Repair, Defer or Do Nothing

Structure Movement Monitoring for Efficient Planning and Decision Making

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Symptoms of building movement can develop obviously and suddenly, or more subtly over years or decades. Common symptoms include cracks in walls or floors, racked windows and door frames, and sloping or uneven floors. While each of these symptoms causes concern, not all are equal. Some symptoms could be a sign of structural deterioration in need of immediate repair. In contrast, other symptoms may be a remnant of previous movement that occurred years ago and has since stabilized. In between, a range of conditions exist. Given the range of potential repair actions and related costs, it is essential to identify the cause and an appropriate scope of repair.

Severe symptoms require immediate investigation to determine whether emergency actions are required. However, suppose the engineer and building owner determine that immediate actions are not warranted. In that case, a thoughtful structure movement-monitoring program serves as a valuable tool to identify the appropriate type, timing, and extent of repairs. Collecting the data and understanding the symptoms provide significant value to the owner, the building, and its tenants, as repairs can focus on what is essential.

This article highlights types of structure movement monitoring (referred to herein as monitoring or the monitoring program) that can be implemented to help the owner isolate the cause of damage and plan for effective repairs, along with several examples that illustrate varying conditions and subsequent actions.

Crack in masonry unit block wall.

Instrument Types and Considerations

Monitoring may employ a variety of instruments depending on the conditions and type of structure. Several instruments commonly used with considerations for selection and installation are listed below. Costs can vary widely depending upon the sophistication of the instruments.

Crack and Joint Measurements

- Purpose: Monitor displacement at joints or cracks.
- Instruments: Crack monitors and displacement gauges (visual/manual or electromechanical readout; 1-D, 2-D, or 3-D); tiltmeters; hand-held levels; and many others.
- Considerations: Choose based on the configuration, access, and anticipated movement (type, magnitude, and direction). Sometimes the best solution is the least sophisticated (e.g., pen marks or pins mounted on either side of a crack and measured with a tape measure or calipers).

Cracks in masonry block wall repaired with supplemental carbon reinforcement. The monitoring program verified the performance of these repairs.

Deformation Survey

- Purpose: Measure displacement of structural components, ground surface, utilities, etc.
- Instruments: Digital or optical levels, total station, 3-D laser scans, deformation monitoring points (DMPs).
- Considerations: Determine whether long-term repeatability is necessary. Identify appropriate location, quantity, and type of permanent or temporary DMPs and reference benchmarks (BMs). Evaluate the level of accuracy needed and sophistication of the equipment

Below-Grade Measurements

- Purpose: Measure soil movements or groundwater elevations.
- Instruments: Groundwater observation wells, extensometers, and inclinometers.
- Considerations: Installation requires test borings which can be disruptive to building operations and occupancy. Interior access is often more challenging than exterior access.

Additional considerations are common to all instruments. Business considerations include the building's value and expected useful life, time-horizon for repairs, potential repair costs, owner budget, and safety. Technical considerations include accuracy requirements, frequency and duration of data collection, repeatability, manual or automated readings, power source, and cell service for remote data transmission. Logistical considerations include access, durability, protection from the weather, construction, vandalism, impacts to tenant use of the space (e.g., trip hazards or aesthetics), and possible placement near sensitive equipment affected by vibrations or levelness (e.g., manufacturing, medical, or testing).

Developing Monitoring Programs

Developing an effective monitoring program requires investigation to identify the program objectives. The investigation includes a visual assessment, a desktop study, and sometimes destructive or invasive activity that includes building openings or subsurface exploration.

- Visual Assessment: A visual assessment identifies the type of distress symptoms, magnitudes, locations, trends, construction materials, and age of the symptom.
- Desktop Study: A review of available data, including construction drawings, repair records, construction permits, historical photos, or prior subsurface investigations gives a head start in understanding building construction, foundation types, and potential load paths.
- Invasive Investigations: When conditions permit or when historical data is absent, an invasive investigation consisting of building openings (e.g., at framing connections, column to foundation interfaces) and/or subsurface investigations (e.g., soil test borings or test pits) provides critical information to diagnose a problem.

Temporary repair involving underslab void filling. Coring, filling voids with grout, and patching can be performed over a few days compared to a longer construction period for a permanent repair.

Permanent repair involving slab replacement is usually more disruptive to the client's space compared to temporary repairs.

An immediate visual assessment of severe distress symptoms coupled with a brief desktop study can quickly identify the potential need for immediate emergency stabilization. In many cases, after ruling out immediate safety issues, the engineer can develop correlations between building construction (or renovations), foundation type, and subsurface conditions, identify possible contributors to distress symptoms, and identify what to measure. Then, armed with knowledge, the engineer can develop a targeted instrumentation plan with the type, location, and quantity of instruments and the frequency of data collection to help establish whether movement has stabilized or is worsening.

The owner and its engineer must work together to balance priorities. For example, what areas are most important to diagnose and repair? What areas must be maintained without disruption in the short term? Does the owner's time-horizon permit monitoring beyond a year? The owner's specific needs and input influence the program.

The monitoring program informs decisions for a range of outcomes, from no action needed, to implementation of repairs, to deferred action where repairs are prioritized over time.

No Action

The engineer's recommendation may be *No Action* if the monitoring data shows that movement is no longer ongoing, the distress symptoms are remnants of long-ago movements, and no safety risk exists. This condition is a somewhat best-case scenario, where proactive instrumentation, monitoring, and patience save the owner repair cost and disruption. In some cases, *No Action* may result from several rounds (or years) of monitoring and a thorough investigation and assessment.

Example of No Action

An owner was concerned that its building was settling. Multiple tenants reported cracked wall finishes, gaps between wood trim and floors, and sloped floors in a 100-year-old, multi-story residential building. The structure consisted of wood framing and masonry-bearing walls supported on concrete and stone foundations.

After performing a visual assessment of the structure and symptoms, the engineer implemented a monitoring program that included crack gauges, a structure deformation survey, and floor levelness readings every six to twelve months over two-plus years. Results showed that the symptoms were not caused by foundation settlement but rather a combination of creep of the wood framing and localized framing reconfiguration and repairs over the life of the building. Seasonal dimensional change of wood trim and flooring finishes caused gaps to be more apparent in the winter months, and the foundation was stable. No repairs were required. The instrumentation remained on the structure to allow future readings if new symptoms develop.

Repairs (with Verification)

In many cases, the need for repairs is evident based on visual inspection. However, desktop study, instrumentation, and monitoring help define the appropriate type of repair. In some cases, instrumentation and monitoring can verify the adequate performance of a more cost-effective repair.

Example of Repairs with Verification

An owner reported cracks in the shear walls for a multi-story masonry apartment building. The engineer completed an investigation and monitoring program to evaluate the cause. The monitoring program consisted of deformation surveys and crack gauges and showed that the foundation was no longer moving. The engineer developed repairs for the shear wall, supplemented with a monitoring program for a few years after repairs to confirm performance, saving the client the costs and disruption of more significant and conservative foundation repairs.

Repairs (Temporary, with Monitoring)

Depending on the project, permanent repair may not be the best option for the client. For example, permanent settlement mitigation repairs such as soil improvement grouting, foundation underpinning, or replacement of a slab-on-grade with a structural slab are often disruptive to the client's operations, even if repairs are phased.

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Test pit excavation to observe buried wood pile foundations and extract specimens. The monitoring program informed the locations for the test pit investigation.

Example of a disruptive foundation underpinning repair requiring capital planning. Foundation underpinning repairs consist of needle beams supported on micropile foundations.

Depending on the structure, rate of measured movement, cause of settlement, and the client's use of the space, a temporary repair can "buy time" and serve as an effective means to limit disruptions to operations. While a permanent repair could be the most robust solution, the temporary repair supplemented with monitoring may better suit the client's needs.

Example of Temporary Repairs with Monitoring

An owner reported settlement of a slab-on-grade at a cleanroom medical manufacturing facility. The building's structural framing was supported on deep foundations and exhibited little to no movement. The slab-on-grade settlement significantly impacted serviceability and facility operations due to racked door frames, damaged utilities, and reduced equipment usage.

A subsurface investigation identified the presence of voids beneath the slab-on-grade, in addition to compressible subgrade. The engineer implemented a monitoring program combined with temporary repairs in targeted areas to mitigate slab settlement by filling the under-slab voids with a lightweight grout. The monitoring program consisted of frequent structure deformation surveys and annual ground penetrating radar surveys to detect under-slab voids and identify areas at risk of sudden settlement. The monitoring program allowed the owner to slow damage to the floor slab and equipment, manage risk of additional settlement, and maintain facility operations.

Repairs (Deferred and/or Prioritized)

In many instances, repairs are warranted but not required immediately. The owner and engineer can work together to plan for what can often be costly and disruptive foundation repairs. Since repairs are deferred and implemented over time, monitoring is a critical tool to help plan and prioritize repairs.

Example of Deferring and Prioritizing Repairs

A historic and iconic masonry building previously experienced settlement due to timber pile deterioration resulting from lowered groundwater levels. The monitoring program consisted of groundwater observation wells, borehole extensometers, tiltmeters, various types of crack monitors, and an extensive network of structure deformation monitoring points on walls and foundations.

The structure deformation survey was critical for repair planning. High accuracy and repeatability of the survey data are essential to understanding behavior. In this case, structure deformation monitoring techniques involved a high precision digital level and an invar survey rod, collecting multiple rounds of data, and performing a least-squares adjustment of the elevation data to obtain an appropriate accuracy not achievable with traditional survey methods. This was particularly important since the survey traversed multiple interior building spaces.

For this high-value building, the owner agreed to engage the engineer to evaluate and estimate the remaining service life of the timber piles supporting the structure. Combined with the groundwater and structure movement monitoring program, the engineer identified trends and established a low to high-risk priority matrix for repairs within the structure. This priority matrix helped the owner develop a capital plan for long-term repairs. The owner continues to use the monitoring program to update its capital plan as needed based on measurements as time progresses.

Conclusion

There are a variety of instruments available for monitoring the behavior of structures and their foundations. Some tools can be used in day-to-day work; others are more complex and require planning, investigation, and some level of disruption to the tenants.

When initial investigations determine that structural safety is not a concern, time for thoughtful and targeted monitoring typically can save the owner unnecessary disruption and repair costs. An effective monitoring program helps owners understand the source of distress, serves as a tool to document symptoms over time, and ultimately helps the owner and its engineer make decisions about the extent and timeliness of needed repairs, if any. Ultimately, the successful monitoring program allows owners to control priorities and budgets for repairs and provides time to plan for disruptions to occupancy and facility operations.▪

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