e-Journal of Nondestructive Testing - ISSN 1435-4934 - www.ndt.net

2nd Latin-American Workshop on Structural Health Monitoring
LATAM-SHM 2026
January, 7-9 2026

STRUCTURAL HEALTH MONITORING USING RASPBERRYSHAKES. LA SERENA AND SANTA MARTA BUILDINGS.

FRANCISCO HERNANDEZ[*] AND MIGUEL COLQUE[†]

[*] Faculty of Engineering and Applied Science
Universidad de Los Andes, Chile
Las Condes, Región Metropolitana de Santiago, Chile
e-mail: fjhernandez@uandes.cl, www.uandes.cl

[†] Faculty of Engineering
Universidad de La Serena, Chile
La Serena, Región de Coquimbo, Chile
e-mail: miguel.colque@userena.cl, www.userena.cl

Key words: RaspberryShake RS4D, low-cost seismic instrumentation system (LCSIS), Structural Health Monitoring (SHM).

Abstract. A low-cost seismic instrumentation system (LCSIS) was successfully developed and validated for structural health monitoring (SHM) of three Chilean buildings: the Penuelas Tower, the Santa Marta Building, and the Serena Building. The LCSIS integrates RaspberryShake® RS4D accelerographs connected through a local network managed by a Raspberry Pi 4B (RPi4B), which functions as an NTP server to ensure precise time synchronization, enables remote access, and periodically estimates the building's dynamic properties using horizontal geophone velocity records processed via the Frequency Domain Decomposition (FDD) method. To account for environmental influences on structural behavior, the LCSIS was coupled with a temperature and relative humidity monitoring unit, later upgraded with a BME280 sensor for continuous ambient data acquisition. The system is powered by a traditional UPS and an industrial PoE switch, ensuring uninterrupted operation during electrical outages. The article presents the main aspects of implementing a low-cost seismic instrumentation system (LCSIS) using RS4D devices. Its performance was verified through shake table tests, showing strong consistency with conventional instrumentation for frequencies below 25–30 Hz. Ambient vibration data are automatically processed hourly, enabling continuous tracking of the temporal evolution of dynamic properties. The LCSIS has proven effective at recording multiple seismic events and identifying dynamic properties for the two study cases.

1 INTRODUCTION

The US Geological Survey emphasizes that strong-motion recordings in urban areas are essential for designing earthquake-resistant structures and mitigating losses from future events [1]. In this context, seismic instrumentation should be prioritized in seismically active countries. Although Chile is one of the world's most earthquake-prone regions (averaging 7.6 Mw ≥ 7.0 earthquakes per decade since 1900), few structures are instrumented due to the high cost of monitoring systems, a common issue in developing nations.

 https://doi.org/10.58286/32469

To address this gap, a low-cost seismic instrumentation system (LCSIS) was developed using Raspberry Shake® RS4D seismometers/accelerographs, providing a cost-effective alternative for structural monitoring. Although Raspberry Shake devices have demonstrated reliability in seismological applications [2], their integration into structural monitoring systems has been scarcely documented. A seismically instrumented structure requires more than simply deploying low-cost sensors such as the RS4D accelerographs. Specifically, an effective instrumentation system must ensure device synchronization, reliable communication and data transfer, continuous power supply during outages, remote connectivity and control, real-time data visualization, and the capability to store and process seismic and ambient vibration data.

The first Chilean implementation of an LCSIS using RS4D accelerographs was carried out in the Peñuelas Tower—the first six-story light-frame timber building constructed in Latin America—whose details were reported by Alarcón et al. [3]. Although the system implemented in the Peñuelas Tower proved functional, it revealed several opportunities for improvement. Consequently, the LCSIS was upgraded in 2025 for the seismic instrumentation of the Santa Marta and La Serena buildings, achieving compliance with industrial standards (IEEE 802.3af/at). The upgraded system is more elegant and robust, as it reduces the number of devices and electrical connections required, extends the feasible distance between sensors, enhances internet connectivity, and integrates horizontal geophones suitable for SHM of reinforced concrete buildings.

Section 1 presents the main aspects of implementing this multi-device RS4D instrumentation network, which fulfills the aforementioned requirements and provides a versatile, reliable, and cost-efficient LCSIS solution for structural monitoring applications.

The sensitivity and synchronization of the RS4D sensors were verified through shake table experiments (Section 2), where multiple RS4D units operating under the LCSIS framework were tested simultaneously. Additionally, the system's performance was assessed through system identification analyses—based on both seismic and ambient vibration data—conducted on a small-scale structure instrumented with the LCSIS.

Sections 3 and 4 present the initial results obtained for the Santa Marta and La Serena buildings, respectively, from ambient vibration data that were automatically recorded and processed by the LCSIS, demonstrating its effectiveness for structural health monitoring (SHM) applications. Moreover, the seismic records automatically stored by the system (with redundant backup in a NAS server) were also processed, yielding consistent and reliable results.

1 LOW-COST SEISMIC INSTRUMENTATION SYSTEM (LCSIS) USING RS4D ACCELEROGRAPHS

An initial version of the Low-cost seismic instrumentation system (LCSIS) using Raspberry Shake® RS4D (dynamic range 144 dB-24 bits, DC to 44 Hz) accelerographs [4] was installed at the Peñuelas Tower in November 2021 (Figure 1(a), the first six-story light-frame timber experimental building in South America). Details about the LCSIS implemented in the Penuelas Tower can be reviewed in [3], related to a collaborative research project conducted between the Timber Innovation Center UC at the Pontificia Universidad Católica de Chile and RENADIC from the University of Chile.

The LCSIS with RS4D accelerographs was improved for the seismic instrumentation of the Santa Marta and La Serena buildings (Figure 1(b) and (c)), performed by the Universidad de los Andes, Chile, in 2025. Figure 2 shows a general scheme of the equipment required to implement the LCSIS system. Overall, the seismic instrumentation includes seven RS4D units installed within the structures, totaling approximately 7500 USD per project.

(a) Penuelas Tower (b) Santa Marta Building (c) La Serena Building

Figure 1: Chilean Buildings with an LCSIS with RS4D accelerographs.

A standard electrical source powers the LCSIS via a Hikvision 3000 VA/1800 W uninterruptible power supply (UPS), ensuring continuous operation and protection during power outages. The LCSIS consumes approximately 75 W, providing an estimated electrical autonomy of about 24 hours under battery operation. The UPS supplies power to an industrial 4G router (Milesight UR32L-L04AU), an industrial PoE switch (Milesight MS-S0208-G), and the central auxiliary unit, a Raspberry Pi 4 Model B 8 GB (RPi4B). All components are installed centrally inside a metal cabinet (Figure 3).

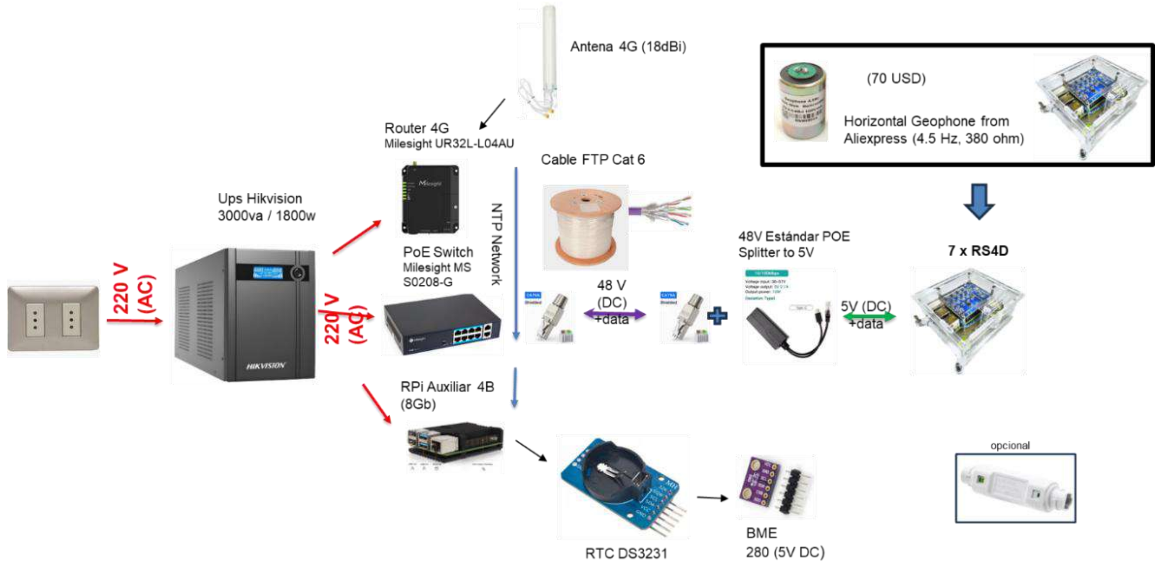


Figure 2. Equipment employed for the LCSIS of the Santa Marta and La Serena Buildings.

The 4G router is equipped with a cellular SIM card and connected to an external 18 dBi antenna, providing internet access to all devices (RS4D units and the RPi4B), even inside a building enclosed by RC walls. It should be noted that the industrial router includes an internal watchdog function capable of rapidly restoring the internet connection whenever the cellular provider temporarily drops the service—a common issue when using mobile broadband (BAM) networks. This configuration enables remote control, real-time monitoring, and automatic data transfer. The RPi4B and the seven RS4D accelerographs are interconnected via the industrial PoE switch and router, forming a local network that enables fast communication. The RPi4B operates as an NTP server, and each RS4D queries it every 8 seconds, maintaining precise time synchronization between R4SD accelerographs with offsets below 1 ms.

A Real-Time Clock (RTC) module (DS3231) and a barometric sensor (BME280, 5 V) are connected to the RPi4B via SPI. The RPi4B periodically queries the BME280 to obtain relative humidity and temperature measurements, while the RTC ensures accurate timekeeping during extended power interruptions. When internet connectivity is available, the RPi4B automatically updates its UTC using a SHOA NTP server, maintaining precise temporal synchronization.

Figure 3. Photographs of equipment installation, a) RPi4B central, b) PoE Switch Milesight MS S0208-G , c) Router 4G Milesight UR32L-L04AU, d) BME 280 barometric sensor, e) UPS Hikvision 3000 VA / 1800 W , f) 4G Antena (18dBi), g) RS4D installed on the roof, h) RS4D before roof's installation, i) JT-COM PoE splitter, j) details of RS4D roof´s installation, k) RS4D installed on the ground floor.

The industrial PoE switch operates using Power over Ethernet (PoE) technology, featuring eight ports that enable simultaneous data transmission and 48 V DC power delivery through a single Ethernet cable. The RS4D accelerographs are connected to the switch using FTP Cat 6 cables terminated with shielded Zoerax Cat 6A RJ45 connectors at both ends. A dedicated industrial JT-COM PoE splitter is installed before each RS4D unit to convert the 48 V DC input into a 5 V DC / 2.1 A output and provide a micro-USB connector (or USB-C, depending on the RS4D model) for power supply. The splitter also separates the Ethernet data line, which is directly connected to the RS4D accelerograph for data transmission. It is worth noting that the industrial PoE switch complies with the IEEE 802.3af/at standard, enabling communication with sensors or CCTV cameras over standard transmission distances of up to 100 m. Furthermore, an extended mode is available, allowing data and power transmission over distances of up to 250 m. Furthermore, 48 V PoE repeaters can be optionally incorporated to extend the transmission range beyond 250 m, ensuring reliable data and power delivery over longer cable runs. Compared to the LCSIS implementation of the Penuelas Tower [3], the current LCSIS solution (implemented in Santa Marta and La Serena Building) uses industrial-standard protocols, connections, and power supply, reducing the number of connections and auxiliary devices, offering a more compact and reliable LCSIS. It provides a robust internet connection and can be employed to connect RS4D accelerographs over longer distances. In fact, the LCSIS installed in the La Serena building was mounted within 3 days and has been operational and working without any issues since then. Therefore, the LCSIS can be easily installed and provides a robust solution for structures that do not need periodic inspection or maintenance.

The RS4D is a promising seismometer & accelerometer with one vertical geophone, a triaxial MEMS accelerometer orthogonally oriented, an acquisition system, and a computer in one box. The RS4D accelerographs sample data to 100 sps [5]. The R4SD-V8 is a portable Raspberry Pi 3 Model B computer that acquires sensor data and supports internet or local network communication**.** The disadvantages of MEMS accelerometers are that they do not allow ambient vibration testing due to their low signal-to-noise ratio. However, the incorporated vertical geophones enable estimation of natural frequencies from ambient vibration data. In this context, the natural frequencies of the Penuelas Tower were estimated hourly using 30-minute ambient vibration data from the vertical geophones incorporated into the RS4D. In this context, the Penuelas Tower is a slender building that allows estimating the natural frequencies associated with its structural modes (longitudinal, transverse, and torsional) from ambient vertical vibration recordings. It should be pointed out that the geophones work with certain directivity (i.e., either in horizontal or vertical direction); therefore, it is not enough to reorient the geophone to record horizontal velocities.

In this context, the RS4D were modified (Figure 4) for the Santa Marta and La Serena projects. In particular, horizontal geophones (fn = 4.5 Hz, 375 Ω, 28.8 V/m/s) were procured, and the original vertical geophones supplied with the RS4D sensors were substituted by disconnecting their original leads and rewelding them to the newly installed horizontal geophones (Figure 3). The new horizontal geophones were mounted in the horizontal plane (aligned with the E–W axis) using a metal clamp. As a result, the modified RS4D accelerographs can record ambient vibrations associated with the building's horizontal motion (longitudinal or transverse), enabling hourly estimates of its natural frequencies from ambient vibration data.

Figure 4. Replacement of vertical geophones by horizontal geophones of the RS4D accelerographs.

Overall, the central RPi4B unit serves multiple functions:

i) It operates as an NTP server, ensuring synchronization of all RS4D sensors.

ii) It is equipped with a BME280 sensor that measures relative humidity and temperature, recorded hourly, together with the ambient vibration tests.

iii) It connects to the Internet via a 4G router, allowing remote communication and control through the Raspberry Pi Connect software.
iv) It interfaces with the RS4D accelerographs through the local network established by the router and the PoE switch, enabling remote management of the RS4D units.
v) Real-time data visualization is achieved using SWARM software, which allows the display on the screen of real-time histories, Fourier spectra, spectrograms, and particle motion plots derived from any of the MEMS accelerometers or the horizontal geophone of the RS4D accelerographs.
vi) The RS4D data can also be requested via the ObsPy library, allowing the RPi4B to retrieve ambient vibration or seismic records stored by the RS4D, which retains acceleration and velocity data for the most recent 21 days.

Moreover, multiple routines can be elaborated using bash scripts, Python routines or Octave software (that can interact between them). In fact, the routines can be performed on a defined schedule using the crontab option built into the Raspberry Pi. Then, the RPi4B was formally programmed to perform multiple tasks as follows:

i) It checks every 5 minutes if the two RS4D accelerographs have reached a certain acceleration threshold (0.003g). If it has been reached, the RPi4B saves seismic data (5 minutes before and 5 minutes after the PGA) from the three triaxial accelerometers for all the RS4D connected to the LCSIS. Moreover, it saves ambient vibration data from the geophones related to 30 minutes before the seismic event, then waits 30 minutes after the earthquake, and saves the ambient vibration data after the seismic event. Moreover, it automatically sends a warning email reporting the PGA and PFA recorded by all RS4D accelerometers. Finally, the seismic data (and the ambient vibration data) are automatically transferred to a NAS server at the University of Los Andes, Chile, using the lftp software, enabling an automatic backup of the seismic data (if the internet is available). Seismic data is saved in a folder of the RPi4B; similarly, each RS4D accelerograph stores seismic data for 21 days inside the equipment (which can be extracted using Filezilla software from the RPi4B).
ii) Once a week, it records and saves ambient vibration data from the horizontal geophones (saving also the temperature and relative humidity). The ambient vibration data is automatically transferred to the NAS server. The ambient vibration data is stored in the RPi4B for 3 months.
iii) Hourly, it extracts 30 minutes in length ambient vibration data from the geophones incorporated in the RS4D accelerographs. Then, it uses the Frequency Domain Decomposition (FDD) system identification technique to estimate the current natural frequencies, mode shapes, and damping ratios of the monitored structure. Then it saves the history of the identified dynamic properties in a file along with the temperature and relative humidity measured by the BME280 sensor. The file is saved daily on the NAS server. It allows generate an effective SHM tool.
iv) Daily, it sends an email evaluating the operation of the RS4D accelerographs, allowing verifying the proper functionality of the LCSIS.

2 VALIDATION OF THE SEISMIC INSTRUMENTATION

Shake table tests were performed at the University of Los Andes on a TDG-250 kgf shake table (Figure 5) to compare the seismic records from the MEMS accelerometers of the RS4D accelerographs with commercial acceleration traces recorded with Endevco 44A16 accelerometers (using a HBK MX1601B acquisition system with a sampling frequency of 200 sps).

First, a series of tests was conducted by installing seven RS4D accelerographs on the TDG shake table. The acceleration records were compared with those obtained from a commercial accelerometer, yielding NRMSE values below 0.4. The observed discrepancies were attributed to high-frequency noise generated by friction in the shake table. Furthermore, cross-correlation analysis confirmed that the time offset among RS4D records was less than 1 ms, indicating that the LCSIS system achieved proper synchronization. These results are consistent with those reported in [3].

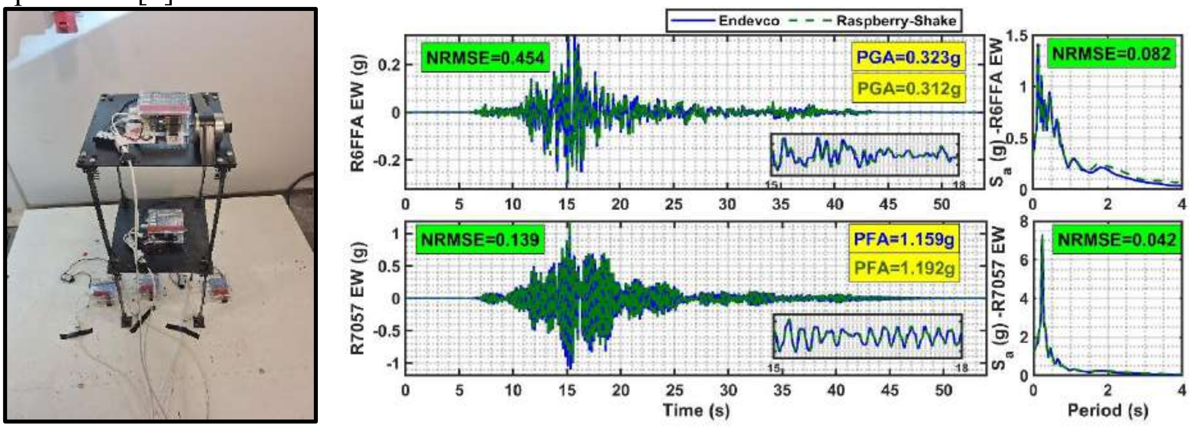


Figure 5. Comparison of Seismic records between Endevco and RS4D

A second set of shake-table tests was conducted using a small-scale structural model. Figure 5 compares the acceleration records measured at the base and top floors, showing excellent agreement between the Endevco 44A16 sensor and the RS4D accelerographs. Figure 5 also presents the SFDD and DSI stabilization diagrams derived from seismic data recorded by the RS4D units on the small-scale structure. Overall, the seismic recordings enabled accurate identification of the structure's dynamic properties, comparable to those obtained from the commercial sensors.

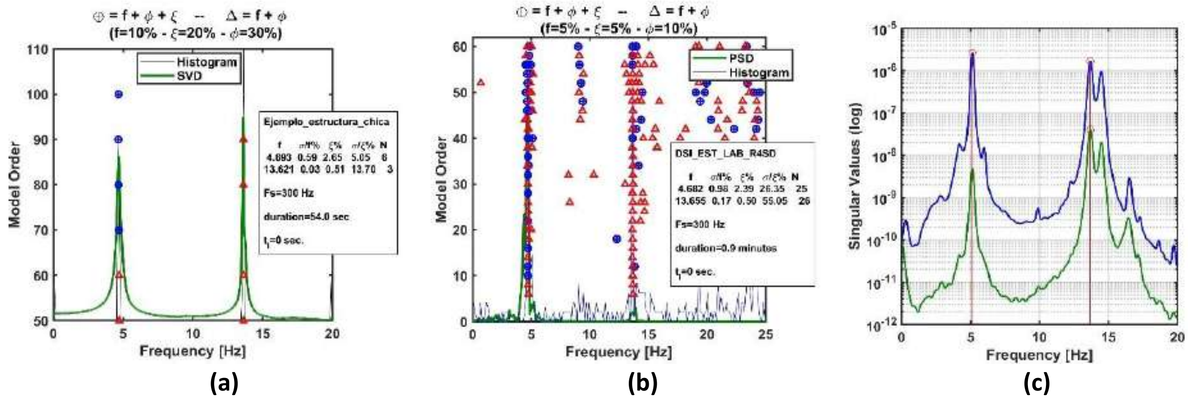


Figure 6. (a) Stabilization diagram obtained with the SFDD method (seismic case), (b) Stabilization Diagram obtained with the DSI method (seismic case), (c) Singular value decomposition obtained from the FDD method (ambient vibration data)

In addition, ambient vibration tests were performed on the same small-scale structure. The FDD method was applied to the velocity records obtained from the horizontal geophones (which replaced the original vertical ones). Figure 6 (c) shows the singular value decomposition derived from the FDD analysis of the RS4D velocity records, where two predominant modes were clearly identified, which are consistent with the dynamic properties observed in the shake table tests.

Moreover, high-sensitivity PCB 393B31 accelerometers, connected to a Dewesoft Krypton acquisition system, were used simultaneously to record ambient vibrations. The results closely matched those from the RS4D horizontal geophones, confirming that the modified RS4D units can reliably estimate the natural frequencies of structures from ambient vibration data. Finally, ambient vibration measurements were also conducted on the Engineering Building at the University of Los Andes (Chile), again showing close agreement in identified natural frequencies and damping ratios between the RS4D geophones and the PCB 393B31 accelerometers.

3 SANTA MARTA (SM) BUILDING IDENTIFICATION

The Santa Marta (SM) building is in the Huechuraba suburb of Santiago, Chile. It was built in 2006 over relatively soft soil. According to previous studies [6], it is close to experiencing the double resonance phenomenon. This 16-story R/C shear wall building is used for residential purposes, and its natural frequencies recorded in 2018 with Tromino® sensors were 1.08 Hz, 1.17 Hz, and 1.32 Hz in the longitudinal, transverse, and torsional directions, respectively [6]. The SM building is located on a soft-soil deposit with a natural frequency of 0.9-1.5 Hz, a peak H/V value of 5-6, and a V_{s30} of 270 m/s. To summarize, the SM building is an ideal case for evaluating whether the N-W Santiago soft soil can significantly amplify the seismic response of a mid-rise residential building.

The SM building was seismically instrumented using the LCSIS described in Section 1, with seven RS4D accelerographs (one on the second underground floor— the base level —, two on the roof of the 3rd level, two on the roof of the 8th level, and two on the roof of the 13th level). They were strategically placed to monitor the longitudinal, transverse, and torsional response of the monitored floors. The RS4D accelerographs were oriented in different directions so that horizontal geophones could be used to track the structure's natural frequencies.

Figure 7 shows the Singular Value Decomposition (SVD) for the FDD-AR method applied to 30 minutes of ambient vibration data from the RS4D horizontal geophones, from which the dynamic properties (natural frequencies and damping ratios) can be identified. Similarly, Figure 7 shows the evolution of the first three natural frequencies of the building from the day of installation to the end of October 2025, indicating that the natural frequencies change slightly with variations in environmental conditions (i.e., lower frequencies are observed in spring than in winter).

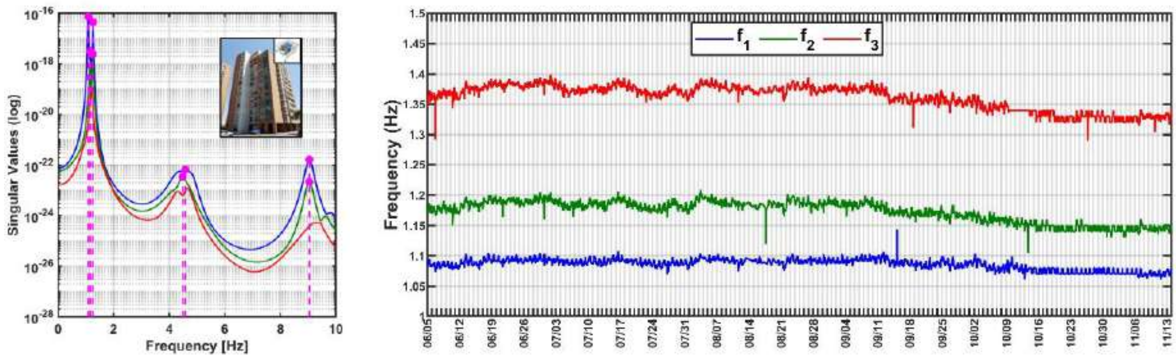


Figure 7. SVD obtained from ambient vibration data using the FDD method, and the time evolution of the first three natural frequencies identified from ambient vibration data of the SM building in 2025.

The LCSIS was formally implemented on 5 June 2025. Until the end of October 2025, the LCSIS of the SM building has automatically recorded six seismic events (ranging from ML=4 to Mw=6.2 with epicenters at different locations). Figure 8(a) shows the acceleration traces recorded by the seven RS4D accelerometers along the longitudinal direction of the SM building (transverse and vertical accelerations were also recorded) related to a seismic event that occurred on 15 October 2025, Mw=5.5. Figure 8(b) displays the response spectra (ξ=5%) for the base acceleration traces, accompanied by vertical lines corresponding to the natural periods identified from ambient vibration data for the first three structural modes (Figure 7). Overall, the spectra peak is near 0.7-1.0 seconds, indicating that the principal structural modes are subjected to high seismic demands (near double resonance).

Figure 8(c) shows the stabilization diagram obtained from the SFDD method using the recorded seismic data, where the identified dynamic properties are consistent with those from ambient vibration data (the natural frequencies identified from low-intensity seismic events are always slightly smaller than those estimated from OMA).

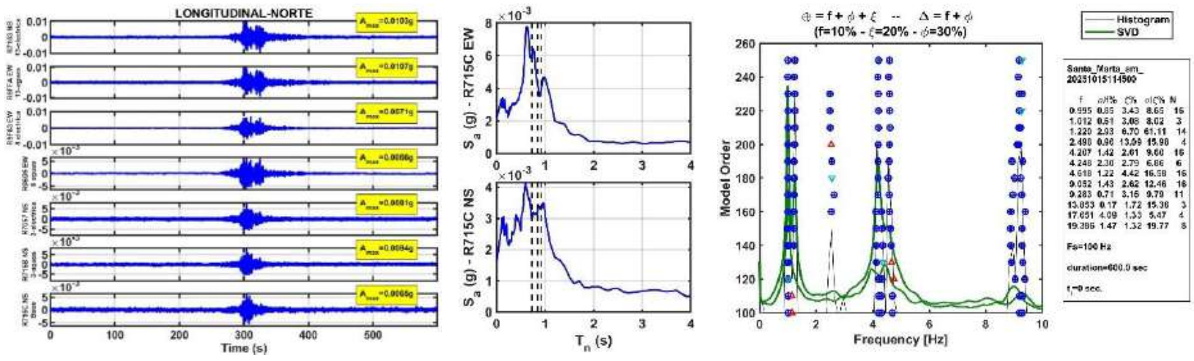


Figure 8. (a) Longitudinal seismic records, (b) response spectra ξ=5% related to the base acceleration records, (c) Stabilization Diagram of the SFDD. All applied to the seismic data recorded on 15 October 2025, Mw=5.5.

4 LA SERENA (LS) BUILDING IDENTIFICATION

The "La Serena" (LS) building is located in La Serena city, Coquimbo Region, Chile, near the casino and the coast. It is a 24-story reinforced concrete wall building composed of two twin, symmetrical towers separated by a seismic joint. Only the northern tower has been instrumented with the LCSIS. The city lies at the southern edge of the well-known seismic gap between Copiapó and La Serena, where no major earthquake has occurred since 1922. That event, known as the Vallenar earthquake (Mw = 8.5), generated a significant tsunami and released the accumulated strain energy in the region. Before that, the last major earthquake in the same area occurred in 1819 (Mw = 8.5, the Copiapó earthquake, also followed by a tsunami), suggesting a recurrence interval of approximately 103 years—pointing to 2025 as a plausible time window for the next large event. Consequently, it is technically reasonable to focus seismic instrumentation efforts in Chile on cities such as Huasco, Vallenar, Copiapó, Caldera, La Serena, and Coquimbo, given the elevated probability of a major earthquake in the coming decades. It should also be noted that other areas in northern Chile exhibit similarly high seismic potential.

The LCSIS was implemented in a building in La Serena, located at the northern edge of the Chilean seismic gap, given that the city hosts several mid-rise reinforced concrete buildings suitable for seismic instrumentation. Additionally, the collaboration with the University of La

Serena provided essential logistical support, facilitating access to a suitable building and offering local assistance in case of technical issues with the LCSIS. La Serena's proximity to Santiago (approximately 400 km from the University of Los Andes) also reduces transportation time and costs, which is critical for rapid deployment and maintenance activities.

Following the successful upgrades applied to the LCSIS at the Peñuelas building—originally developed and validated in the Santa Marta building—the system had reached sufficient robustness to be installed in a single campaign, without the need for subsequent on-site corrections typically required during earlier development stages. Consequently, the LCSIS at the La Serena building was fully deployed in just three days, with no significant issues encountered during installation and without requiring a return visit. Since its installation on 9 October 2025, the system has operated continuously and reliably, successfully recording two seismic events (Mw 4.9 and Mw 5.5) by the end of that month.

The LS building was instrumented with the LCSIS described in Section 1, employing seven RS4D accelerographs. The devices were strategically installed as follows: one unit on the second ground floor (base level), two on the roof of the 8th floor, two on the roof of the 15th floor, and two on the roof of the 23rd floor. This configuration was designed to capture the building's longitudinal, transverse, and torsional dynamic responses. The RS4D accelerographs were oriented in different directions to ensure optimal coverage of the horizontal components, enabling the horizontal geophones to track the structure's natural frequencies and mode shapes effectively.

Figure 9 presents the Singular Value Decomposition (SVD) results obtained using the Frequency Domain Decomposition (FDD-AR) method applied to 30 minutes of ambient vibration data recorded by the horizontal geophones of the RS4D sensors. From this analysis, the building's dynamic properties—namely, its natural frequencies and damping ratios—can be identified. The same figure also illustrates the temporal evolution of the first three natural frequencies from the date of installation until the middle of November 2025. Specifically, the natural frequencies tend to slightly decrease at higher temperatures.

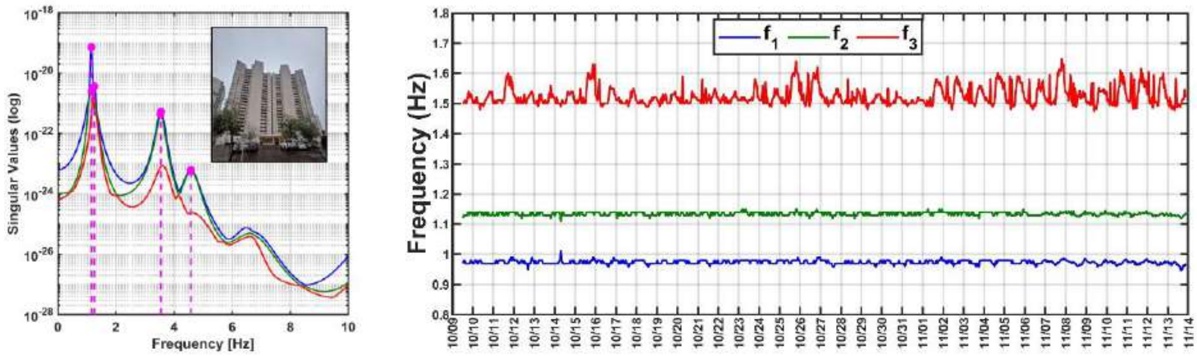
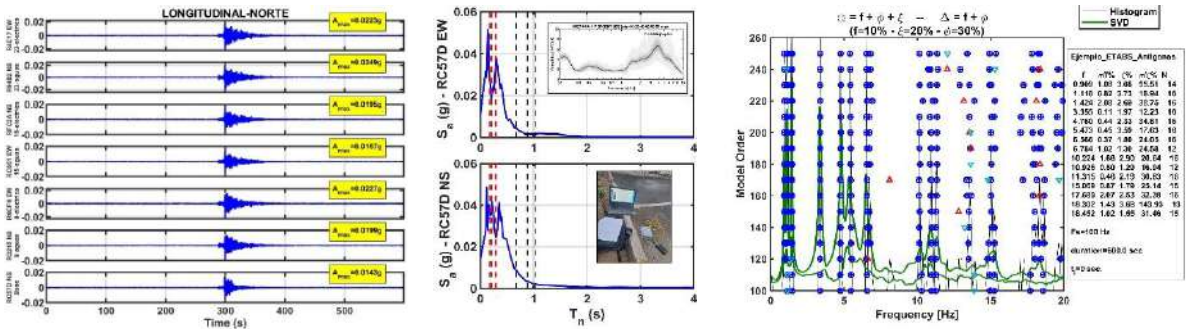


Figure 9. SVD obtained from ambient vibration data using the FDD method, and the time evolution of the first three natural frequencies identified from ambient vibration data of the LS building in October 2025.

Figure 10(a) presents the acceleration time histories recorded by the seven RS4D accelerometers installed along the longitudinal direction of the LS building during the Mw = 5.5 earthquake that occurred on 15 October 2025. Transverse and vertical accelerations were also recorded but are not shown here for brevity. Figure 10(b) shows the 5%-damped response spectra computed from the base acceleration traces. Dashed black vertical lines indicate the natural periods corresponding to the first three structural modes identified from ambient vibration analyses (Figure 9), while dashed red vertical lines denote the fourth to sixth modal frequencies identified from Operational Modal Analysis (OMA).

As shown in Figure 10(b), the highest spectral demands are concentrated within natural periods ranging from 0.1 s to 0.4 s. To better characterize the site conditions, a Nakamura (HVSR) test was performed adjacent to the building using a RaspberryShake RS3D equipped with a triaxial geophone (natural frequency = 4.54 Hz). The HVSR results indicate a predominant site frequency of approximately 4 Hz (i.e., a natural period of 0.25 s). This implies that while site effects do not significantly amplify the first three structural modes, the fourth to sixth modes experience notably higher seismic demands. Therefore, its fundamental modes do not solely govern the seismic response of the LS building; higher modes (fourth to sixth) also play an important role, particularly for tall buildings founded on relatively stiff soil profiles with high predominant frequencies.

Figure 10(c) presents the stabilization diagram obtained using the Seismic Frequency Domain Decomposition (SFDD) method applied to the recorded seismic data. The identified dynamic properties are consistent with those derived from ambient vibration analyses, although the natural frequencies estimated from low-intensity seismic events are slightly lower than those obtained from OMA.



(a) (b) (c)

Figure 10. (a) Longitudinal seismic records, (b) response spectra ξ=5% related to the base acceleration records, (c) Stabilization Diagram of the SFDD. All applied to the seismic data recorded on 15 October 2025, Mw=5.5.

5 CONCLUSIONS

An upgraded version of the LCSIS initially implemented in the Penuelas Tower is presented. While the same fundamental design principles were retained, all auxiliary components were redesigned to comply with industrial standards commonly used in CCTV systems. This new configuration significantly reduces the number of electrical connections and peripheral devices, resulting in a more robust and straightforward solution. Consequently, the LCSIS can be deployed with a high degree of reliability, minimizing installation time and mitigating common sources of malfunction.

The upgraded system incorporates Power over Ethernet (PoE) technology through an industrial PoE switch compliant with the IEEE 802.3af/at standard. This allows the RS4D sensors to operate within a local network capable of covering longer distances while relying on dedicated industrial-grade PoE hardware. An industrial 4G router equipped with an external antenna further enhances internet connectivity, providing stable access to both the central Raspberry Pi 4B unit and the RS4D accelerographs.

Additionally, the vertical geophones originally integrated into the RS4D units are not optimal for tracking the building's longitudinal, transverse, or torsional vibration modes, as they primarily capture vertical motion. To address this limitation, the system was upgraded with horizontal geophones of comparable specifications, enabling more accurate tracking of horizontal vibrations and improving the identification of structural modes from ambient vibration data. This modification makes the system particularly suitable for structural health monitoring (SHM) of reinforced concrete wall buildings.

The upgraded LCSIS has been successfully implemented in the Santa Marta and La Serena buildings, enabling continuous tracking of dynamic properties at an hourly rate using Operational Modal Analysis (OMA). Furthermore, the system has effectively recorded multiple seismic events with excellent synchronization (time offsets of less than 1 ms between sensors), ensuring reliable estimation of dynamic properties from real seismic data.

ACKNOWLEDGMENTS

The authors acknowledge the financial support from the Chilean National Agency for Research and Development (ANID) through the research grant FONDECYT-Iniciacion grant 11251253.

REFERENCES

[1] U.S. Geological Survey, Advanced National Seismic System—Current status, development opportunities, and priorities for 2017–2027, 2017.

[2] A. Manconi, V. Coviello, M. Galletti, R. Seifert, Short communication: Monitoring rockfalls with the Raspberry Shake, Earth Surf. Dyn. 6 (2018) 1219–1227. https://doi.org/10.5194/esurf-6-1219-2018.

[3] M. Alarcón, P. Soto, F. Hern, P. Guindos, Structural health monitoring of South America's first 6-Story experimental light-frame timber-building by using a low-cost RaspberryShake seismic instrumentation, Eng. Struct. 275 (2023) 1–17. https://doi.org/10.1016/j.engstruct.2022.115278.

[4] Raspberry Shake, Raspberry Shake Main Page, (2022).

[5] Raspberry Shake, Specifications for : Raspberry Shake RS4D, (2021).

[6] I. Horta, Estudio de vulnerabilidad sismica de estructuras altas en sector norponiente de santiago empleando metodos de identificacacion de estructuras (In Spanish), University of Chile, 2019.