GROUND ANCHOR LOADS MEASURED IN A SEISMIC EVENT IN SOUTH ACCESS MALLECO VIADUCT ANCHORED WALL

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Abstract

Here we present the load measurements of an instrumented Anchored Wall which was built in 2002 in the south access of the Malleco Viaduct, Route 5 Temuco-Collipulli, IX Region of Chile.

Twelve of the ground anchors of the structure were monitored since its construction with vibrating wire load cells. Some of them suffered component damage and vandalism, but we can still get data from seven of them after 14 years of performance.

An automated data recollection system was put in place (a data logger) and it was assembled with a seismic switch with a set of acceleration of 0,07g. It allowed to measure the load of the ground anchors in the seismic event of 27th of February of 2010.

The measurements indicate us what was formulated in some papers before, that the load variation was very low (below 3%) due to two facts: the free length of the anchors that influences in reducing the response to differential displacements between extremes of the free length of an anchor (anchor head and fixed length) and a possible block behavior of the anchored wall.

Keywords: ground anchor; seismic perfomance; monitored anchored wall; Malleco Viaduct.

1. Introduction

The Anchored Wall at the south access of Malleco Viaduct is located on the eastern side of route 5 section Collipulli - Temuco, IX Region of Chile.
The wall was executed to give a double-track for the route 5 for the concessionary company RUTA DE LA ARAUCANÍA SOCIEDAD CONCESIONARIA S.A., and it was established a long-term monitoring based on load cells located in permanent ground anchors within the wall and inclinometers in the lower slope. A dataloger with a seismic switch that operates and records the ground anchor loads at a seismic event higher than 0,07g was installed. This paper presents and tries to analyze the data collected over the years.

2. Anchored wall location

The study area is located 533 km south from Santiago, in a climate zone called warm climate with a dry season and rainy like, six months dry. The annual precipitation is about 1300mm with 30 % in autumn, 50 % in winter, 15 % in spring, and 5% in summer. The rainy season influences the behavior and instability of slopes. The measure of temperatures in the monitoring control booth during 2003 indicates minimum temperatures of 4 degrees Celsius and maximum of 28 degrees.

Fig. 1 – Malleco Viaduct location (in Collipulli).

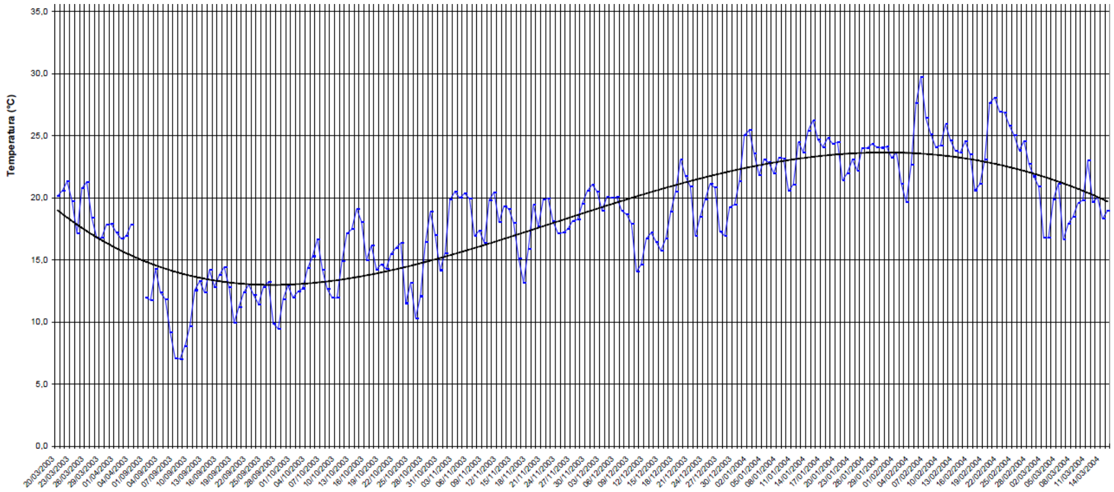

Fig. 2 – Temperature in the control booth throughout 2003

3. Anchored wall design and construction

The viaduct is located immediately south of the city of Collipulli and the south access to the road running along the hillside on a high-rise slope that in the past showed serious problems of global instability [1]. So in 1973 the slope movements were recorded and necessary remedial measures were adopted, including drains and reinforcing piles in the lower areas near the foot of the slope were. After these measures no more problems were registered in this slope.

The expansion of the roadway of the existing road to a double-track contemplated in the original project the execution of an important filling over the failed slope, but in final design it was concluded that the eventual construction of the landfill would adversely affect the overall stability of the slope. As an alternative solution it was then chose to cut the upstream slope to accommodate the expansion of the road. This vertical section involved sustaining a cohesive soil slope, in which crown the train tracks are located. The project consisted of a wall of about 180m development plan, with heights from 3 to 10 m, the average height 7m. The reinforced concrete wall was of a thickness of 28 to 30 cm with shotcrete 25 MPa of characteristic compressive resistance and double steel mesh reinforcement. The design resulted in a total of 239 pre-stressed ground anchors with loads between 500 kN and 825 kN, with total lengths between 10 and 35 m. The fixed lengths of 5-7m were executed in “maicillo” (weathered granodiorite V) and rock (granodierite II-III). The slope is formed by a plio-quaternary glaciofluvial sediments (sandy silt).

Fig. 3 – Excavation, draining strips, mesh and shotcrete. Execution of ground anchors.

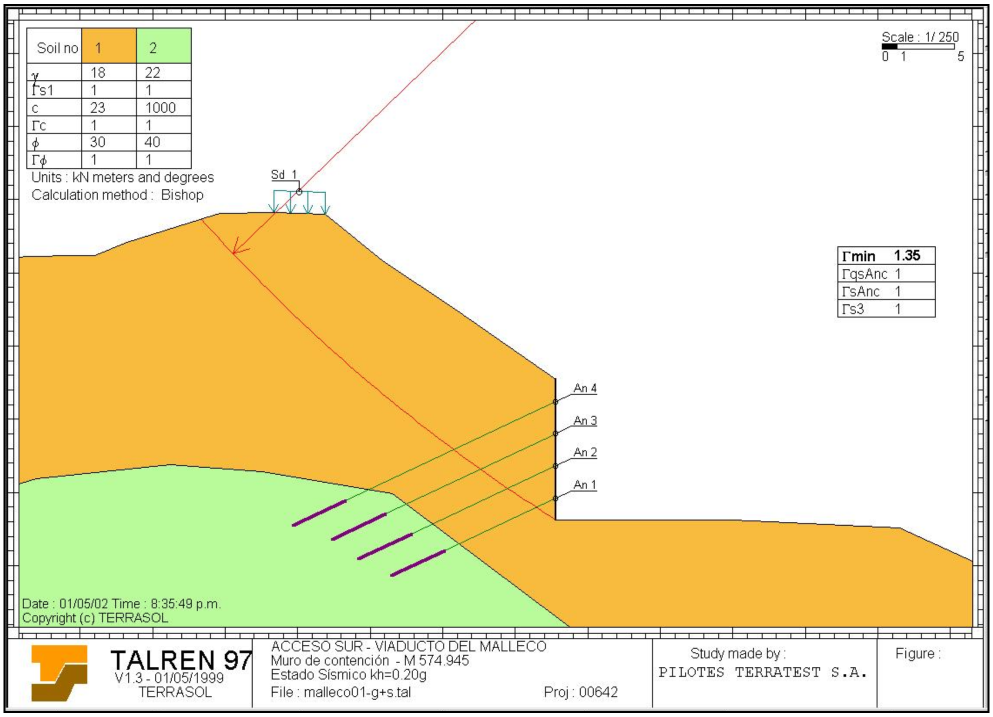

Fig. 4 – Limit state seismic design of highest section.

Fig. 5 – Anchored Wall building just finished.

The construction of the wall was made by shotcrete and in panels, moving progressively in a sequence such that the upper cloths had their stability ensured by the lower support on the ground still unexcavated or already concreted panels. The normal construction sequence consisted of drilling anchors, then install the reinforcement, shotcrete and then finally, tensioning and testing of ground anchors with the corresponding termination (injection) of the head.

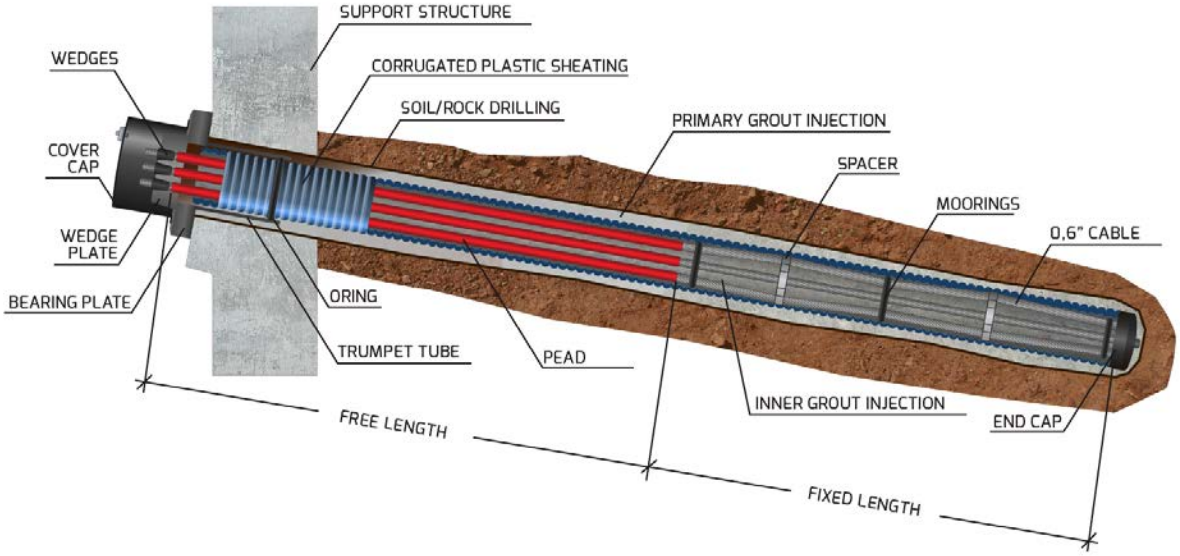

Fig. 6 – Description of the ground anchor.

4. Load cell monitoring

As a control element of the wall stability, four vertical sections of load monitoring of the service loads of the anchors were implemented. Twelve RST vibrating wire load cells were installed, whose signals are transferred via a cable to a box where a reader or datalogger is located which also has a seismic device to allow reading of the load cells during a seismic event. Currently only seven load cells are kept operational, due to component damage and vandalism.

The load variation of the anchors is influenced by:

a) own system reading measurement errors and temperature correction,
b) construction sequence and timing of tensioning the anchor,
c) the ratio of different wall-soil stiffness and their variation along the wall,
d) load losses due to creep of the soil-grout-steel system.
e) deformation of the retaining wall (high level of loading, wetting-drying cycles which induce ground movements).

The load loss of these structures is within the expected. The literature shows that the behavior of the anchored wall of Malleco does not escape from what would be expected in this type of structure, reflected in a initial loss of load, and then reaching a stabilization of it in time. Instrumentation errors being systematic, do not affect the trend of it.

In the records, it has been detected that several anchors have reduced their load in the summer and then increase it again in the winter due to seasonal humidity changes.

Table 1 – Description of instrumented ground anchors.

Anchor No	Date			Type	Inj	Lv	Lf	Lo	$Lf_{effective}$
	Executed	Shotcrete	Tested			m	m	m	m
3,64	19-03-2002	11-03-2002	07-05-2002	P-Terra 6-5	IGU	6,00	22,00	28,00	18,52
2,64	31-05-2002	06-06-2002	13-06-2002	P-Terra 6-5	IGU	6,00	15,00	21,00	16,82
1,64	11-07-2002	15-07-2002	25-07-2002	P-Terra 6-5	IGU	6,00	13,00	19,00	11,17
3,52	11-03-2002	07-03-2002	05-04-2002	P-Terra 6-5	IGU	6,00	26,00	32,00	19,10

2,52	18-04-2002	22-04-2002	02-05-2002	P-Terra 6-5	IGU	6,00	22,00	28,00	19,59
1,52	19-06-2002	09-07-2002	26-07-2002	P-Terra 6-5	IGU	5,00	18,00	23,00	10,60
4,28	07-03-2002	25-03-2002	04-04-2002	P-Terra 6-6	IGU	7,00	22,00	29,00	15,21
3,28	11-04-2002	19-04-2002	24-04-2002	P-Terra 6-6	IGU	7,00	19,00	26,00	21,12
2,28	03-06-2002	11-05-2002	16-06-2002	P-Terra 6-6	IGU	7,00	16,00	23,00	15,14
1,28	17-06-2002	28-06-2002	18-07-2002	P-Terra 6-6	IGU	5,00	15,00	20,00	19,33
2,04	27-03-2002	03-04-2002	10-04-2002	P-Terra 6-5	IGU	6,00	25,00	31,00	14,29
1,04	08-05-2002	19-04-2002	30-07-2002	P-Terra 6-5	IGU	6,00	20,00	26,00	14,12

IGU: Injection global and unique (end of casing pressure)
Lv: fixed length
Lf: free length
Lo: total length
$Lf_{effective}$: free length after acceptance test data.

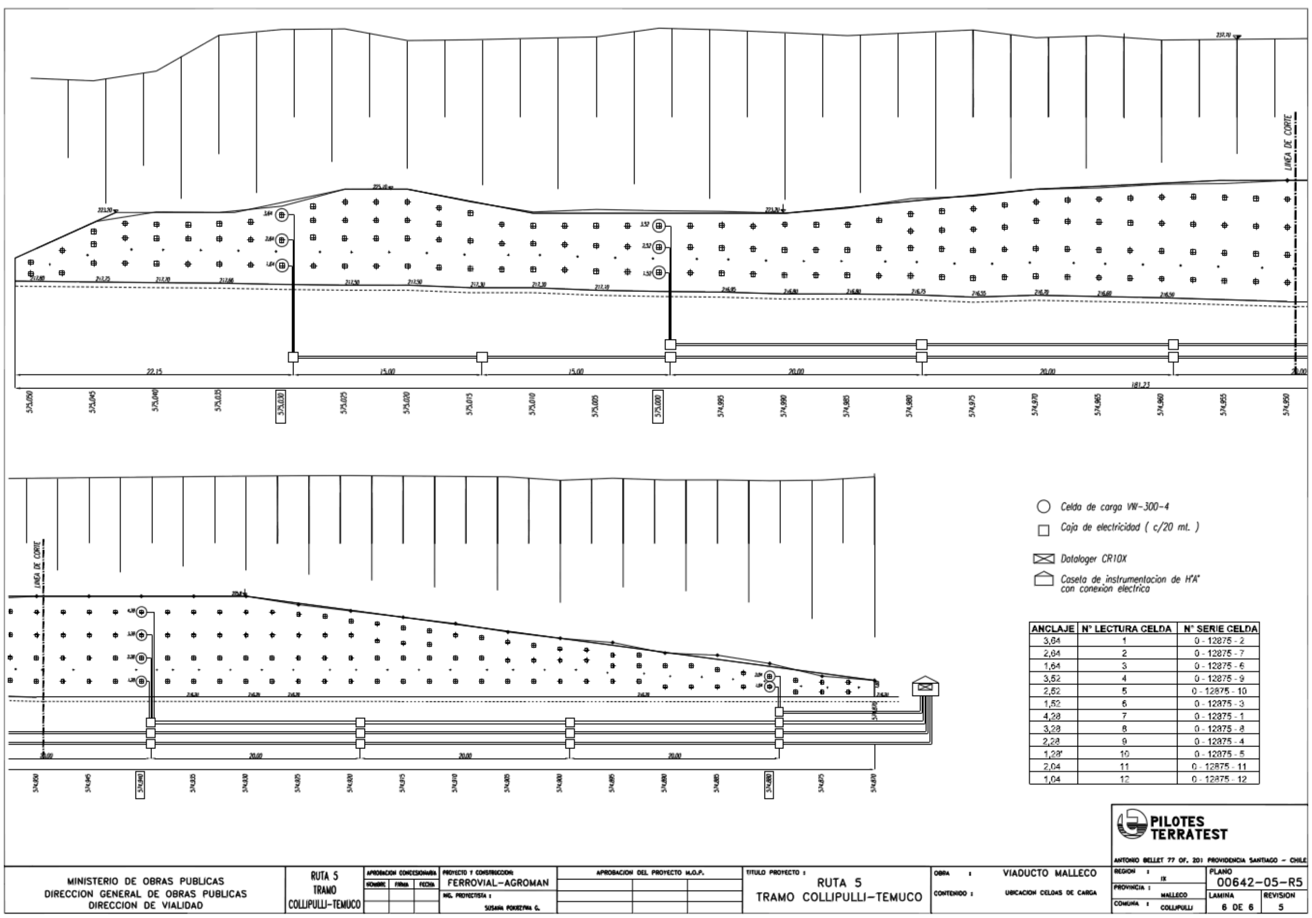

Fig. 7 – Drawing of the anchored wall with its instrumentation.

Load losses after the first year, most likely are a consequence of deformations of the wall (compressibility of the soil and its heterogeneity, cycles of wetting-drying), as the creep of the ground anchors was verified at the time, ruling out the possibility (100% acceptance of the anchors with a creep displacements ks < 0,8mm, after DIN 4125).

The current safety factors of static and seismic design for the different sections are 1,62-2,00 and 1,16-1,32 respectively and yield acceleration of 0,30-0,37g. These results serve as a reference when evaluating the current stability and seismic performance of the wall.

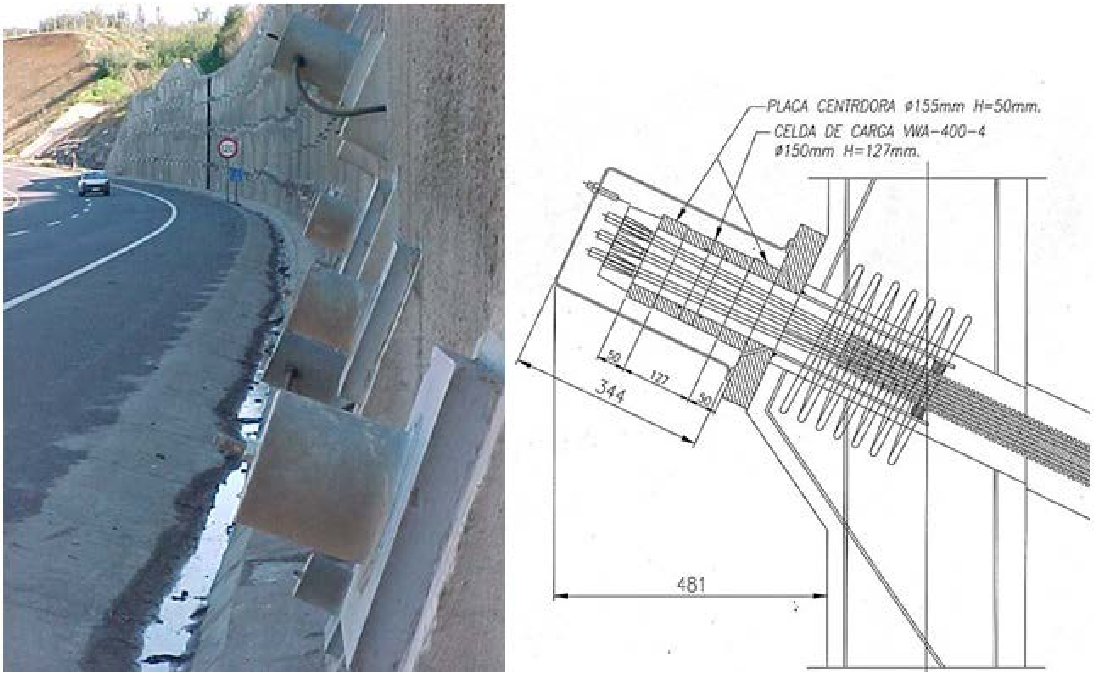

Fig. 8 – Heads of permanent anchors with load cells on the wall and its detail.

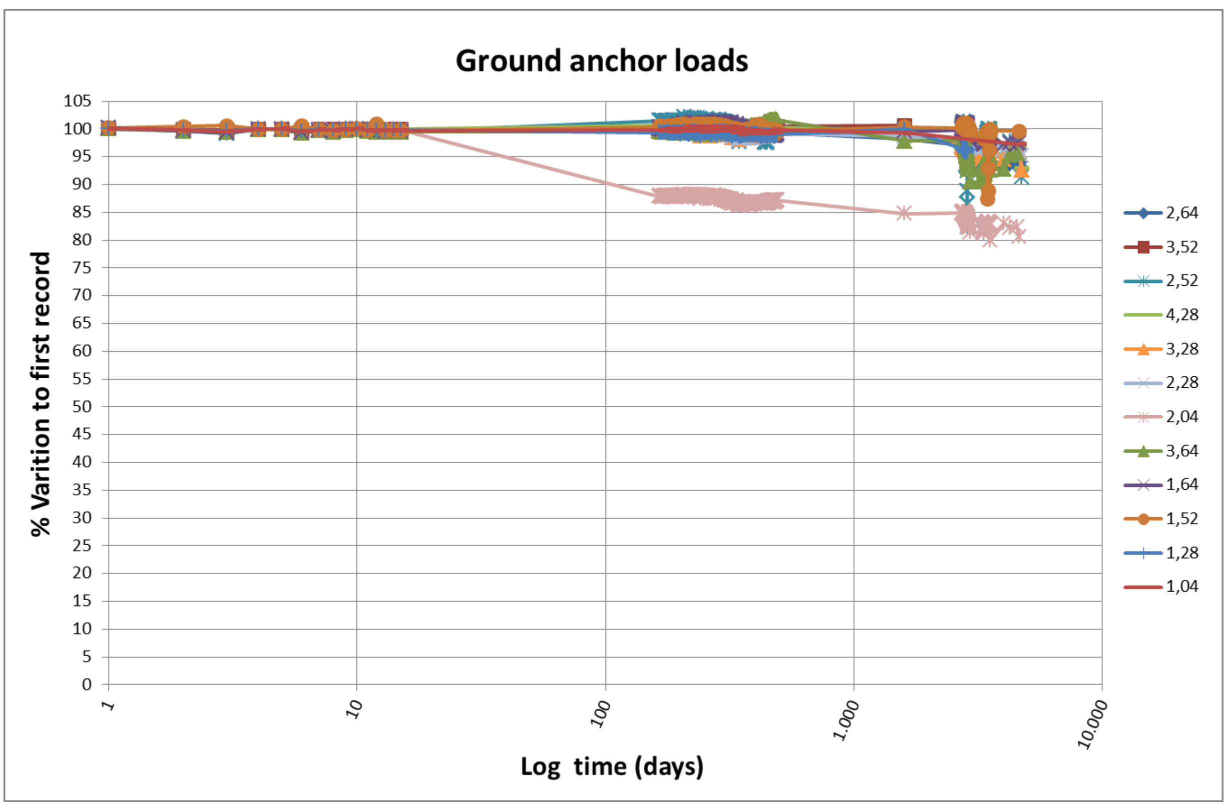

Fig. 9 – Load monitoring as a percentage of load variation along its life.

Table 2 – recorded loads of ground anchors.

No	Period	Loads (kN)											
		3.64	**2.64**	**1.64**	**3.52**	**2.52**	**1.52**	**4.28**	**3.28**	**2.28**	**1.28**	**2.04**	**1.04**
1	01-03-2003	504,0	647,6	538,2	443,9	472,7	693,4	602,0	588,0	599,7	712,5	695,1	641,4
33	26-11-2015	483,3	609,1	525,4	428,4	463,3	689,9	584,6	565,3	577,4	-	572,8	624,6
34	04-03-2016	-	602,4	-	404,4	432,3	-	560,2	545,1	572,4	-	560,8	-
Variation to first record:		-	7,0%	-	8,9%	8,5%	-	7,0%	7,3%	4,6%	-	19,3%	-
Variation last year:		-	0,3%	-	3,2%	5,0%	-	2,2%	2,1%	1,0%	-	-0,9%	-

5. Loads during the seismic event

The seismic event of the 27th of February 2010 was of a 8,8 Magnitude, the epicenter is estimated to be about 260 km north from the wall location, and peak ground acceleration at site is estimated of 0,25g (after USGS). The data recorded of six anchors consist of fifteen measurements at different seconds after the trigger of the seismic switch up to the 243rd second. Although there is no continuous record of the loads, the random measures suggest a trend.

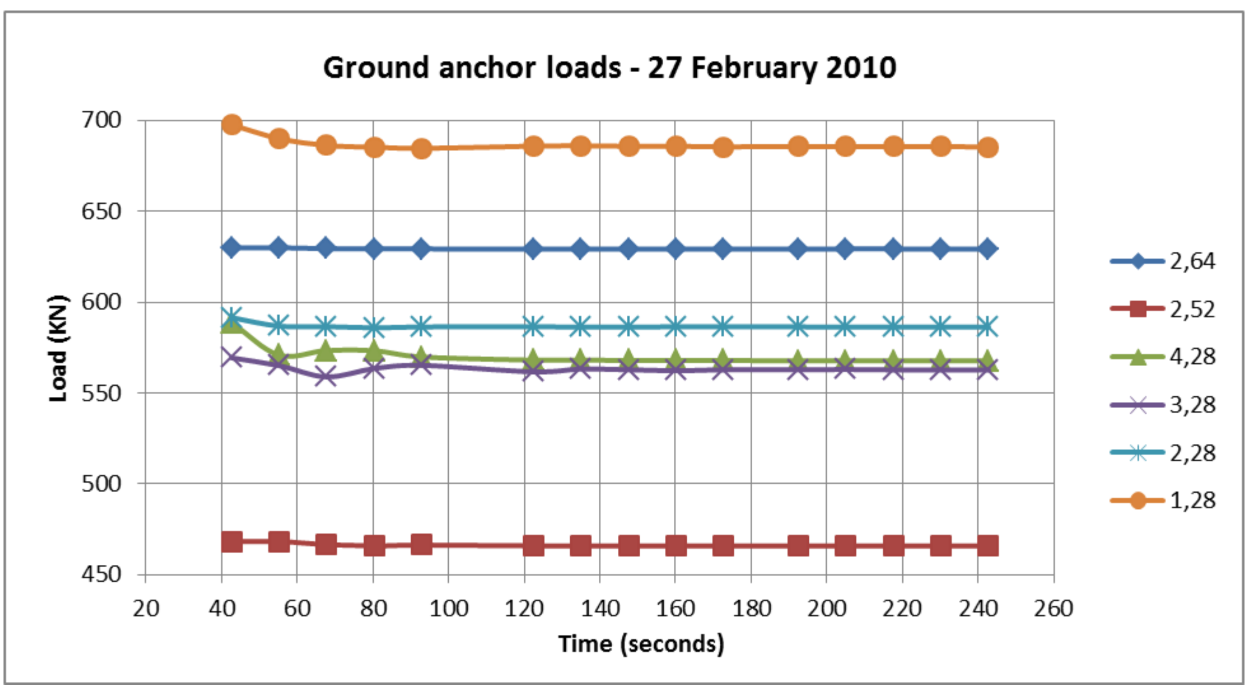

Fig. 10 – Load monitoring during the seismic event.

Table 3 – recorded ground anchor loads 27-02-2010

Date	Second	Anc 2,64	Anc 2,52	Anc 4,28	Anc 3,28	Anc 2,28	Anc 1,28
27-02-2010	43	629,9	468,1	588,8	569,4	591,5	697,7
27-02-2010	55	630,0	468,3	570,9	565,2	586,9	690,1
27-02-2010	68	629,5	466,5	573,4	558,9	586,6	686,3
27-02-2010	80	629,4	465,8	573,3	563,5	585,9	685,3
27-02-2010	93	629,3	466,3	569,9	565,2	586,4	684,7
27-02-2010	123	629,2	465,9	568,1	561,7	586,5	685,9
27-02-2010	135	629,3	465,8	568,1	563,2	586,3	686,1
27-02-2010	148	629,3	465,8	568,0	562,8	586,3	685,8
27-02-2010	160	629,3	465,9	568,0	562,3	586,5	685,8
27-02-2010	173	629,3	465,8	567,9	562,8	586,5	685,5
27-02-2010	193	629,2	465,8	567,8	562,8	586,4	685,7
27-02-2010	205	629,3	465,8	567,7	563,0	586,3	685,6
27-02-2010	218	629,3	465,9	567,8	562,7	586,3	685,7
27-02-2010	230	629,3	465,9	567,8	562,8	586,3	685,7
27-02-2010	243	629,3	465,8	567,8	562,6	586,3	685,4

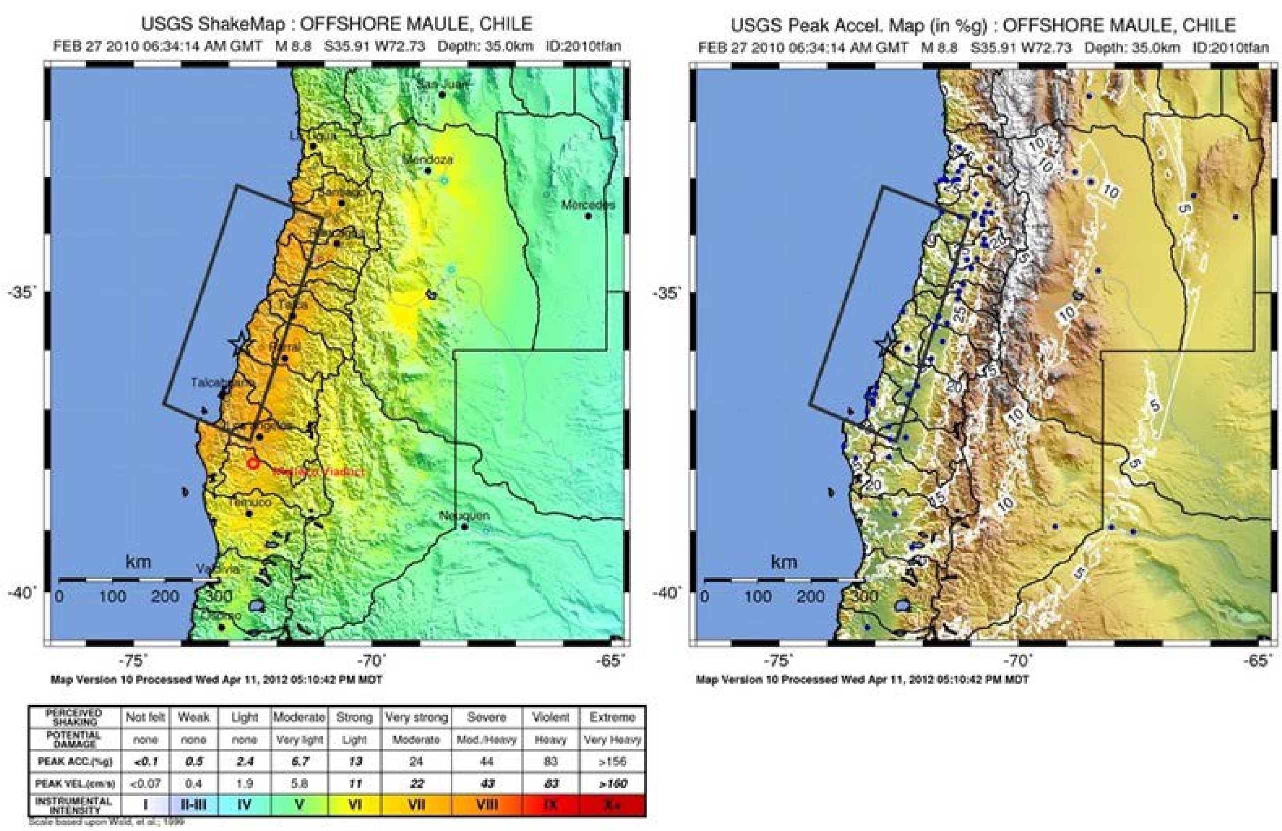

Fig. 11 – Malleco Viaduct location and 27F 2010 seismic Shake and PGA map after USGS.

6. Analysis of collected data

Taking the first data as reference, the loads of the anchors varies between 0,70 and 21 kN, and in percentage between 0,70 to 3,57%. From this variation of load and taking into account the effective free length we can estimate the variation of deformation between the anchor head and the fixed length using equation (1).

If we agree that the wall and anchor move with the retained soil, the relative deformation indicated in table 5 can be taken as the movement of the wall.

Table 4 – Analysis of ground anchors variations

	Anc 2,64	**Anc 2,52**	**Anc 4,28**	**Anc 3,28**	**Anc 2,28**	**Anc 1,28**
ΔP (kN)	0,70	2,30	21,00	10,5	5,60	12,90
ΔP (%)	0,11	0,49	3,57	1,84	0,95	1,86
$Lf_{efective}$ (m)	16,82	19,59	15,21	21,12	15,14	19,33
Δs (mm)	0,09	0,33	2,34	1,62	0,62	1,83

$$\Delta s_{4,28} = \Delta P.\ Lf_{effective} \,/\, A.\ E = 21.000\ N.\ 15.210\ mm \,/\, (5.\ 140\ mm2).\ 195.000\ N/mm2 = 2{,}34mm \quad (1)$$

Table 5 – relative deformation of anchors after equation (1)

Second	**2,64**	**2,52**	**4,28**	**3,28**	**2,28**	**1,28**
43	0,0	0,0	0,0	0,0	0,0	0,0
55	0,0	0,0	-2,0	-0,7	-0,5	-1,1
68	-0,1	-0,2	-1,7	-1,6	-0,6	-1,6
80	-0,1	-0,3	-1,7	-0,9	-0,6	-1,8
93	-0,1	-0,3	-2,1	-0,6	-0,6	-1,8
123	-0,1	-0,3	-2,3	-1,2	-0,6	-1,7
135	-0,1	-0,3	-2,3	-1,0	-0,6	-1,6
148	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
160	-0,1	-0,3	-2,3	-1,1	-0,6	-1,7
173	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
193	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
205	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
218	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
230	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7
243	-0,1	-0,3	-2,3	-1,0	-0,6	-1,7

It is also noticeable that the PGA of the seismic event was about of 0,25g, and the yield acceleration (Ay) of the wall is bigger (0,30-0,37g), so there were not expected any plastic deformations that can be translated in a deformation of the anchors.

6. Behavior of anchored walls in seismic events

There are several reports of the performance of anchored walls that indicates its good behavior in seismic events in California, even when they were not designed to withstand seismic forces.

Fragaszy [2] suggests that there is little relative movement between the wall and the retained soil. In cases where the wall and the soil tend to move in phase, dynamic loading on the wall may be relatively low. Care should be taken to the occurrence of out of phase movements (variation of the ratio of wall period/input motion period) and also for the embedded part of the wall

Haeri et al [3] states that the low mass and the flexibility of the tieback walls in addition to the fact that these walls are anchored by the retained soil, allows this retaining system to move with the surrounding soil. Similarly, the out of phase movements of the retained soil and the stable soil behind, it seems to be the predominant factor in controlling the maximum dynamic loads produced in the anchors. At lower excitation levels, the movement of the tieback wall mainly consists of a rotational movement about the base of the wall. By increasing excitation levels, finally a sliding block of soil forms behind the retaining wall. This is concomitant with a noticeable increase in the axial loads of the lower tiebacks.

McManus [4] report presents New Zealand's recommendations for tieback walls and in his study reports that the effect of increasing the free length of the anchors for the analyzed cases was to reduce the wall displacements. This is coherent with this project, in which the free length of the anchors is longer than usual in order to find a better soil or rock to execute the fixed length.

Gazetas [5] analyzed the temporary prestressed-anchor piled wall of Kerameikos that survived an earthquake with no visible damage. It is shown that the inherent flexibility of the wall leads to minimal dynamic earth pressures in this case of stiff retained soil. The maximum dynamic axial forces in the anchors are also of small magnitude even under strong seismic shaking. The success of that retaining structure was also partially attributable to the high-frequency content of the ground motion.

8. Conclusions

The measurements of the load cells indicate us what was formulated in some papers before, that the load variation was very low (below 3%) due to two facts: the free length of the anchors that influences reducing the response to differential displacements between extremes of the free length of an anchor (anchor head and fixed length) and a possible block behavior of the anchored wall.

The data recorded supports the concepts that the flexibility of the wall leads to minimal dynamic earth pressures, that there is little relative movement between the wall and the retained soil and that the wall (low inertia) and the soil tend to move in phase.

The yield acceleration of the anchored wall was higher than the estimated PGA (0,25g). As there were no plastic deformations expected and signs of them for the seismic event, care should be taken when the design of an anchored wall is done with a ductility factor of 0.5 allowing for permanent seismic deformations of up to 2 inches [6], the load of the ground anchors are expected to increase and should be taken into account in design of it.

The general behavior of the anchored structures (temporary open pits and permanent ones) during the seismic event of 27th of February of 2010 was of good performance, as it is our experience with this kind of structures with 20 years of experience in Chile and Peru.

The data collected gives some light to the behavior of ground anchors in seismic events, but there is more work to do to have a better understanding, so we encourage our colleagues to monitor more geotechnical structures.

9. Acknowledgements

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