Excavation support solutions for a large underground parking

P. L. Oróstegui
Constructora Lancuyen Ltda., Concepción, Chile

F. A. Villalobos
Civil Engineering Department, Catholic University of Concepción, Chile

GeoMos, Moscow, Russia, 7th June 2010

Introduction

- Great Concepción expansion
- Necessity to build underground
- Loose sands and soft silts
- Soldier Pile Wall SPW (Berliner wall) widely used to sustain excavations
- High seismicity $M_w > 8$ (1558, 1570, 1657, 1751, 1835, 1960, 2010)

SPW characteristics

- Anchored SPW offers free movement within excavations
- Continuous and temporal support
- Made up of H-steel sections driven into the soil before digging
- H distances to be calculated, range between 1.2 and 3 m (1.6 m very common)
- Once digging timber laggings are inserted horizontally

More SPW characteristics

- Flexible without anchorage
- Permeable to water (if not, easy to do so)
- Good knowledge of soil geotechnical properties is key for design

The Tribunal car park project

Curved anchored Soldier Pile Wall

Soil mechanics information

- Silty sands SM, fines content is not plastic
- Soil mechanics studies focus mainly on foundation design
  → deeper soil below excavation
- Excavation support companies should participate from the beginning of the project
- Savings in incomplete soil mechanics studies for SPWs can lead actually to more expensive designs or to put in risk the construction

Soil	h m	γ kN/m^3	γ' kN/m^3	G_s	ϕ'_{cr}
Fill	0-2	17.5	7.5	2.6	30
SM	2-7	17.5	7.5	2.8	33
SM	7-16	20.7	10.7	2.8	34

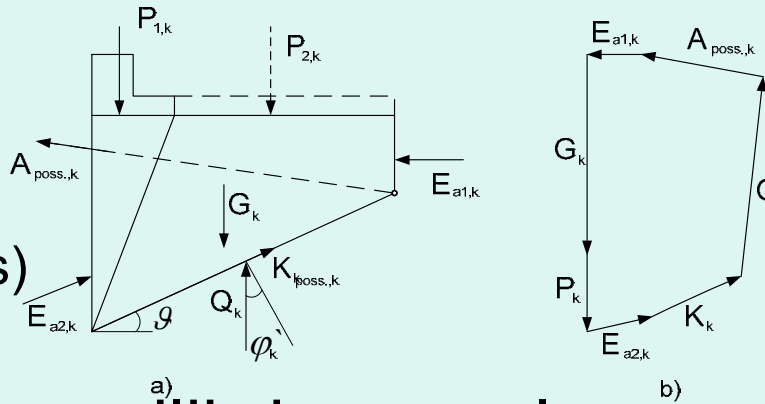
RD, %	ϕ'_{max}, o	c, kPa	$(N_1)_{60}$
45	30	0	15
60	34	0	18
82	37	0	36

Averaged values estimated from soil mechanics data

Design methodology

- Kranz (or block) method for one anchor

(Ranke & Ostermayer for more anchors)



- Static and pseudo dynamic equilibrium analyses

Structural element	overburden, kPa
Street	10
Building, per floor	12
Tribunals at 3 m	100

Static analysis

FS ≥ 1.5

Structure	a_h/g
Tribunals	0.18
General edification	0.15
Street	0.12

Horizontal accelerations used in the dynamic earth pressure and anchor analysis

FS ≥ 1.1

Anchor design

- Stability analysis results obtained from GGU-Retain software allow for:
- Anchor loads, free length, grouting length and number of cables
- Limit tension of the anchor

$$T_u = \pi D_s L_s q_s$$

$D_s \approx \alpha D_d$ is the mean diameter of the grouting section, $\alpha = 1.2$ is an injection coefficient IGU (Injection Global and Unique), D_d perforation diameter, L_s length of grouting, $q_s \approx 300$ kPa limit friction from SPT

- To supply the strength required a number *n* of cables is calculated using the following values:

Parameter	value
Cable diameter D, mm	15.2
Cable area A_c, mm^2	140
Yield stress f_y, MPa	1670
Characteristic ultimate load T, kN	250
Characteristic yield load T_y, kN	235

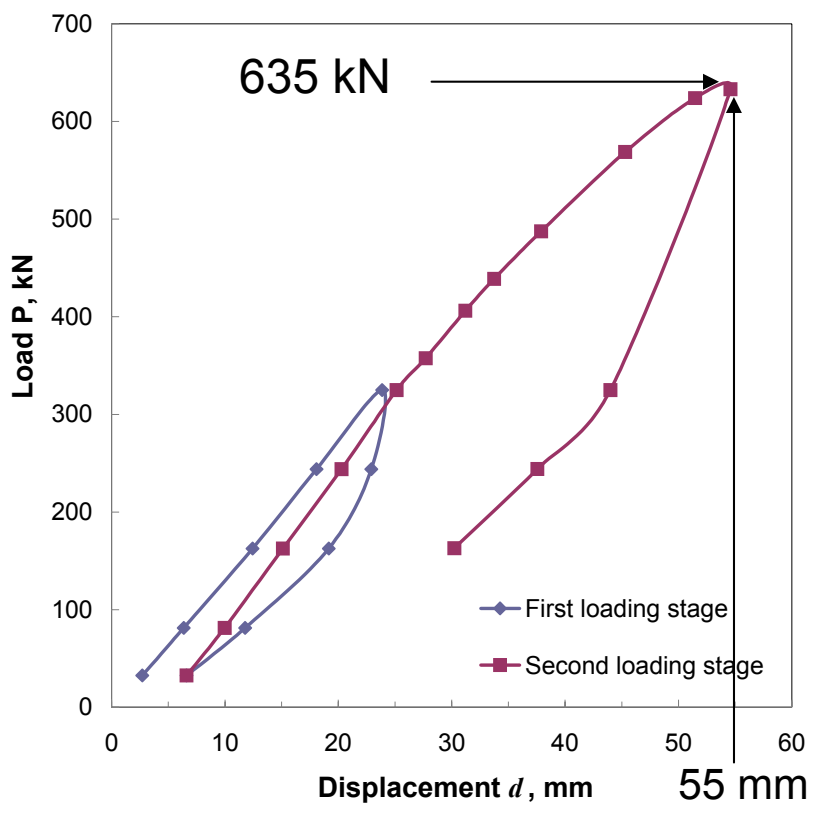
$$T_a = nA_c f_y / FS$$

FS = 1.5

Nº of cables	Allowable load, kN
2	313
3	470
4	627
5	783
6	940

$T_o \rightarrow T_a$ anchor resistance from GGU per spacing 3.2 m

Anchor loading test with 3 cables in second row

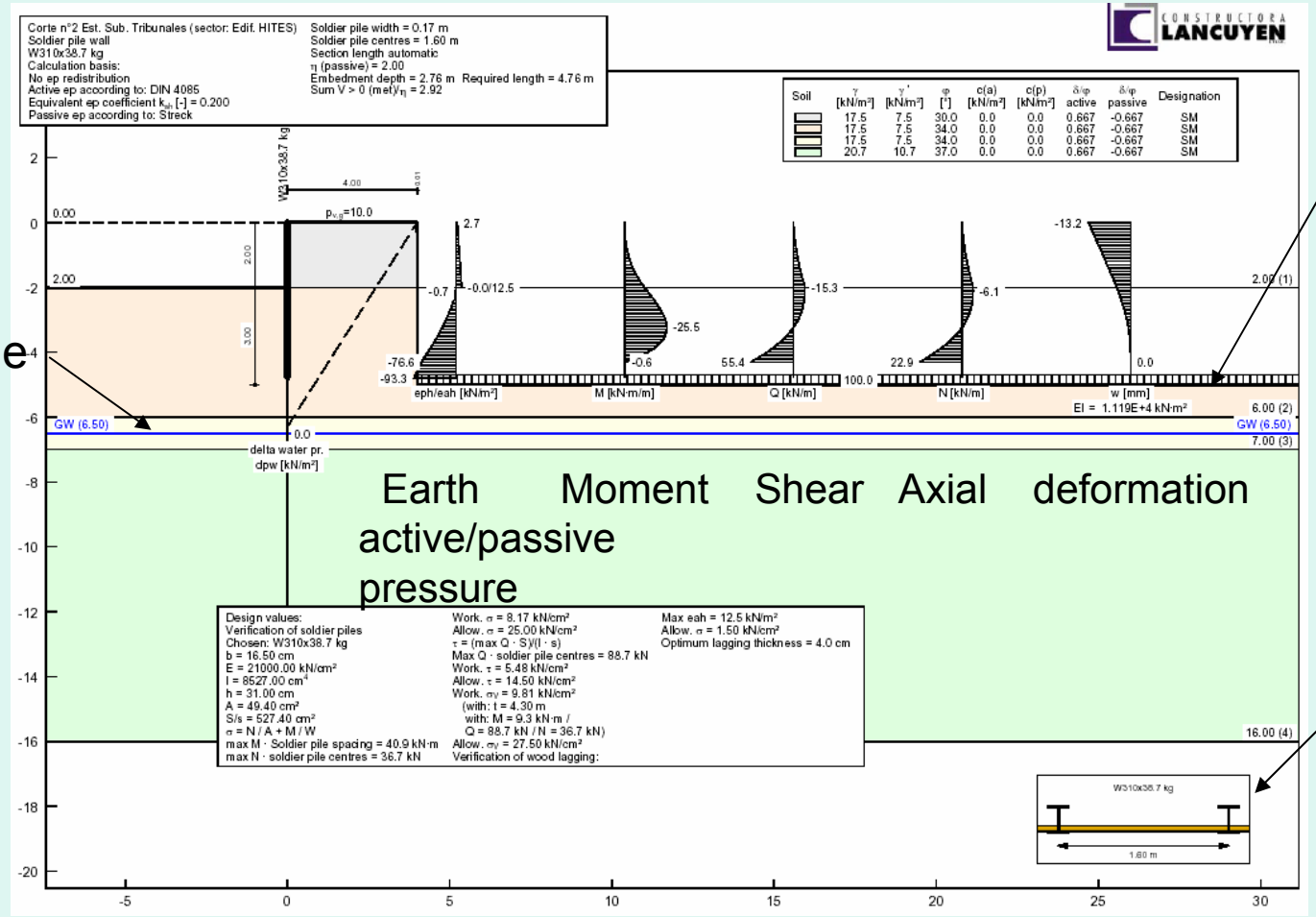


- Maximum capacity defined as: 90% of T_y = 235 kN x 3 = 635 kN
- L_s = 2.5 m (grouting length)
- Linear response up to 325 kN and considerable recovery during unloading
- Stopped when d = 55 mm due to larger stiffness reduction
- No cable failure was measured, before mobilising grouting strength
- Coincidentally a maximum capacity assumed is 635 kN
- Dense sand according to Ostermayer (1974)

Stability analysis following the construction sequence

- Excavation geometry, soil deposits, water table level, street and buildings on the side
- Results of lateral earth pressure, moment, shear and axial loads, lateral deformation

Stability analysis without anchor, 2 m

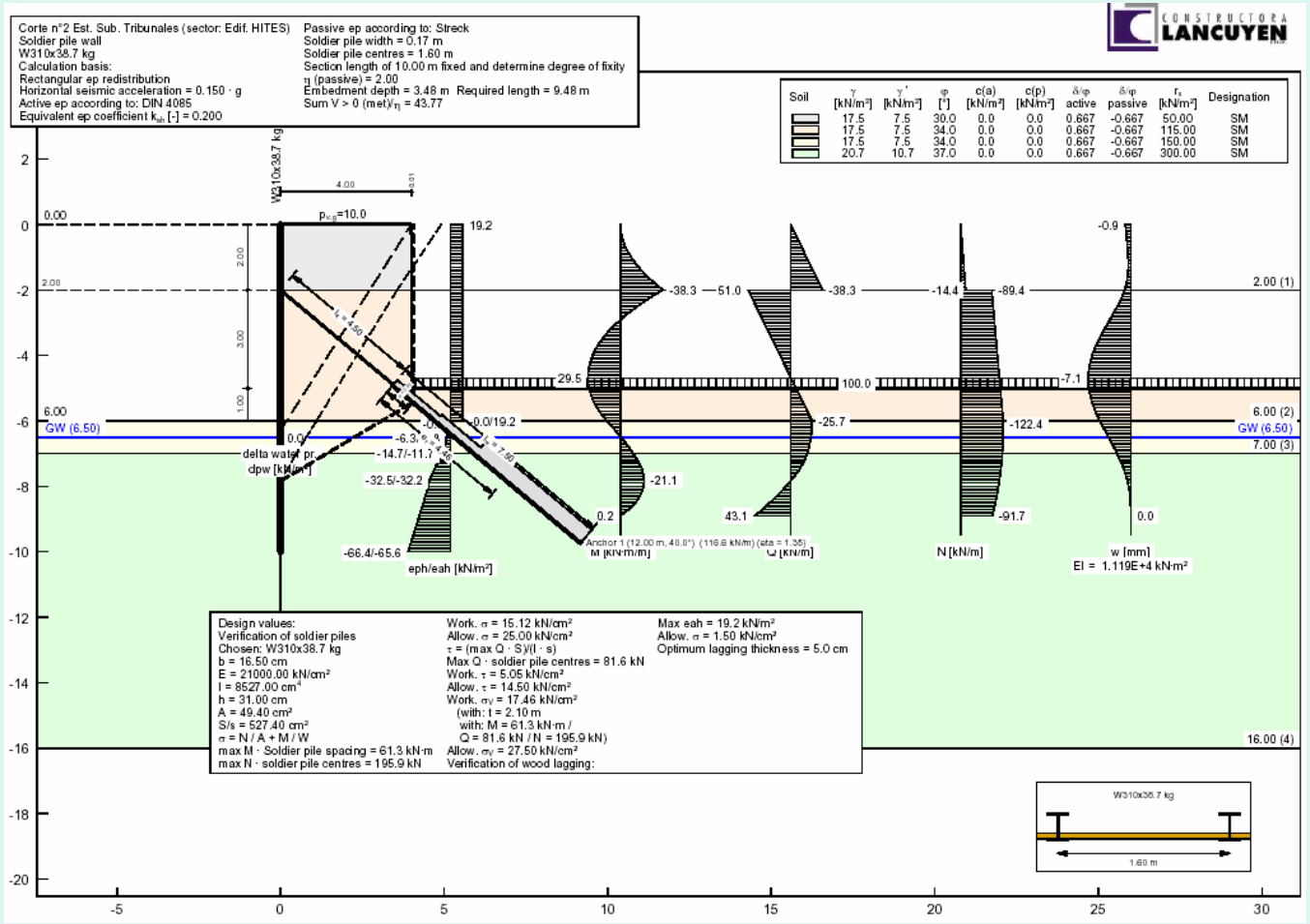


Water table

Hites building

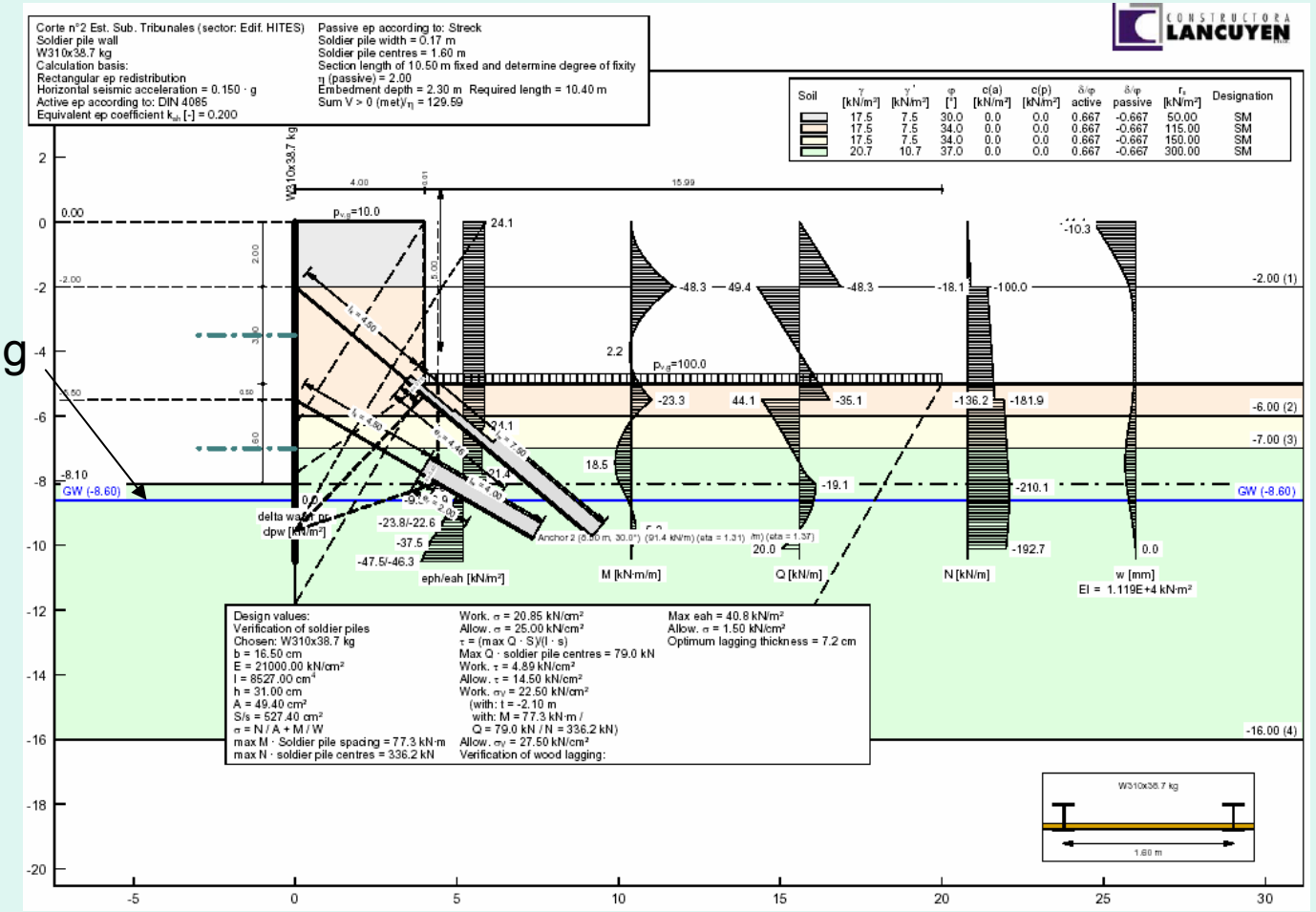
Soil pile wall

Stability analysis with one anchor at 1 m, 6 m

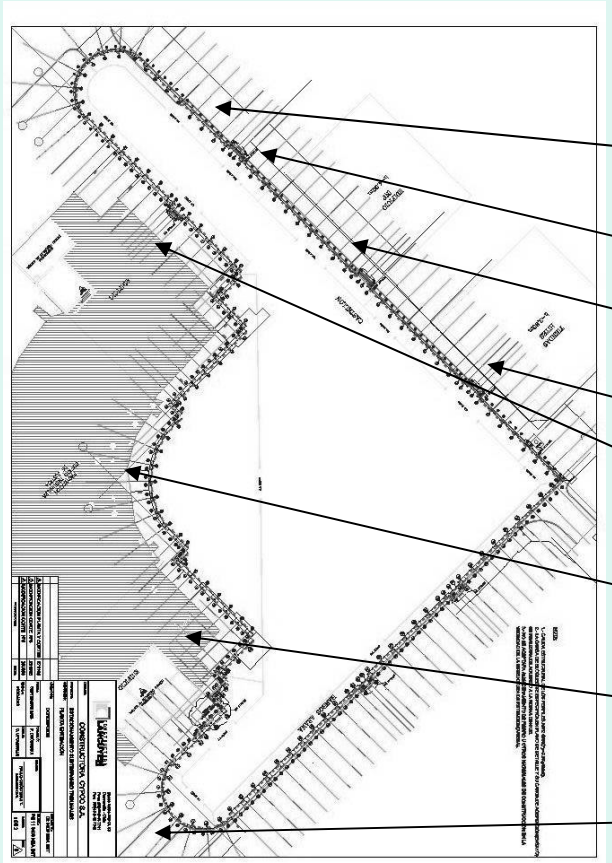


Stability analysis with two anchors at 1 m and 5.5 m, 8.1 m excavation depth

dewatering



Anchor design



T_o kN	L m	L_s m	β º	buildings	D_f m
350 280	12.5 8.5	8 4	30 25	Fiscalía, Tucapel St	0
370 480	12.5 11	8 6.5	30 25	Entrances INP	1.5
450 325	11.5 9	7 4.5	45 35	INP	5
410 300	12 8.5	7.5 4	40 30	Hites	5
350 330	12.5 9	8 4.5	30 25	Tribunals	3
330 520	13 12.5	8.5 8	30 25	Tribunals	3
400 300	12.5 8.5	8 4	35 25	Tribunals	5.5
370 480	12.5 11	8 8.5	30 25	Barros Arana St	1.5

T_o anchor resistance from GGU per spacing 3.2 m

L total length, L_s grouting length, β angle of anchor inclination, free length 4.5 m

Final remarks

- 3596 m^2 of SPW with 314 postensioned anchors under loads between 300 and 560 kN
- 300 H sections totalling 3200 m
- Transfer of loads from definitive RC walls and slabs to H piles
- Integrity of timber and H piles with time?
- No damage (cracks) has been found after the 27 February earthquake M_w = 8.8
- Further research is suggested by monitoring

Contacts:

orostegui@lancuyen.cl www.lancuyen.cl
avillalobos@ucsc.cl www.civil.ucsc.cl