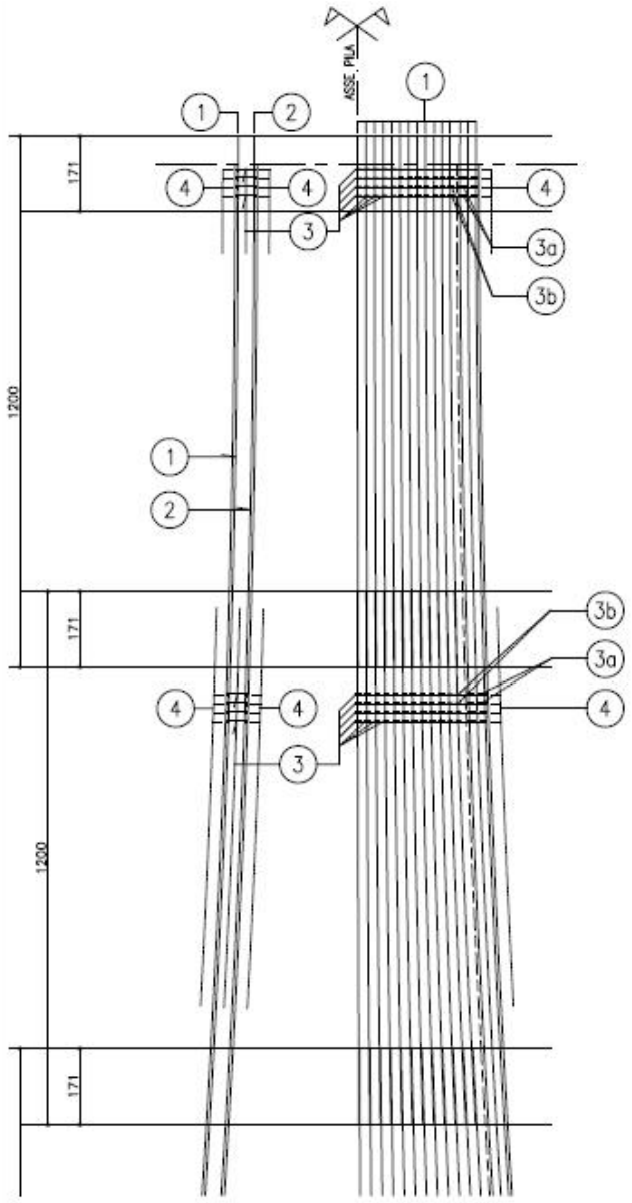
Pier P1 (53m tall) reinforcement (section B-B)



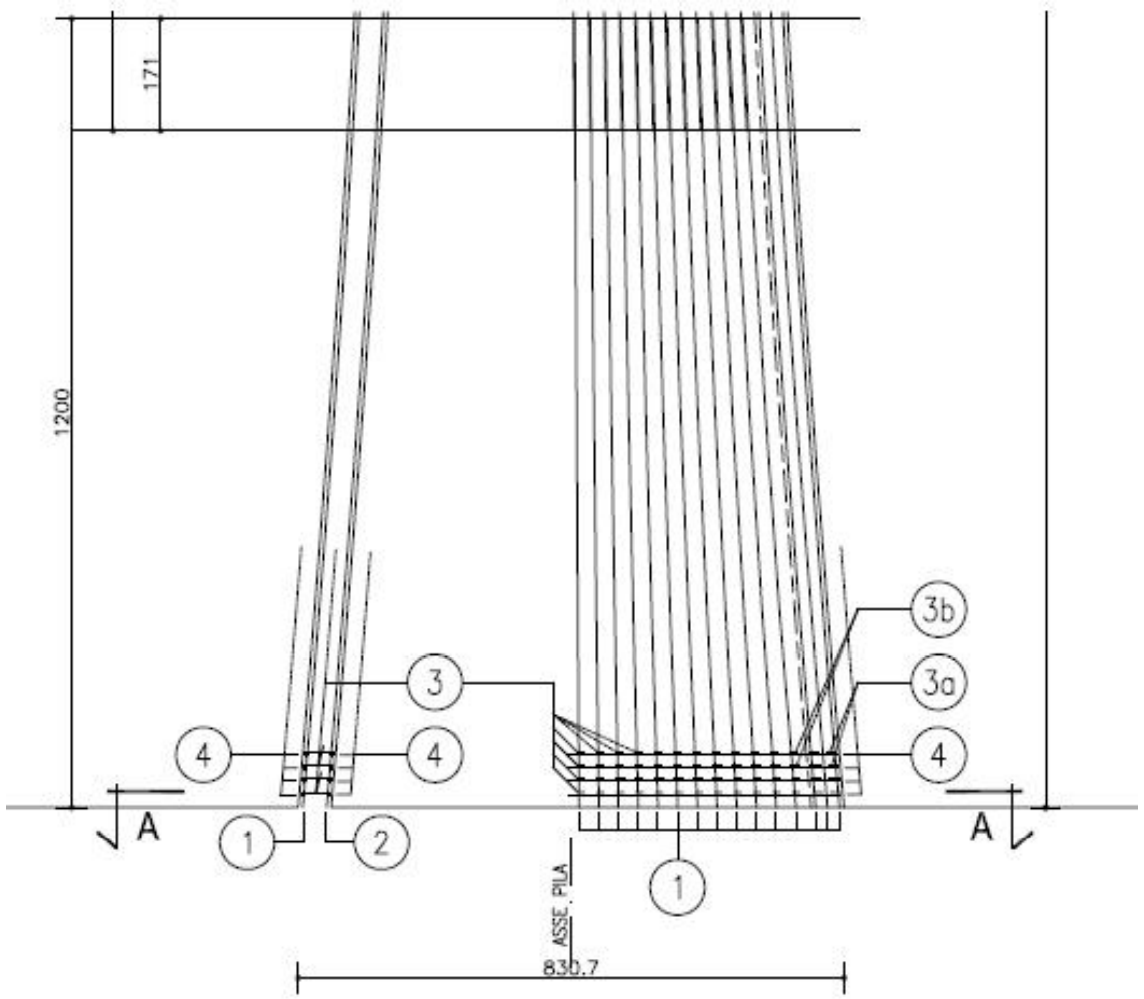
Pier P1 (53m tall) reinforcement

Lower half

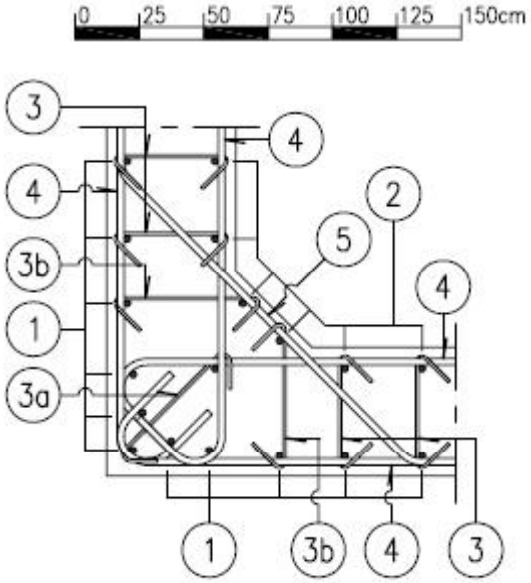
(front view and vertical section)

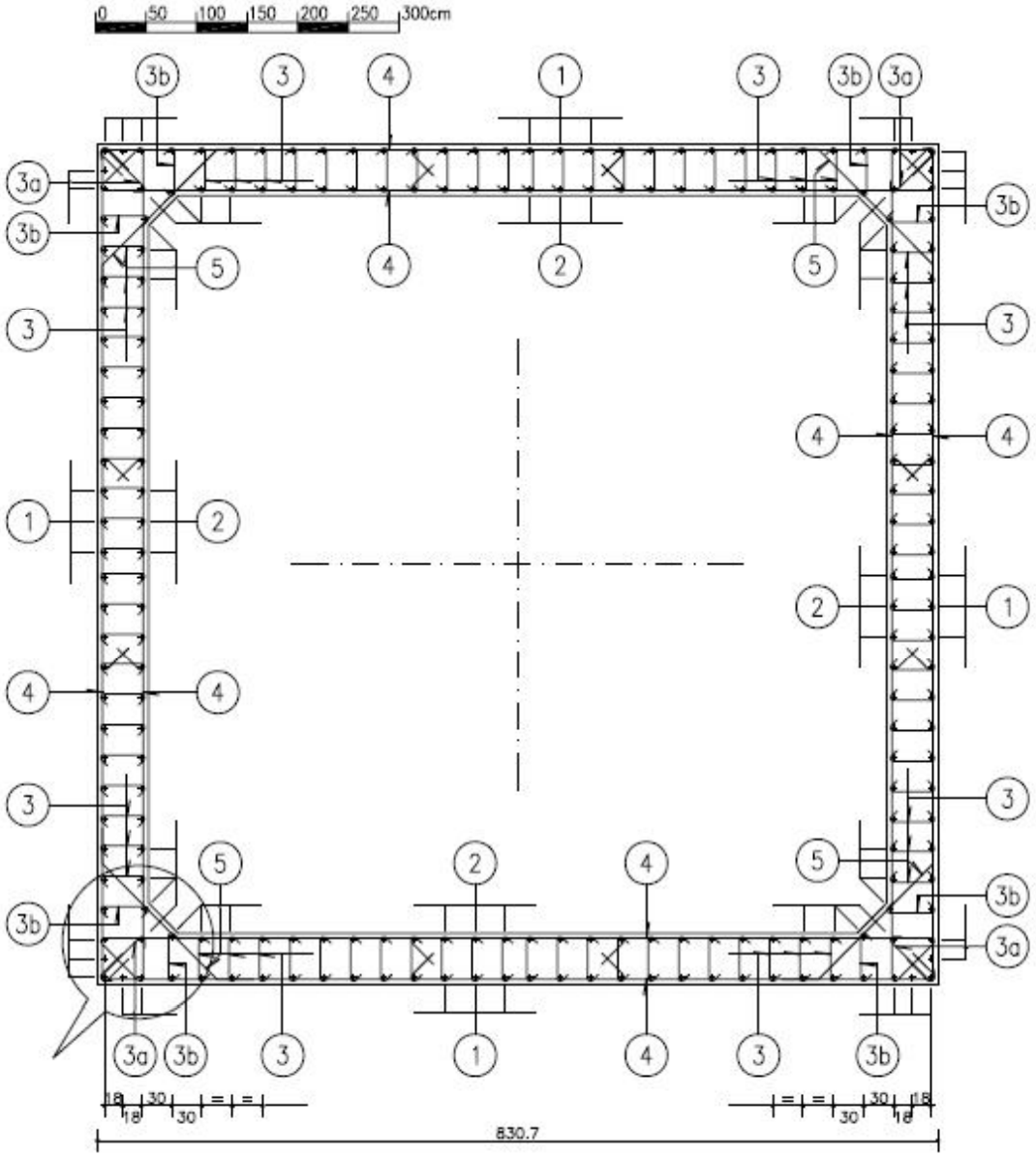


Pier P1 (53m tall) reinforcement
Base (front view and vertical section)



Pier P1 (53m tall) reinforcement (section A-A)





Pier P1 (53m tall) reinforcement table

Pos	ø (mm)	Shape	L. (cm)	N.
1	25	sovr.≥171 1200 1200 1200	1200 x 3	29 x 4
2	25	sovr.≥171 1200 1200 1200	1200 x 3	25 x 4
3	12 / 20	15 45° 52 15	82	(22x4) x 159
3a	12 / 20	15 45° 67 15	97	4 x 159
3b	12 / 20	15 45° 55÷65 15	85÷95	8 x 159
4	26 / 20	sovr.≥178 36 45° 525 36 36 45° 525 36	597 x 2	8 x 159
5	26 / 20	45° 36 160 36	232	4 x 159
6	20	sovr.≥137 1000 1200	1000 + 1200	29 x 4
7	20	sovr.≥137 1000 1200	1000 + 1200	25 x 4
8	12 / 40	disporre a quinconce 15 45° 52 15	82	(11x4) x 97
8a	12 / 40	disporre a quinconce 15 45° 67 15	97	2 x 97
8b	12 / 40	disporre a quinconce 15 45° 55÷65 15	85÷95	4 x 97
9	18 / 20	sovr.≥123 22 45° 346 22 22 45° 346 22	390 x 2	8 x 97
10	18 / 20	45° 22 160 22	204	4 x 97

Thank you for the kind attention