# Telecommunication Network Reliability under seismic event considering the dependence on the power supply

Latin American Congress on Industrial and Applied Mathematics

**D. Jiménez**, L. Gacitua, H. Cancela, D. Olivares and J. Barrera

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# UN warns that world risks becoming ‘uninhabitable hell’ for millions unless leaders take climate action

https://edition.cnn.com/2020/10/13/world/un-natural-disasters-climate-intl-hnk/index.html

World Africa Americas Asia Australia China Europe India Middle East United Kingdom

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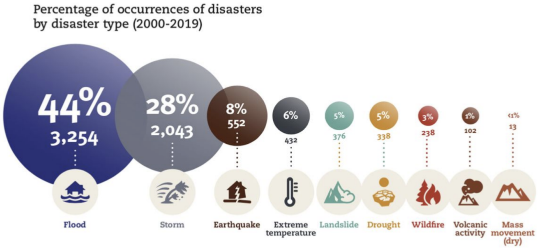


*https://edition.cnn.com/2020/10/13/world/un-natural-disasters-climate-intl-hnk/index.html*

UNDRR United Nations Office for Disaster Risk Reduction

EN

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# UNDRR ROAMC: Regional assessment report on disaster risk in Latin America and the Caribbean (RAR 2021)

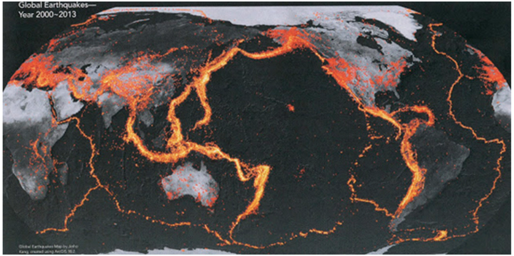
*Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and environment. Such knowledge can be leveraged for the purpose of pre-disaster risk assessment, for prevention and mitigation and for the development and implementation of appropriate preparedness and effective response to disasters.*

***Priority 1, Sendai Framework for Disaster Risk Reduction 2015-2030***

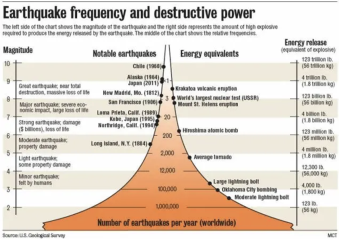
# Where do earthquakes occur?



a)




b)




c)

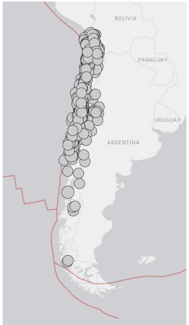


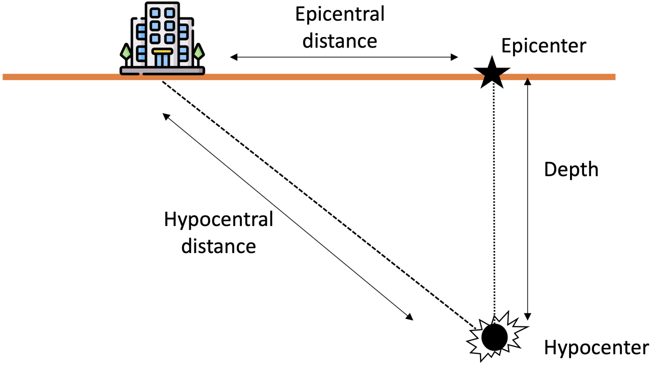

Figure: a) Ring of Fire (Source: ArcNews Vol 36, No 2, by ESRI, page 7), b) Historical Location of earthquakes in Chile (Source: [1], c) Earthquakes and their equivalence in released energy (Source: [1])

# Motivation



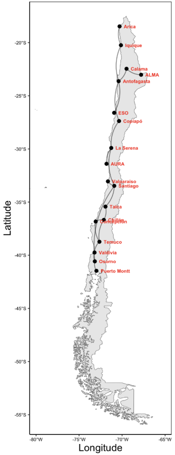
- We need to consider ground motion
- We cannot get there from direct observation
- The Probabilistic Seismic Hazard Analysis (PSHA) approach attempts to solve this

# How to assess the damage generated in an earthquake?



# The PSHA (Probabilistic Seismic Hazard Analysis)

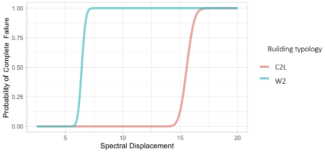
1) The necessary seismic data is generated




2) The Intensity measure is calculated

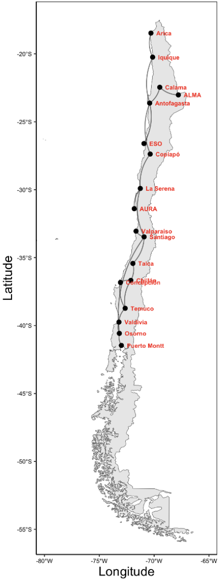
$$\mu(\ln(SA(T))) = f(M_w, Z_h, R, \vec{\theta}, V_{S30}|T)$$

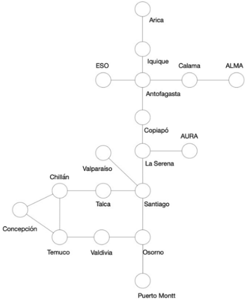
3) Using fragility curves, we know the probability of damage.




$$P\left[ds|S_d\right] = \Phi\left[\frac{1}{\beta_{ds}}\ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right]$$

# Telecommunications network




REUNA

Nodes

Links

# Peak ground displacement (PGD)

$$\ln(PGD) = 5.52 - \frac{4.43k_c}{PGA} - 20.39\left(\frac{k_c}{PGA}\right)^2 + 42.61\left(\frac{k_c}{PGA}\right)^3 - 28.74\left(\frac{k_c}{PGA}\right)^4 + 0.72\ln(PGA)$$

The repair rate is $RR_l = \alpha(4.317PGD - 0.324)$

Details [2]. Damage of cables after the earthquake in New Zealand [3]

# Reliability metrics



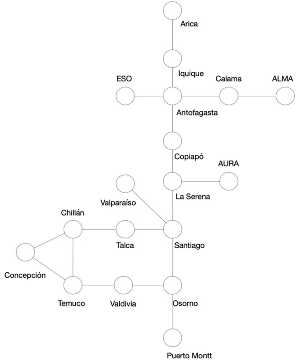
Let the set of components $C$ by $C = N \cup L$ ($N$= nodes and $L$= links) The network state is stored in a structure function $\phi$.

$$\phi : \{0,1\}^{|C|} \to \{0,1\} \tag{1}$$

We obtain an incidence matrix $M^{\bar{t}}_{|N|\times|L|}$ associated to the telecommunication network. We use the reliability metrics associated with network connectivity for telecommunications networks (the *st* reliability and the *st*-DC reliability,[4]).

$$r_{st}(\bar{t}) = P(\phi(X_{\bar{t}}) = 1) = \mathbb{E}(\phi) \tag{2}$$

# Network used in the study: REUNA




| Design | Addicional links |
|---|---|
| R-3A | (Valparaíso-ESO), (Arica-Pto.Montt), (AURA-ALMA) |
| R-3B | (Valparaíso-ALMA), (Arica-Pto.Montt), (AURA-ESO) |
| R-3C | (Valparaíso-ALMA), (Arica-AURA), (Puerto Montt-ESO) |
| R-3D | (Valparaíso-Arica), (ALMA-AURA), (Pto.Montt-ESO) |
| R-3E | (Valparaíso-ESO), (Arica-AURA), (Pto.Montt-ALMA) |
| R-3F | (Valparaíso-Arica), (ESO-AURA), (Pto.Montt-ALMA) |

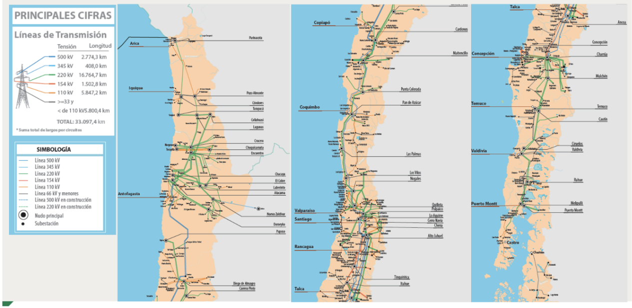
Design

versions proposed in [5]

# We now incorporate dependence

- We incorporate the impact that the electricity grid has on the telecommunications network.
- There is a geographical correlation in the earthquake failures in these networks.
- The study of dependence is new
- We evaluate how networks evolve over time.

# Electricity grid

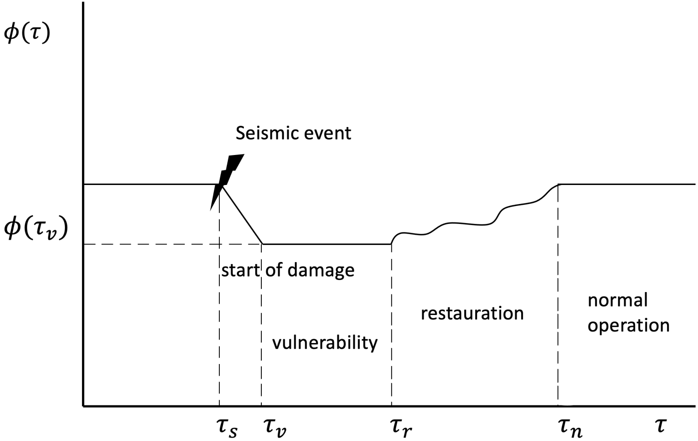



SEN

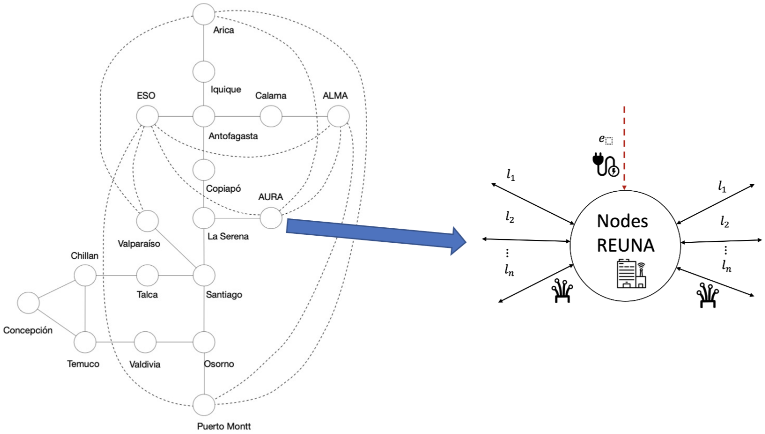
Nodes

Edges

# We evaluate how networks evolve over time.



# Let's see what happens with REUNA



# Characteristics of REUNA and SEN



## REUNA

- 18 nodes
- 29 arcs:
  - 19 arcs REUNA
  - 22 arcs (REUNA +3 links)
  - 23 arcs (REUNA +4 links)
- 8 versions of REUNA
- Different damage levels

## SEN

- Nodes:
  - 327 Substations
  - 218 Power plants
- 405 transmission lines (connecting substations)
- A single grid design
- Considers restoration over time
- We evaluated 3 impact scenarios

# REUNA without dependence



| *st* reliability | | | |
|---|---|---|---|
| Design | Min. | Avg. | Max. |
| Original | 0.416 | 0.703 | 0.949 |
| R-3A | 0.538 | 0.765 | 0.950 |
| R-3B | 0.661 | 0.844 | 0.950 |
| R-3C | 0.654 | 0.839 | 0.950 |
| R-3D | 0.500 | 0.753 | 0.950 |
| R-3E | 0.704 | 0.850 | 0.950 |
| R-3F | 0.705 | 0.849 | 0.950 |
| R-3A+1 | 0.538 | 0.765 | 0.950 |
| R-3C+1 | 0.659 | 0.841 | 0.950 |
| R-3F+1 | 0.714 | 0.853 | 0.950 |

$st$ reliability for the different network designs ($k_c = 0.4$)

| $st - DC$ reliability | | | |
|---|---|---|---|
| Design | Min. | Avg. | Max. |
| Original | 0 | 0.539 | 0.949 |
| R-3A | 0 | 0.629 | 0.949 |
| R-3B | 0 | 0.664 | 0.949 |
| R-3C | 0 | 0.669 | 0.949 |
| R-3D | 0 | 0.640 | 0.949 |
| R-3E | 0 | 0.654 | 0.949 |
| R-3F | 0 | 0.659 | 0.949 |
| R-3A+1 | 0 | 0.674 | 0.949 |
| R-3C+1 | 0 | 0.728 | 0.949 |
| R-3F+1 | 0 | 0.708 | 0.949 |

Average $st - DC$ reliability for the different network designs ($k_c = 0.4$)

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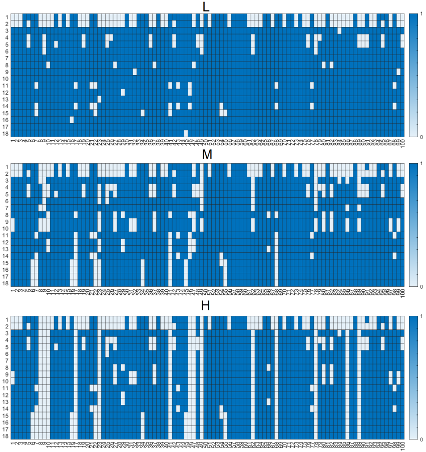
Average $st-DC$ reliability for the different network designs ($k_c = 0.4$)

# SEN Performance



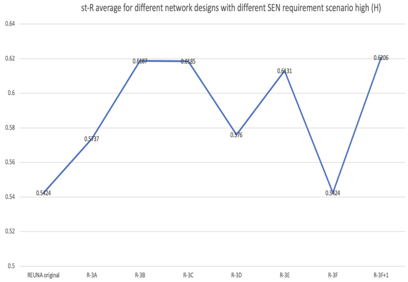
The availability of REUNA nodes immediately after the earthquake.

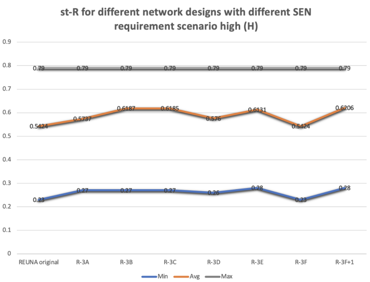


# $st$ reliability for different network designs with SEN (high (H))



## Evaluation of $st$ reliability in $\bar{t} = 0$



# Conclusions

- When the dependence on SEN is considered, the st reliability of REUNA decreases by 10-20%.
- Adding additional links in the original topology is not always significant when considering dependency.
- Consideration of how SEN affects the REUNA extension versions influences the future design decision for all extensions analyzed.
- The proposed extensions will only make sense if backup equipment (batteries, solar cells,...) is considered.


Patrocinio: CAPES, ModeMat, CMM Center for Mathematical Modeling, CeMEAI CEPID - Centro de Ciências Matemáticas Aplicadas à Indústria, FAPERJ, INCTMat

Organización: FGV EMAp Escola de Matemática Aplicada, SBMAC

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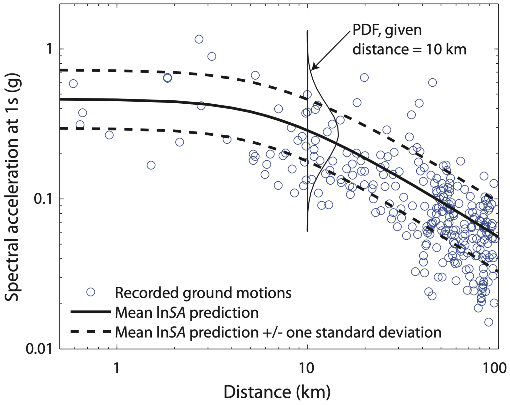
# Anexos



PDF, given
distance = 10 km
1
0.1
0.01
1
10
100
Spectral acceleration at 1s (g)
Distance (km)
Recorded ground motions
Mean ln*SA* prediction
Mean ln*SA* prediction +/- one standard deviation

# Ground-motion prediction equation (GMPE) [6]

$$\ln(\mathrm{SA(T)}) = \theta_1 + f_{\text{source}} + f_{\text{path}} + f_{\text{event/depth}} + f_{\text{site}} + f_{\text{FABA}}$$

$$f_{\text{source}} = \theta_4 \Delta C_1 + f_{\text{mag}}(M_w)$$

$$f_{\text{mag}} = \begin{cases} \theta_4 \left(M_w - C_d\right), & \text{if } M_w \leq C_d \\ \theta_5 \left(M_w - C_d\right), & \text{if } M_w > C_d \\ C_d = C_1 + \Delta C_1 \end{cases}$$

$$f_{\text{path}} = [\theta_2 + \theta_{14} + \theta_3 \left(M_w - 7.8\right)] \times \ln\left(R + C_4 \exp\left(\theta_9 \left(M_w - 6\right)\right)\right) + \theta_6 R$$

$$f_{\text{event/depth}} = [\theta_{10} + \theta_{11} \left(\min\left(Z_h, 120\right) - 60\right)]$$

# Ground-motion prediction equation (GMPE)

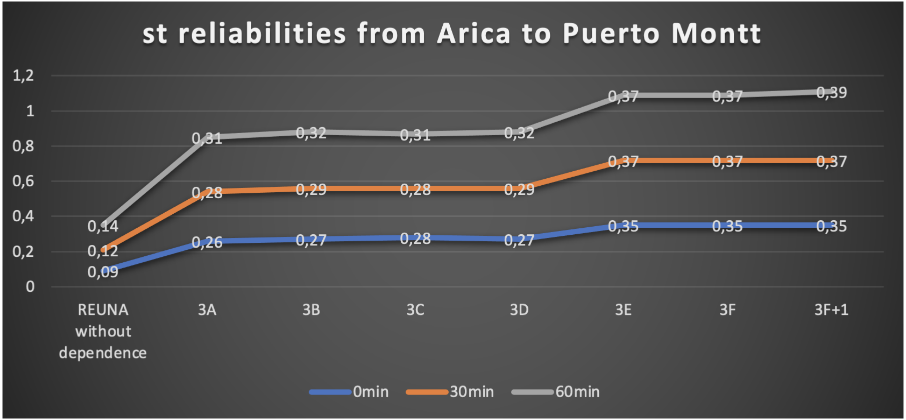


$$
\begin{aligned}
&f_{\mathrm{site}}\left(PGA_M, V_{\mathrm{S30}}\right)\\
&= \begin{cases}
\begin{array}{c}
\theta_{12} \ln\left(\dfrac{V_S^*}{V_{\mathrm{lin}}}\right)\\
-b \ln\left(PGA_M + c\right)\\
+b \ln\left(PGA_M + c\left(\dfrac{V_S^*}{V_{\mathrm{lin}}}\right)^n\right)
\end{array}, & \text{if } V_{\mathrm{S30}} < V_{\mathrm{lin}}\\
\theta_{12} \ln\left(\dfrac{V_S^*}{V_{\mathrm{lin}}}\right) + b \ln\left(\dfrac{V_S^*}{V_{\mathrm{lin}}}\right), & \text{if } V_{\mathrm{S30}} > V_{\mathrm{lin}}
\end{cases}
\end{aligned}
$$

$$
V_S^* = \begin{cases} 1000, & \text{if } V_{\mathrm{S30}} > 1000\\ V_{\mathrm{S30}}, & \text{if } V_{\mathrm{S30}} \leq 1000 \end{cases}
$$

$$
f_{\mathrm{FABA}}(R) = \left(\theta_7 + \theta_8 \ln\left(\frac{\max(R, 85)}{40}\right)\right).
$$

# Results



st reliabilities from Arica to Puerto Montt
1,2
1
0,8
0,6
0,4
0,2
0
0,14
0,12
0,09
0,31
0,28
0,26
0,32
0,29
0,27
0,31
0,28
0,28
0,32
0,29
0,27
0,37
0,37
0,35
0,37
0,37
0,35
0,39
0,37
0,35
REUNA without dependence
3A
3B
3C
3D
3E
3F
3F+1
0min
30min
60min

# Assumptions for calculating PGD

## Critical Accelerations ($a_c$) for Susceptibility Categories

| Susceptibility Category | None | I | II | III | IV | V | VI | VII | VIII | IX | X |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Critical Accelerations (g) | None | 0.60 | 0.50 | 0.40 | 0.35 | 0.30 | 0.25 | 0.20 | 0.15 | 0.10 | 0.05 |

### Landslide Susceptibility of Geologic Groups

| | Geologic Group | Slope Angle, degrees | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0-10 | 10-15 | 15-20 | 20-30 | 30-40 | >40 |
| | (a) DRY (groundwater below level of sliding) | | | | | | |
| A | Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\phi' = 35^o$) | None | None | I | II | IV | VI |
| B | Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c' = 0$, $\phi' = 35^o$) | None | III | IV | V | VI | VII |
| C | Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$ $\phi' = 20^o$) | V | VI | VII | IX | IX | IX |
| | (b) WET (groundwater level at ground surface) | | | | | | |
| A | Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\phi' = 35^o$) | None | III | VI | VII | VIII | VIII |
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| C | Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$ $\phi' = 20^o$) | VII | IX | X | X | X | X |

# Results

The reliability $r_{st}(j, \bar{t})$ is the probability of correct operation for each time instant $\bar{t}$, is calculated for each energy supply scenario $j$:

$$r_{st}(j, \bar{t}) = P(\phi(X^{j}_{\bar{t}}) = 1) = \mathbb{E}(\phi) \tag{3}$$