Supplement of Nat. Hazards Earth Syst. Sci., 20, 1533–1555, 2020
https://doi.org/10.5194/nhess-20-1533-2020-supplement

Natural Hazards and Earth System Sciences
Open Access
EGU

Supplement of

Contrasting seismic risk for Santiago, Chile, from near-field and distant earthquake sources

Ekbal Hussain et al.

Correspondence to: Ekbal Hussain (ekhuss@bgs.ac.uk)

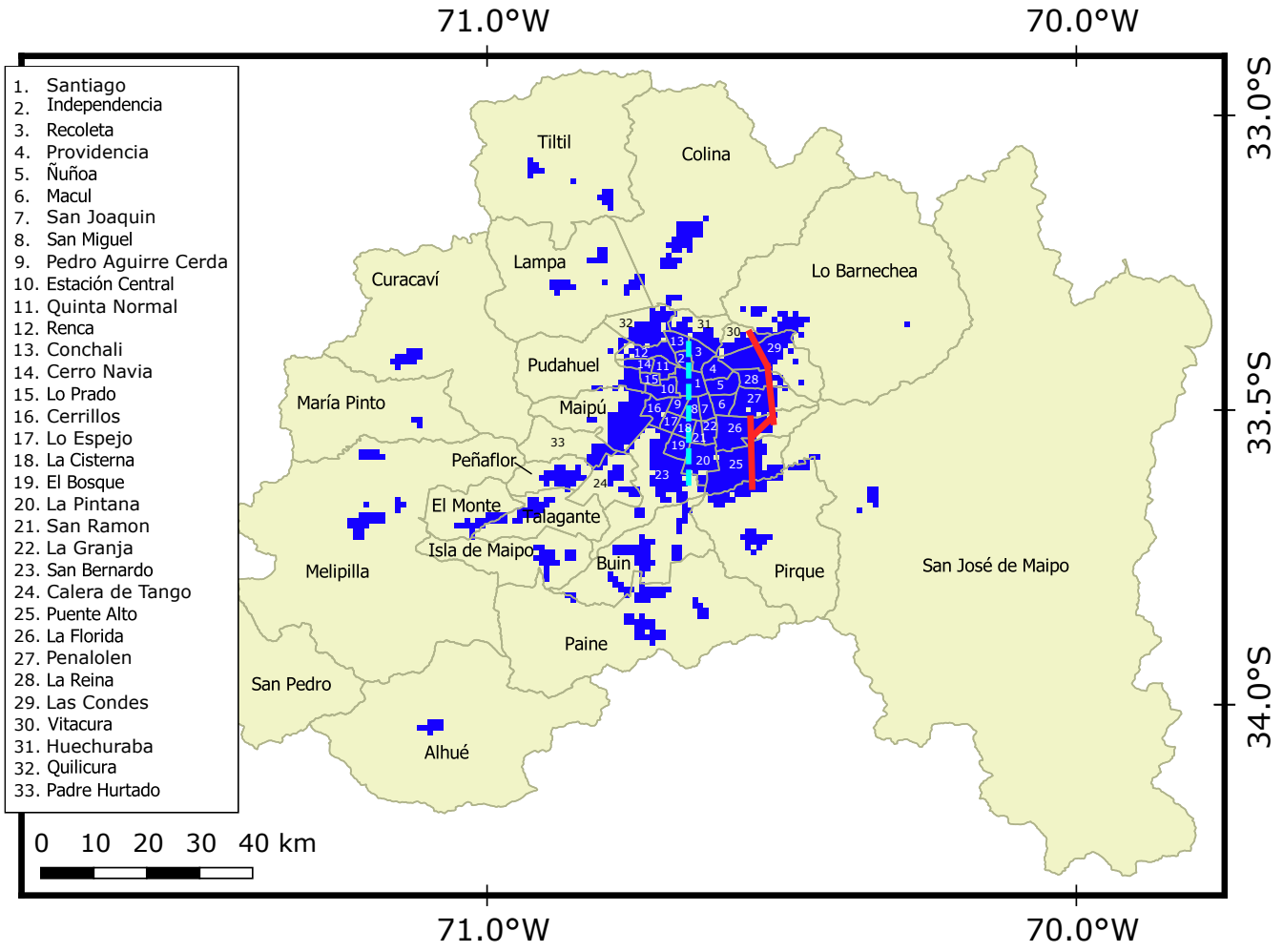

Figure S1. Map showing the communes of the Santiago Metropolitan Region and the distribution of the residential building exposure model used in the risk calculations. The exposure model is downsampled to a 1×1 km grid from Santa-María et al. (2017). The red lines indicate the surface trace of the San Ramón fault used in the seismic risk scenario calculations, and the dashed cyan the buried fault splay.

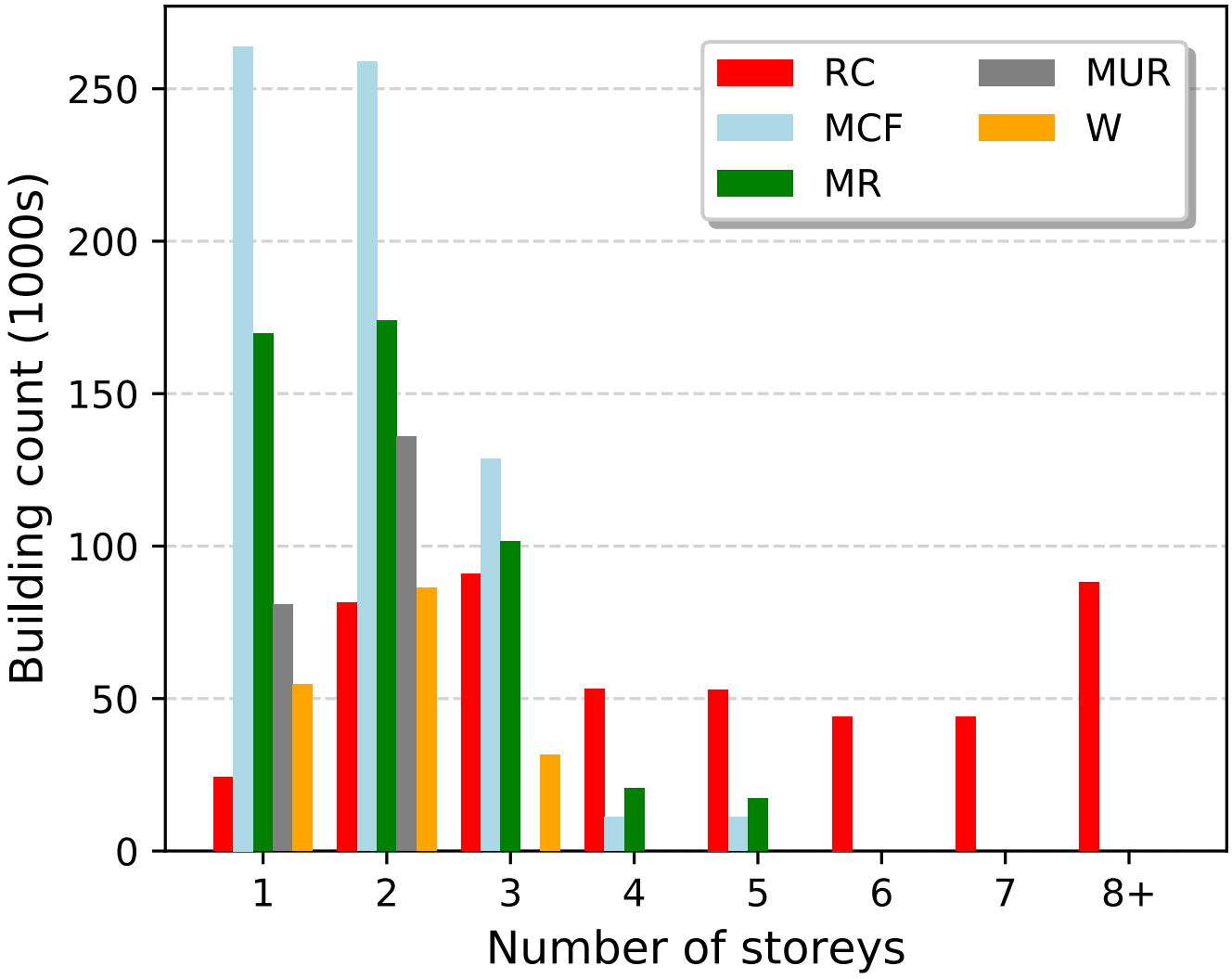

Figure S2. A histogram of the number of buildings in the exposure model for Santiago against the number of storeys. The buildings are colour coded with the residential building class, where RC is reinforced concrete, MCF is confined masonry, MR is reinforced masonry, MUR is unreinforced masonry and W is wooden. The majority of residential buildings are 3 storeys or less, with mostly reinforced concrete structures comprising the 4+ storey buildings.

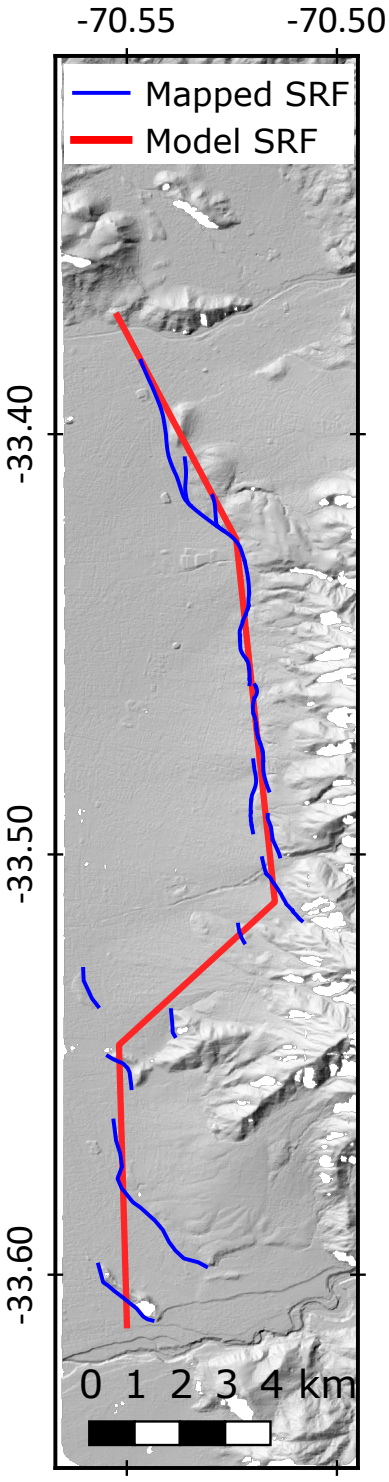

Figure S3. The mapped San Ramón Fault (SRF) shown in blue and the 4-segment model SRF used in the seismic risk calculations overlain on the Pleiades hillsided DEM.

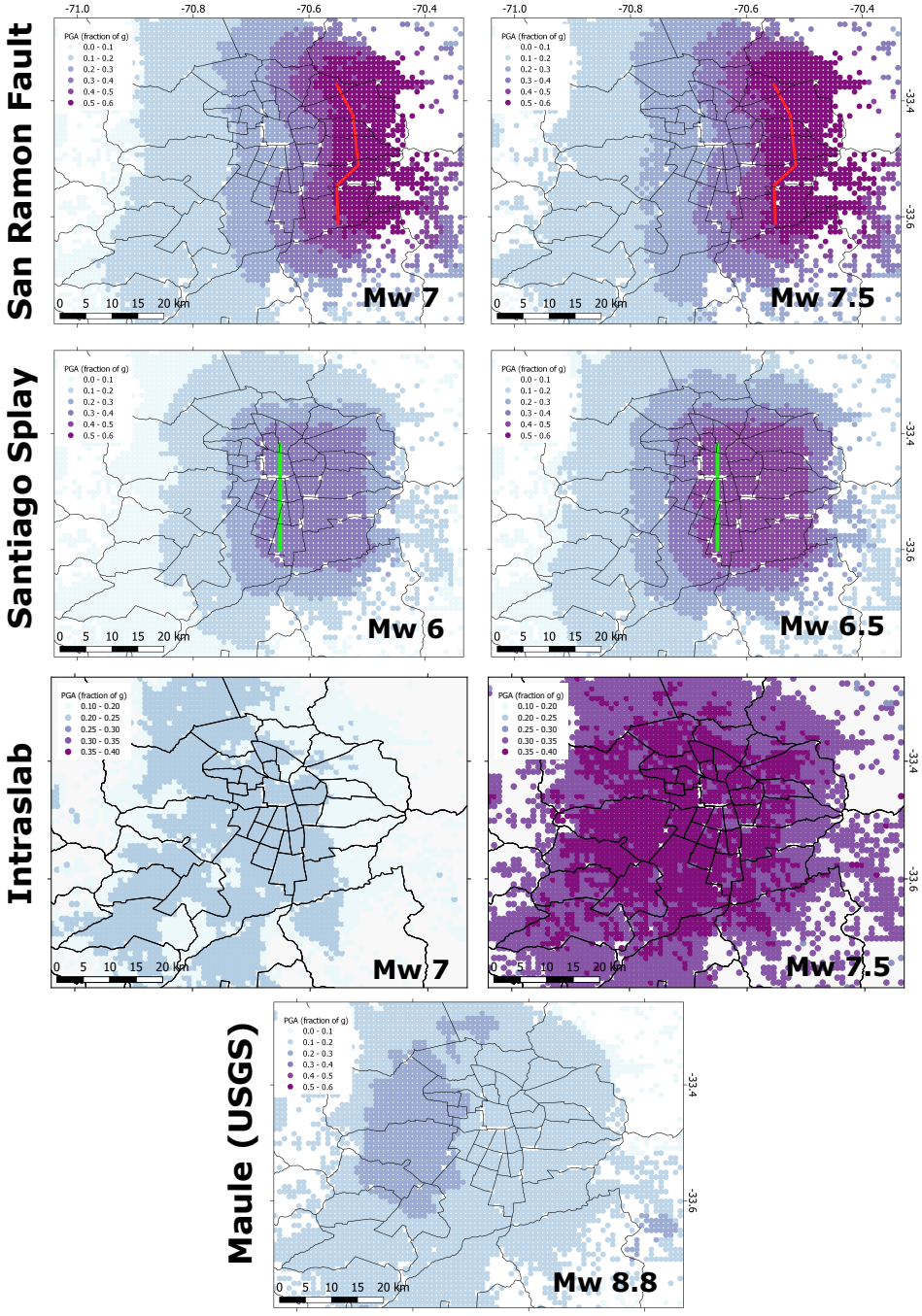

Figure S4. The estimated median Peak Ground Acceleration (PGA) as a fraction of *g*. For the the San Ramón (red line) and Santiago splay fault (green line) cases, these represent estimates using the Akkar et al. (2014) ground motion prediction equation, while those for the intraslab fault are estimates from the Abrahamson et al. (2016) equation. Note that the scale is the same for the San Ramón and Santiago splay scenarios but different for the intraslab scenarios. The USGS peak ground accelerations for the Mw 8.8 Maule earthquake is shown at the bottom.

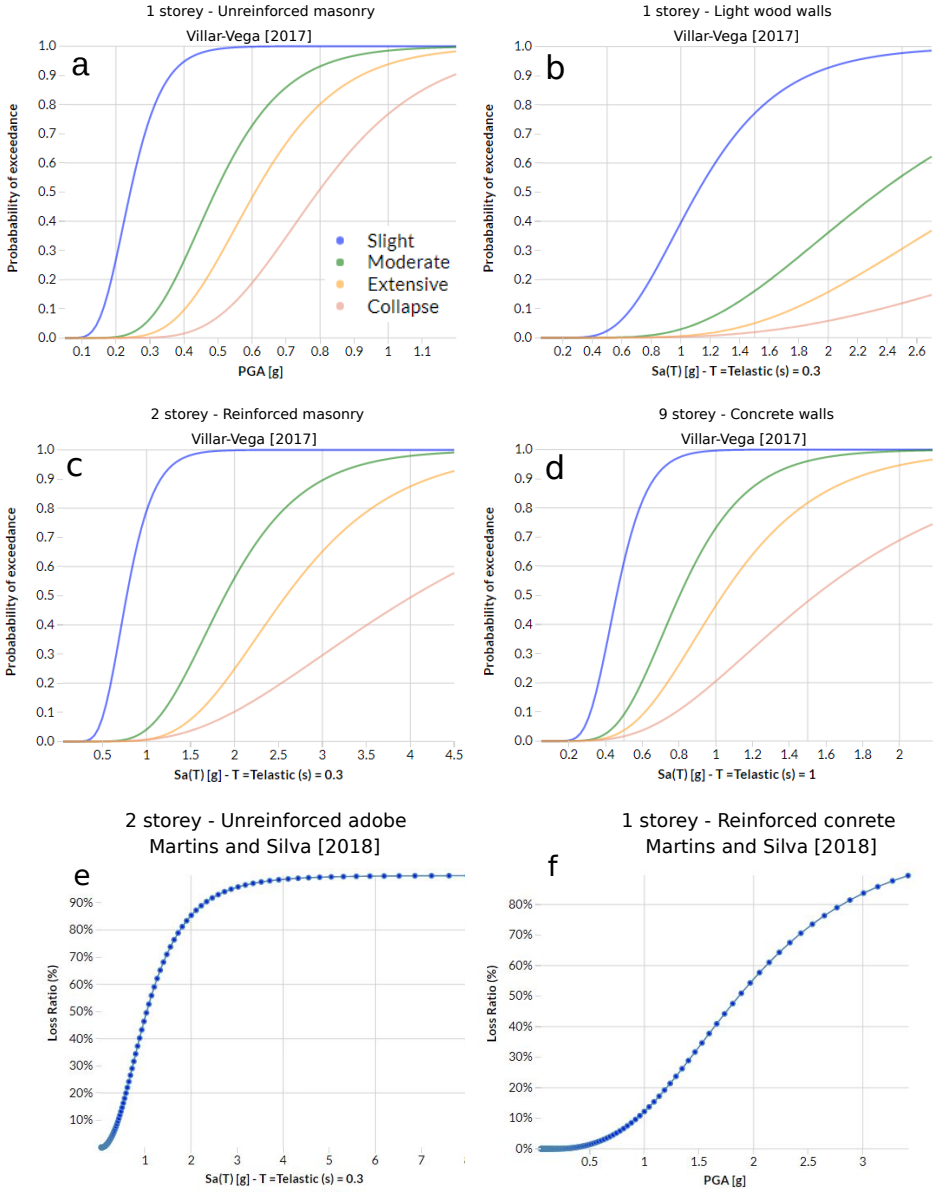

Figure S5. A few examples of the range of fragility and vulnerability functions used within the scenario analysis. *a-d* are examples of building fragility functions from Villar-Vega et al. (2017a) with each colour coded line representing the probability of exceedance of a specific damage state for a given shaking intensity. The shaking intensity is represented by the Peak Ground Acceleration (PGA) in *a*, and by the spectral acceleration (Sa) in *b-d* at the elastic period (Telastic) indicated in the axis label. Figures *e* and *f* show two examples of replacement cost vulnerability curves showing the loss ratio (loss over exposed), for a given ground shaking intensity. The first, *e* is a continuous curve from Martins and Silva (2018) with the shaking intensity in spectral acceleration for a 2 storey unreinforced adobe building, while *f* shows a continuous vulnerability curve also from Martins and Silva (2018) against the PGA scale for a single storey reinforced concrete building.

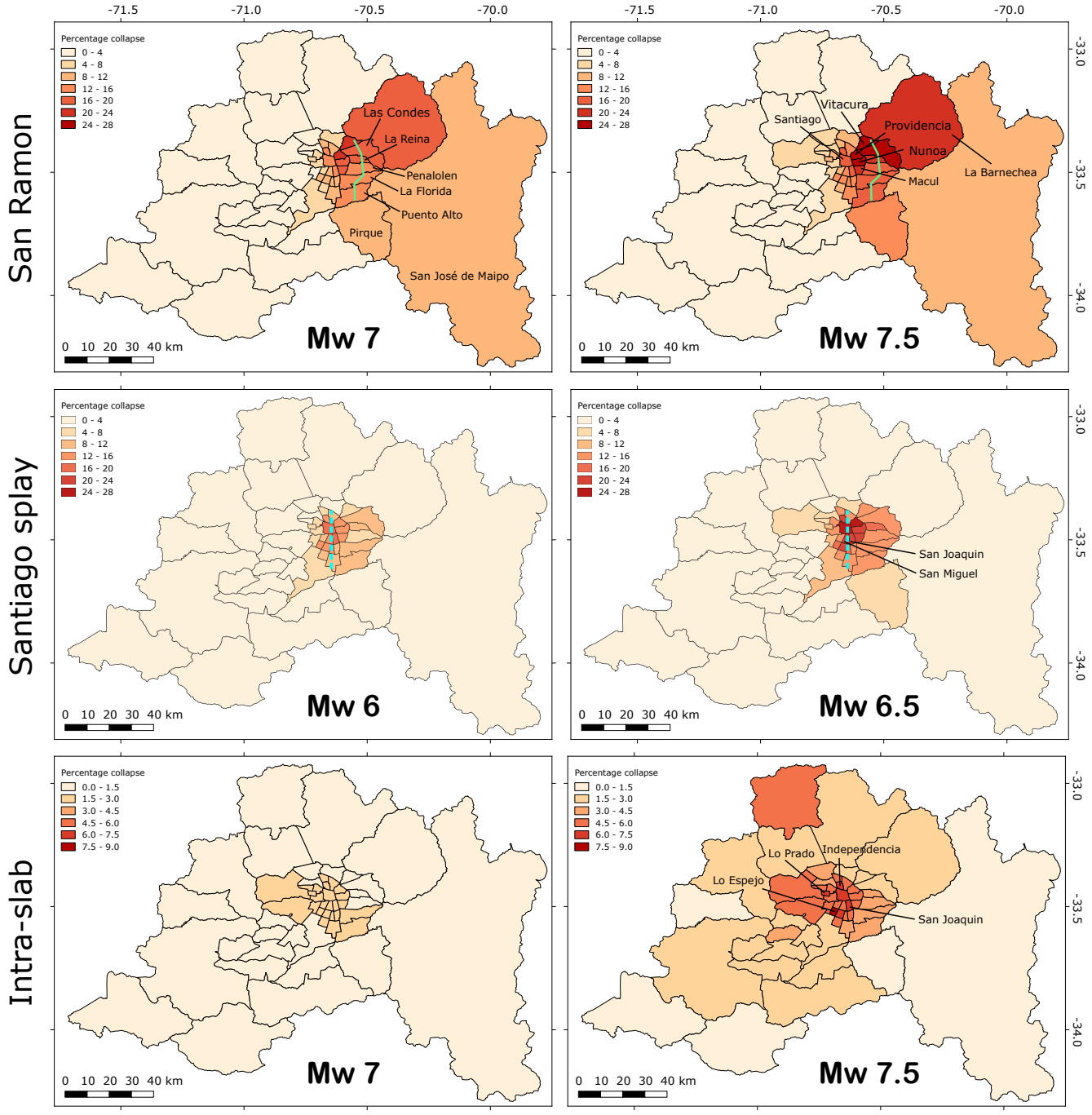

Figure S6. The distribution of collapsed building fraction in each comuna for the earthquakes considered in each scenario for the San Ramón Fault (green lines), the Santiago splay fault (dashed cyan line) and a deep intraslab fault. Note that the range of the colour scale changes between the upper four and lower pair of panels.

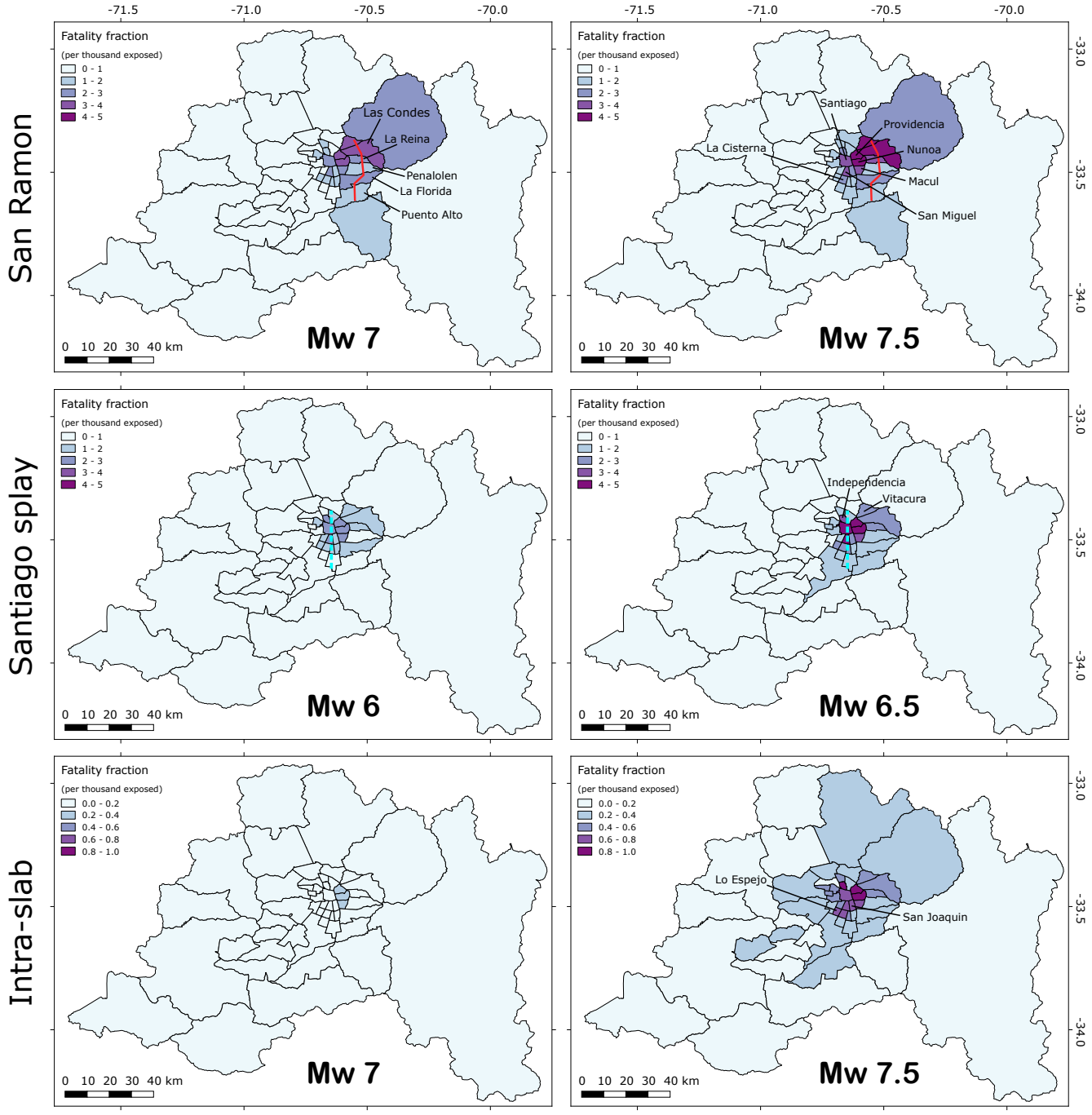

Figure S7. The fatality fraction, in fatalities per thousand exposed, in each comuna for the earthquakes considered in each scenario for the San Ramón Fault (green lines), the Santiago splay fault (dashed cyan line) and a deep intraslab fault. Note that the range of the colour scale changes between the upper four and lower pair of panels.

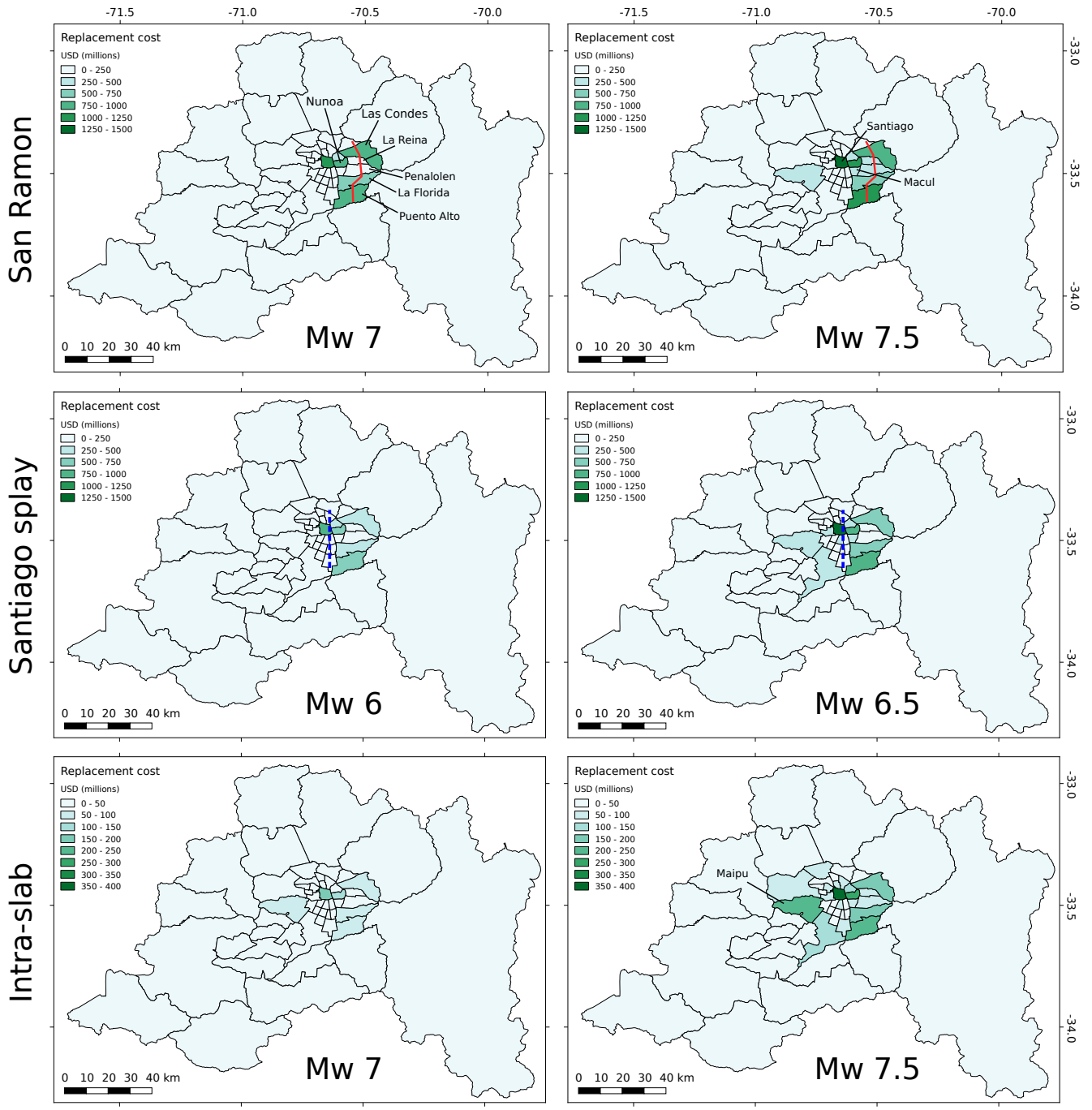

Figure S8. The residential building replacement cost, in USD millions, in each comuna for the earthquakes considered in each scenario for the San Ramón Fault (red lines), the Santiago splay fault (dashed blue line) and a deep intraslab fault. The replacement costs also include an estimate of the non-structural costs and contents of each building. Note that the range of the colour scale changes between upper four and lower pair of panels.

Table S1. Summary of fault properties used as sources in each of the earthquake scenarios.

	San Ramón	**Santiago Splay**	**Intra-slab**
Magnitudes (Mw)	7, 7.5	6, 6.5	7, 7.5
No. of segments	4	1	1
Total length (km)	35	25	35
Dip (degrees)	45	45	70
Top depth (km)	0	0.5	85
Bottom depth (km)	12	12	98
Rake (degrees)	90	90	-90
Average strike (deg)	-1	0	0

Table S2: Exposed populations broken down by building classification for each commune in the Santiago Metropolitan Region. RC - reinforced concrete, MCF - confined masonry, MR - reinforced masonry, MUR - unreinforced masonry, W - wooden.

Commune	**Population**				**Buildings in exposure model (% of Total)**					
					RC	**MCF**	**MR**	**MUR**	**W**	**Total**
Alhué	845	2,811	3	-	0	9	11	41	39	816
Buin	214	71,315	333	-	3	48	24	8	17	18,028
Calera de Tango	73	13,248	181	-	3	23	26	14	34	3,013
Cerrillos	21	54,253	2,583	-	2	46	21	18	13	12,097
Cerro Navia	11	133,301	12,118	12.1	3	32	24	19	21	27,831
Colina	971	119,224	123	12.6	10	40	25	11	15	26,521
Conchalí	71	113,175	1,594	10.2	6	33	17	25	19	24,651
Curacaví	693	17,428	25		2	38	25	9	25	4,565
El Bosque	14	134,951	9,639	14.5	3	25	32	19	21	29,407
El Monte	118	31,483	267		14	33	19	6	28	7,678
Estación Central	14	169,744	12,125	6.2	13	33	25	19	9	30,353
Huechuraba	45	90,838	2,019	-	10	45	23	6	16	19,060
Independencia	7	93,134	13,305	-	21	20	17	37	5	15,248
Isla de Maipo	189	15,066	80	-	1	26	18	21	33	3,816
La Cisterna	10	89,268	8,927	-	11	22	16	37	14	20,277
La Florida	71	356,925	5,027	3.1	6	51	26	9	8	81,493
La Granja	10	117,465	11,747	7.2	3	41	25	13	18	26,369
La Pintana	31	191,306	6,171	13.9	2	39	36	10	13	40,847
La Reina	23	123,960	5,390	-	24	35	21	15	5	27,058
Lampa	452	44,417	98	-	0	44	19	1	36	10,912
Las Condes	99	296,251	2,992	0.6	38	31	21	8	1	51,646
Lo Barnechea	1,024	113,652	111	-	27	40	16	10	8	20,204
Lo Espejo	7	87,587	12,512	-	3	19	15	48	15	17,322
Lo Prado	7	53,638	7,663	-	2	22	27	32	17	11,500
Macul	13	116,694	8,976	5.3	16	32	17	27	7	23,528
Maipú	133	608,094	4,572	5.2	4	44	35	12	6	142,828
María Pinto	395	1,393	4	-	0	21	35	7	36	376
Melipilla	1,356	61,827	46	14	0	34	34	11	20	16,313
Ñuñoa	17	273,354	16,080	2.4	36	32	18	13	1	42,598
Padre Hurtado	81	42,409	524	-	5	50	18	4	23	10,792

Paine	678	34,965	52	-	0	40	21	8	31	8,955
Peñaflor	69	86,437	1,253	-	2	50	25	8	16	20,668
Peñalolén	54	197,909	3,665	4.8	5	39	30	9	17	42,562
Pedro Aguirre Cerda	10	103,653	10,365	11	11	30	28	18	11	22,656
Pirque	445	7,045	16	-	0	19	24	25	30	1,773
Providencia	14	88,928	6,352	0.7	51	25	18	6	0	22,080
Pudahuel	197	246,265	1,250	7.8	6	36	32	15	10	53,971
Puente Alto	88	622,356	7,072	8	3	61	29	3	4	143,463
Quilicura	58	192,337	3,316	7.8	4	42	45	6	4	40,530
Quinta Normal	12	112,819	9,402	5.9	12	29	23	23	12	23,671
Recoleta	16	135,001	8,438	13.9	12	33	19	21	15	28,251
Renca	24	93,265	3,886	8.5	2	35	42	6	15	21,187
San Bernardo	155	277,422	1,790	9.2	4	46	31	7	12	60,199
San Joaquín	10	88,891	8,889	-	10	32	10	40	8	18,778
San José de Maipo	4,995	4,841	1	-	2	15	13	24	47	1,447
San Miguel	10	102,712	10,271	3.5	24	31	20	18	7	18,826
San Pedro	788	105	0	-	0	19	34	17	31	29
San Ramón	7	76,872	10,982	-	3	23	24	28	21	16,814
Santiago	22	371,250	16,875	5.9	38	19	15	27	1	57,341
Talagante	126	61,932	492	12	2	33	44	9	12	15,149
Tiltil	653	7,758	12	0	0	30	0	41	30	2,212
Vitacura	28	83,032	2,965	36	36	36	16	11	1	14,513
Total/Mean	15,474	6,634,005	4,857	9	10	33	24	17	17	1,402,219

[a] defined as $400 monthly income (in 2015 US dollars) for a family of 4 (Ministerio de Desarrollo Social, 2016)

Table S3. Summary of damage and loss results for every commune. SR - San Ramón fault, SS - Santiago splay, IS - intraslab, Col - building collapse count, Fat - number of fatalities, Cost - building replacement cost (millions USD). The collapse counts are rounded to the nearest 100, the fatalities to the nearest 10 and the replacements costs to the nearest USD 10 million. Note that the replacement costs also include an estimate of the non-structural costs and contents of each building.

	SR7			SR7.5			SS6			SS6.5			IS7			IS7.5		
	Col	**Fat**	**Cost**	**Col**	**Fat**	**Cost**	**Col**	**Fat**	**Cost**	**Col**	**Fat**	**Cost**	**Col**	**Fat**	**Cost**	**Col**	**Fat**	**Cost**
Alhué	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buin	300	10	20	500	20	20	0	0	0	200	0	10	200	0	0	600	20	20
Calera de Tango	100	0	0	100	0	0	0	0	0	0	0	0	0	0	0	100	0	0
Cerrillos	500	30	30	900	40	50	600	30	30	1,100	50	50	200	0	10	600	20	20
Cerro Navia	1,100	70	70	1,800	100	90	1,000	50	50	2,000	100	90	600	20	20	1,400	60	50
Colina	700	40	30	1,100	60	50	0	0	0	200	10	10	300	10	10	900	40	30
Conchalí	2,100	120	90	3,000	170	120	1,900	90	70	3,100	160	120	500	20	20	1,300	60	40
Curacaví	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0
El Bosque	2,100	110	100	3,100	150	130	2,800	120	110	4,300	190	160	600	20	20	1,400	50	50
El Monte	0	0	0	100	10	10	0	0	0	0	0	0	0	0	0	200	10	10
Estación Central	1,700	150	150	2,600	230	200	2,300	150	150	3,800	300	260	600	30	30	1,500	90	80
Huechuraba	1,500	90	80	2,100	120	100	700	40	40	1,400	80	70	200	10	10	600	30	30
Independencia	2,000	190	150	2,700	260	190	2,500	190	140	3,700	330	220	500	20	20	1,100	80	60
Isla de Maipo	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	100	0	0
La Cisterna	2,300	150	120	3,200	200	150	3,000	150	120	4,400	240	170	600	20	20	1,400	60	50
La Florida	12,400	760	640	15,700	920	750	8,400	410	410	12,900	680	600	1,400	50	70	3,600	150	160
La Granja	2,900	160	130	3,900	200	160	2,900	130	110	4,300	200	160	500	10	20	1,300	50	40
La Pintana	3,800	180	180	5,200	240	220	4,100	180	170	6,200	270	240	700	20	30	1,700	60	60
La Reina	5,000	370	240	6,200	450	290	2,800	190	140	4,500	320	220	300	20	20	1,100	70	60
Lampa	100	0	0	100	0	10	0	0	0	0	0	0	0	0	0	200	0	0
Las Condes	10,500	1,080	850	12,800	1,330	990	4,700	410	430	8,200	820	690	400	40	60	1,800	170	180
Lo Barnechea	3,700	260	190	4,500	330	230	400	30	30	900	80	70	100	10	10	600	50	40
Lo Espejo	1,600	100	60	2,300	140	80	2,200	120	70	3,300	180	100	600	20	10	1,400	60	30
Lo Prado	700	40	30	1,000	50	50	700	30	30	1,300	60	50	300	10	10	800	30	20
Macul	4,200	320	240	5,300	410	290	3,600	230	180	5,300	380	270	600	30	30	1,400	90	70
Maipú	3,400	190	200	5,900	310	300	2,900	130	150	6,100	290	280	2,500	80	90	6,700	240	220
María Pinto	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melipilla	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	400	10	10
Ñuñoa	8,400	1,120	880	10,600	1,420	1,050	6,600	710	640	10,300	1,310	1,000	900	80	110	2,400	260	260
Padre Hurtado	200	10	10	300	10	20	0	0	0	100	0	10	100	0	0	300	10	10
Paine	100	0	0	200	10	10	0	0	0	0	0	0	0	0	0	200	0	0
Peñaflor	300	10	10	500	20	20	0	0	0	200	10	10	300	10	10	800	30	20
Peñalolén	5,900	250	250	7,400	310	300	3,500	140	160	5,600	230	240	400	10	20	1,600	60	60
Pedro Aguirre Cerda	1,500	100	90	2,100	140	120	2,300	110	100	3,500	190	150	500	20	20	1,200	50	40
Pirque	200	10	10	300	10	10	0	0	0	100	0	0	0	0	0	0	0	0
Providencia	4,600	340	340	5,700	430	410	3,400	240	270	5,500	410	400	400	30	50	1,100	90	110
Pudahuel	1,600	90	100	2,600	150	150	1,400	70	80	2,900	150	150	900	30	40	2,600	110	100
Puente Alto	23,100	1,030	860	28,800	1,260	1,010	13,600	590	560	20,900	930	790	2,200	80	90	5,900	230	230
Quilicura	1,300	60	80	2,200	100	120	700	30	50	1,600	70	100	500	20	20	1,500	60	70
Quinta Normal	1,600	120	100	2,300	180	130	1,800	110	90	3,000	210	150	600	20	20	1,300	70	60
Recoleta	2,600	140	130	3,600	200	170	2,900	150	130	4,500	250	200	500	20	20	1,400	60	60

Renca	700	30	30	1,100	50	50	700	30	30	1,400	50	50	200	0	10	800	20	30
San Bernardo	3,100	170	180	4,700	250	250	3,700	170	190	6,200	300	290	900	30	40	1,500	100	110
San Joaquín	2,600	170	120	3,500	220	140	3,200	170	110	4,500	250	160	600	20	20	1,400	60	40
San José de Maipo	100	0	0	200	0	10	0	0	0	0	0	0	0	0	0	0	0	0
San Miguel	2,100	250	190	2,900	340	240	2,700	220	180	4,100	400	270	400	20	30	1,000	80	70
San Pedro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
San Ramón	2,000	110	90	2,700	140	110	2,300	100	80	3,300	150	120	400	10	10	1,000	40	30
Santiago	8,600	950	1,020	11,500	1,300	1,300	10,000	870	940	15,400	1,600	1,530	1,700	80	160	4,100	300	390
Talagante	100	0	10	200	10	20	0	0	0	0	0	0	200	0	0	500	10	20
Tiltil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0
Vitacura	3,000	290	220	3,600	360	250	1,000	80	80	1,900	180	150	100	10	10	500	40	40
Total	**136,400**	**9,670**	**8,320**	**181,300**	**12,650**	**10,370**	**107,300**	**6,470**	**6,120**	**172,200**	**11,430**	**9,610**	**23,500**	**930**	**1,190**	**63,500**	**3,180**	**3,080**
Mean loss ratio (%)	**8**	**0.15**	**5**	**10**	**0.19**	**7**	**8**	**0.10**	**4**	**12**	**0.17**	**6**	**2**	**0.01**	**1**	**5**	**0.05**	**2**

References

Abrahamson, N., Gregor, N., and Addo, K.: BC Hydro ground motion prediction equations for subduction earthquakes, Earthquake Spectra, 32, 23–44, 2016.

Akkar, S., Sandıkkaya, M., and Bommer, J.: Empirical ground-motion models for point-and extended-source crustal earthquake scenarios in Europe and the Middle East, Bulletin of Earthquake Engineering, 12, 359–387, 2014.

Bonnefoy-Claudet, S., Baize, S., Bonilla, L. F., Berge-Thierry, C., Pasten, C., Campos, J., Volant, P., and Verdugo, R.: Site effect evaluation in the basin of Santiago de Chile using ambient noise measurements, Geophysical Journal International, 176, 925–937, 2009.

Martins, L. and Silva, V.: A Global Database of Vulnerability Models for Seismic Risk Assessment, in: Proceeding of the 16th European Conference on Earthquake Engineering, 2018.

Ministerio de Desarrollo Social: Estimaciones de la pobreza por ingresos y multidimensional en comunas con representatividad (in Spanish), Tech. rep., Gobierno de Chile, http://observatorio.ministeriodesarrollosocial.gob.cl/casen-multidimensional/casen/docs/estimacion_pobreza_ingreso_multidimensional_comunal.pdf, 2016.

Santa-María, H., Hube, M. A., Rivera, F., Yepes-Estrada, C., and Valcárcel, J. A.: Development of national and local exposure models of residential structures in Chile, Natural Hazards, 86, 55–79, 2017.

Villar-Vega, M., Silva, V., Crowley, H., Yepes, C., Tarque, N., Acevedo, A. B., Hube, M. A., Gustavo Coronel, D., and María, H. S.: Development of a fragility model for the residential building stock in South America, Earthquake Spectra, 2017a.