FOUNDATION CRACKS, LEANS, BULGES, SETTLEMENT: INSPECTING FOUNDATIONS FOR STRUCTURAL DEFECTS - DETECTION, DIAGNOSIS, CAUSE, REPAIR

This document describes how to recognize and diagnose various types of foundation failure or damage, such as foundation cracks, masonry foundation crack patterns, and moving, leaning, bulging, or bowing building foundation walls.

Types of foundation cracks, crack patterns, differences in the meaning of cracks in different foundation materials, site conditions, building history, and other evidence of building movement and damage are described to assist in recognizing foundation defects and to help the inspector separate cosmetic or low-risk conditions from those likely to be important and potentially costly to repair.

Methods & Procedures for Evaluating Residential Structural Foundation Cracks, Movement, & Condition

Foundation Inspection Objectives

Home inspectors, building code compliance inspectors, and general building contractors are often able to recognize possible foundation or other building problems which may be costly or dangerous, thus requiring the intervention of an expert foundation repair company or foundation design engineer. These early visitors to a building site, most often the home inspector, see a very large number of *in-service field conditions* leading to building failures.

Foundation inspectors can, without performing any engineering calculations or analysis, learn to recognize signs of important foundation or other structural problems developing well before forensic engineers and foundation experts are asked to design a repair and almost always well before the actual occurrence of a catastrophic building failure. This breadth of field inspection experience and education, combined with an informed and careful building inspection, provide a valuable first line of defense for building owners and occupants who may be facing previously unrecognized costly or dangerous foundation damage.

- **Foundation inspections** are conducted to identify & document potential costly or dangerous conditions. The inspection must consider many factors beyond the obviously visible condition of the foundation, such as attending to site conditions, evidence of the history of building movement, and the type, location, and extent of cracking and movement. This data, combined with education and experience, permit a knowledgeable foundation inspector to advise the client about the urgency of foundation repair and the type of repair that may be needed.
- **Accountability:** the inspector is accountable for visible portions of the foundation and for recognizing signs of defects. In some circumstances this may include invisible or hard-to-see conditions for which there are nonetheless adequate clues: contextual, historical, or other visible secondary evidence.
- **Action:** If appropriate, the inspector may suggest further evaluation/repair including invasive methods such as removing finish materials that cover the foundation, outside excavation, the employment of a foundation engineer, foundation repair company, a test firm to make soil borings, or other investigative measures.
- **Dangers:** Since certain masonry structure defects, such as bulged above ground brick masonry walls, can lead to sudden precipitous and catastrophic collapse, dangerous conditions may be present at some properties. While there are often hidden conditions which can disguise building conditions, the ability to recognize those potentially urgent or dangerous conditions which *can* be detected is important in a foundation inspection.

Note: ***In-service field conditions*** refers to the state of repair of a building or its components while the building is in-use. Building construction standards, engineering and architectural design, and building code compliance have traditionally dealt either with advance specifications for a building which is to be constructed, or with the forensic examination of a building or component after it has failed. The science and practice of *in-sevice* building

inspections and building conditions provide an important but different base of experience about the way in which buildings and building components fail, the causes of building failures, and the detection of clues indicating that failures are developing. In-service building inspections provide an opportunity to detect evidence of developing construction failures which (usually) have not yet reached such dire conditions as to be obvious to the lay person. The home inspection profession (contrasted with the "home inspection industry") focuses on *in-service field conditions* and as such has developed its own unique education, standards, ethics, and practices. Yet it also requires an understanding of design, codes, and building standards as well as traditional failure analysis.

FOUNDATION INSPECTION METHODS

The general procedural steps and major topics in a foundation inspection include these steps. Links to discussions of each of these topics are at the left side of this page.

1. **Site Factors**: Observe site factors affecting the structure such as slope, drainage, rock, or nearby activities such as blasting
2. **Construction**: Identify construction type, materials, sequence of construction
3. **Defects of Occurrence**: Observe defects of occurrence - things that have happened to the structure such as signs of movement, history, other clues
4. **Defects of Omission**: Observe defects of omission - things that have been left-out or removed (harder to spot) such as possible absence of supporting posts, piers, footings, or other critical components
5. **Evaluate Observations**: Evaluate the information which has been collected (history, observations, clues), visual evidence of their impact on the structure, and their importance. Recognize when additional expert evaluation or repair is needed by a foundation or structural engineer or foundation repair specialist
6. **Report Observations & Make Recommendations**: Communicate the observations and recommendations to the client with clarity so that the client understands the implications of the findings and the need for action (if any).

SITE FACTORS - In Foundation Damage Diagnosis: How to Observe Site Factors Which May Damage a Building Foundation

Area History in Foundation Damage Diagnosis: Is there evidence of a history of earthquakes, landslides, mud slides, soil settlement, sink holes, construction on fill, or buried debris on or at sites in the area?

Constructed on fill, or on organic/site: Debris used as fill or buried for disposal, risks future settlement. In some cases, burying site debris or trees, or construction over an old landfill, can result in dangerous settlement or even sudden ground openings occurring years or even decades later.

Constructed over or close to a ravine: Ravines, ditches, filled areas, or underground streams can result in later earth movement, slides, and foundation damage.

Neighborhood history: cracks in other houses in the area. If other homes in an area are observed to have settlement, leaning, or foundation damage, watch for those conditions on the property being inspected. In an area of one Northeastern U.S. city, all of the homes in a hilly neighborhood lean consistently to the right and have suffered major settlement damage.

Area geology in Foundation Damage Diagnosis:

Sink holes: sink holes can appear suddenly and be a catastrophe; they are more prevalent in certain areas of the

country. Sink holes, collapsing soils, voids open suddenly after heavy rains identify by history of area; insurance is available and limited "free" A homeowner should tell insurance company if there is a sinkhole, evidence of one, or suspicion of one.

Lakes and Streams: surface drainage, water & earth loading: observe nearby lakes for evidence of the probable level of the high water table in the soils on which a building has been constructed. Is the basement below lake or stream level?

Solid rock or rocky construction sites: may mean that foundation construction required blasting.

Soils in Foundation Damage Diagnosis: Are there problem soils such as wet, expansive clay soils, scree, bedrock, boulders, buried debris, evidence of fill? Problems having soil characteristics as their origin can show up years later.

Fill: Is there evidence of construction on fill: Look at the surrounding land, its slope and shape. Look for covered tree boles

Expansive soils - are more serious extensive and more common in certain areas: Ontario & Manitoba. Expansive soils shrink and expand significantly as ground water levels vary. In some areas homeowners must install a system to maintain water in the soil below the home to prevent soil shrinkage, settlement, and building damage.

Tree bole is the bottom of a typical deciduous tree where the tree roots begin to leave the trunk and spread underground. Normally the bottom of a tree widens and slopes down away from the tree. If you observe a deciduous tree trunk which is simply vertical, going straight into the ground, you may have found evidence that fill has been added to a site.

Original and Surrounding Slopes: show the original direction of excavation-sequence used in constructing a building. For example, the foundation for a home constructed on a steep hillside will normally be constructed by excavating into the hill from the down-hill side of the foundation footprint. The excavation process cuts into the hillside and moves earth from the "uphill" side of the foundation footprint to the "downhill" side where it serves as fill. If the filled-portion of the foundation area is not adequately compacted or stabilized, a result is that building footings are constructed on virgin soils at the "uphill" portion of the home but on filled soils at the "downhill" portion of the home's footprint. It is common to find evidence of footing and foundation settlement cracking occurring over the on-fill portions of the foundation, and perhaps beginning just at the transition point where the footings moved from being poured on virgin soils to being poured on filled-soil. Observing the site shape tips-off the inspector to watch out for evidence of such movement.

Stepped foundation footings: are normal practices on steep slopes. But where a site has a combination of intermittent bedrock and steep soils, differential footing settlement and movement often occurs at transition points, such as where a footing steps off of rock and onto soils. Similarly, because a house with a basement and a garage often has footings at two very different depths (8' down for the basement and 3'-4' down for the garage) differential settlement may occur between those structures.

Exposure of foundation to mechanical or vehicle damage: A driveway close to the foundation wall, common in older cities, e.g. NYC & Toronto, exposes foundations to damage when heavy trucks such as an oil tank truck or a cement delivery truck pass close to the building to make a delivery. Horizontal earth loading cracks (in a masonry block wall) are likely to appear in a pattern similar to earth loading cracks but higher up than from simple earth loading, perhaps at the center or bottom 1/3 of the wall.

Water, Foundation Leaks, Wet Basements in Foundation Damage Diagnosis: Trees (their roots) and rocks

which are near the foundation define areas to watch out for both root damage to a foundation and, more subtle, water entry from ground water (or roof spillage) which is directed towards the building foundation wall by a combination of these factors:

- Poor site drainage and improper routing of surface runoff, roof runoff, or ground water are very common sources of both basement water entry and foundation damage.
- Water follows underground passages in soils created by tree roots, digging animals, earth worms, excavations for underground utilities such as water lines and buried electrical lines. If these lead towards a foundation, particularly from an uphill slope, watch for foundation leaks inside such locations.
- Water follows underground bedrock which slopes towards a building, and is difficult to keep out. Leaks often are observed in a basement or crawl space where bedrock is exposed and one can see the building footing sitting on (and hopefully pinned-to) bedrock or on large boulders.
- Frost heaving (in freezing climates) - recurrent wet soil freezing, due to poor site drainage or gutter defects, tends to cause horizontal cracks in the upper 1/3 of a foundation wall, always below-grade level, and typically at or just above the natural frost line depth of the soil.
- Nearby Roadways: may expose a building foundation (or other components) to damage from traffic-induced vibration.

FOUNDATION CONSTRUCTION -Identify Foundation Construction Type, Materials, Sequence

Foundation Construction Types

- Slab-on-grade
- Monolithic slabs - resist to problems over sink holes / clay
- Supported slabs - on footing/foundation/pins hairline step cracks in block walls above (FL-mc) hairline to 3/16 common at top of slab elevation (FL-mc)
- Floating slabs - not connected to foundation
- Crawl spaces - wall height is a key factor in predicting crawl space failures. Special crawl space wall and knee-wall reinforcement is required in earthquake areas.
- Basement - wall height vs block width/reinforcement
- Additions - connection to original, varying materials, varying footing depths
- Actual footing/foundation type usually not visible

Foundation Construction Materials

- Masonry block for building foundations
- Poured concrete for building foundations
- Brick for building foundations
- Stone for building foundations
- Wood for building foundations
- Pre-cast Concrete for building foundations

Foundation Construction Sequence Considerations

- Site preparation, construction on fill
- Excavation-errors
- Forms and Footing errors
- Foundation errors

- Backfill errors
- Site Drainage errors
- Modular construction concerns
- Site blasting
- Adjacent Site Blasting

DEFECTS OF OCCURRENCE - Identify Foundation Defects of Occurrence

COMMON FAILURES - Common Foundation Defects of Occurrence - General

- Structural / construction defects & damage
- Concentrated loads
- Excessive backfill height; premature backfill
- Improper materials (soft brick, below grade)
- Shallow/absent/undermined/cut footings, settlement & frost damage
- Improper soil preparation - settling footings & slabs
- Foundation damaged during moved/modular building set
- Equipment damage (backfill, vehicles)
- General Signs of Movement / Damage
- Foundation cracks (see "Diagnosis")
- Leaning or Tipping
- Bulging
- Settlement, uniform or differential
- Excessive loading, fractures
- Interior cracks (trace to source)

Note: use of plumb lines, levels, laser levels, & simple measurements of amount by which a wall is out of level or plumb, or of crack widths and patterns are beyond ASHI Scope but are common simple tools and procedures used by masons, carpenters, builders, as well as foundation experts and engineers.

FAILURES BY FOUNDATION TYPE - Foundation Defects of Occurrence - by Material

Stone Foundation Defect List

- Bulges: due to frost, water, vehicle loading if vehicles are driven close to walls
- Cracks (if mortared): settlement, vehicle driving close to walls
- Other: interruptions for mechanicals may destroy the integrity of these walls. In original construction stones were placed in an overlap pattern from course to course. Removing a section of wall may result in future wall movement unless other steps are taken to stabilize the modified section.

Stone foundation walls on pre-1900 buildings are often quite thick, up to four feet at their base. In their original design these walls tolerated water in the outside soils by permitting it to seep through the wall and often to drain away through a dirt floor or even a through-wall drain in a low corner. Beware of such walls which were later made "water proof" by mortar or by casting an inside thin veneer of concrete against the stone. If this change is made without also taking steps outside to keep water away from the building, frost and water damage to the wall may occur.

Brick Foundation Defect List

- Bulge: bond brick failure - potentially extremely dangerous and very urgent - can presage sudden catastrophic building collapse!
- Cracks and Bulges: frost and earth loading - can push a below-grade brick foundation wall inwards. Often the wall is bulged inwards as well as showing horizontal and step cracking and loose bricks over the bulged area. Damage occurs from slightly above ground level to roughly the frost line.
- Cracks and loose bricks: frost, settlement, expansion, usually diagonal or stair-stepped, often at building corners where roof spillage is concentrated.
- Loose bricks: and movement where mortar is severely washed-out by roof spillage or other water movement against the foundation. Loose and lost bricks may also occur where wood blocks, originally set into a wall to permit nailing of interior components, is damaged by insects or decay. Similarly, if wood joists are damaged and bend excessively or collapse (insect damage, rot, fire) the collapsing joist can, as its in-wall end moves, damage the foundation or building wall. (Fire cuts on wood joists in brick walls were intended to minimize this damage source by angling the end of the joist where it was set into the wall pocket.)
- Spalling: frost, caulked-rusty lintels, "repairs" or re-pointing using hard mortar on soft brick where originally a soft high-lime mortar was used.

Masonry block (concrete & "cinder block") Foundation Defect List

- Leaning: water, frost, vehicles, footings
- Buckled: water, frost, vehicles - potentially urgent depending on circumstances and amount
- Cracks: water, frost, vehicles, shrinkage/expansion, footings
- Poured concrete
- Leaning: water, frost, vehicles, footings
- Cracks*: settlement, shrinkage, cold joints
- Spalling: poor mix, cold weather construction, erosion
- Shrinkage: improper mis-diagnosis. Concrete blocks don't shrink. Check the other possibilities. ...
- Wood foundations (not considered here)
- Pile foundations (not considered here)
- Tipping/undermining - serious defects
- Identify (Possible) Missing Components
- missing footings, piers, reinforcement, drainage

Cracks occur more commonly in mortar joints but can also occur across blocks. Horizontal cracks are more immediately threatening of serious collapse than vertical cracks. Expansion and shrinkage cracks may occur but are less common than in some other materials. Cracks tend to be more severe in the center of walls from external loading and pressure (from any source). Cracks occurring near foundation corners are often from water and frost. In freezing climates, "frost lensing" can cause soil to stick to and lift a building foundation when the ground freezes. These cracks are usually visible above grade.

Wood Foundation Defects

"30-year guaranteed treated wood foundation products" used below grade mean that no permanent building foundation has been provided. This is a temporary structure. In areas of wet soils and insect damage risk damage may occur sooner than the warranty period.

Pre-Cast Concrete Foundations

Pre-cast foundation walls such as the Superior Wall R-5 (TM) or Xi (TM) (extra insulation) systems provide

sections of concrete foundation walls which are lifted into place and bolted together, often sitting on a simple gravel footing-base. The wall sections are sealed, typically with gaskets or caulk or both.

The defects we've observed were in installation and did not involve evidence of structural failures.

- Improper section alignment, poor sealing between sections, particularly at building corners, resulting in foundation leakage
- Inadequate footing drains (or none), and/or inadequate roof drainage system installation (gutters and leaders) resulting in flooding the foundation and water entry passing under the wall bottom and up over the basement slab at the slab/wall joint.
- Excessive spanning of areas with no fill and no footing at all
- Basement water entry and leak problems require adaptation of common internal trench and drain systems, as cutting the slab to excavate for an internal drainage trench exposes the gravel footings

Inspectors should look closely at the connections and sealant between wall sections and look for evidence of leakage.

Foundation waterproofing companies such as B-Dri (TM) who are asked to address water entry in homes built with these systems have to use modified intercept drain materials because the absence of poured footings under the walls gives less depth for an in-basement trench.

We also observed one builder installing some pre-cast foundation wall sections over empty space, spanning voids below the foundation wall of up to four feet. The author, not a structural engineer, performed no analysis on this installation method but it seems likely to demand more of the wall structure sections and connectors than the manufacturer may have intended.

DEFECTS OF OMISSION - Identify Foundation Defects of Omission

Construction defects of omission refer to leaving out or removing necessary structural components. It is considerably more difficult for a building inspector to learn to observe the absence of a component than to notice defects involving a component which is present.

- Missing supporting column such as a basement Lally column, where an owner has removed the column to open up a basement space being remodeled for use as living area
- Missing footings (may or may not be a defect depending on design and soil conditions)
- Omitted steel reinforcement - footings (not visibly detectable after construction)
- Omitted steel reinforcement - walls (not visibly detectable after construction)
- Missing piers beneath interior posts
- Missing control joints in poured concrete
- Missing expansion joints in large brick masonry walls
- Missing expansion joints/materials around windows in brick masonry walls

EVALUATE FOUNDATION CRACKS - How to Inspect & Evaluate Building Foundation Cracks & Movement & Foundation Crack Patterns

The size, shape, pattern, location of foundation cracks on a building, along with correlation with other site and construction conditions helps distinguish among probable causes. By knowing the probable cause and history of foundation cracking or movement one can distinguish between continuing movement (more likely to be a problem) and single events which may, depending on extent of damage, not require repair. This section elaborates

types and patterns of foundation cracks to assist in that evaluation.

VERTICAL FOUNDATION CRACKS - Vertical Foundation Crack Patterns

Vertical foundation cracks often appear in multiples multiple cracks in one or more area.

While a vertical foundation crack could be serious depending on its cause and on the type of foundation in which it appears (stone, brick, masonry block, concrete), these are often the least threat to the building. If there is significant vertical dislocation or signs of ongoing movement, further investigation is more urgent. If the cause is shrinkage (concrete, masonry block) it is probably less of a concern than if due to settlement. A vertical crack due to earth loading or frost would be unusual.

DIAGONAL FOUNDATION CRACKS - Diagonal & Step Crack Patterns in Building Foundations

Clues to help diagnose the probable cause of diagonal foundation cracks in buildings:

- From corner towards adjacent opening, wider at top than bottom - settlement, expansive clay soil, frost, shrub/tree
- Under ground floor window, from sill to ground, sill bowed up - foundation heave, clay soil, frost, shallow or absent footings
- In wall, wider at bottom than top - settlement under building
- At corners in cold climates - frost heave, shallow footings, water problem, or insufficient backfill (common at garage entry)
- Vertical or diagonal crack appears over a short time - settlement over sink holes- serious, open suddenly after rain; or ravines, mulch, fill, organic debris (later rots and settles).
- Over window/door, straight or diagonal - loading/header defect - may appear as horizontal along top or bottom of header, vertical at ends of header (possibly due to differences in thermal expansion of different materials of header vs. wall) or vertical/diagonal at center of header (loading failure) or at corners (possible point-load failure)
- Cracks in a poured concrete foundation which are diagonal or vertical and which are generally uniform in width, *or* which taper to an irregular hairline form, usually in fact a discontinuous crack in the hairline area, are usually shrinkage cracks and should not be ongoing nor of structural significance, though they may invite water entry through the wall.

Note that often at these failures cracks are visible both outside and inside.

HORIZONTAL FOUNDATION CRACKS - Patterns

Horizontal cracks are usually visible only from inside a basement, crawl area, or around an attached garage.

SHRINKAGE vs EXPANSION vs SETTLEMENT - Distinguishing Among Shrinkage, Expansion, and

Settlement Cracks

To the extent that the inspector can see the extent of movement and the potential for damage to a building, and to the extent that the inspector can make a reasonably confident guess about the cause of foundation damage or movement, s/he can estimate the chances of its continuance and thus help set a priority for further evaluation or repair, as well as setting the specifics of outside repairs to reduce further damage such as keeping water or vehicles away from the building.

MOVEMENT ACTIVE/STATIC - Foundation Movement: Determining Active or Dynamic (ongoing movement Static (no ongoing movement)

Age of foundation cracks: Look for clues indicating old vs. new cracks and active vs. static cracks. For example, evidence of repeated repairs (patched, re-cracked, re-patched) is clear indication of recurrent movement. Evidence that a crack occurred at time of construction (in an older house, such as wavy mortar which "bent" in the mortar joints as a wall was loaded) is clear indication of an old condition which may or may not be accompanied by other evidence of later movement.

Horizontal wall movement: Look for evidence of horizontal wall displacement, lateral displacement such as frost push of a masonry block wall. The bottom block course, held in place by the floor slab, may be in the original location while the first course above or higher courses may have been pushed horizontally inwards.

Wall tipping or leaning: Look for evidence of wall tipping or leaning - the entire wall has remained flat but leans inwards at the top.

Wall bulging: Look for evidence of wall bulging, locate the center of the most bulged-in section and note its height above the bottom of the wall and its relative position to the top of grade outside.

Measuring foundation wall tip, lean, or bulge: is simple: drop a plumb line near the most-bulged area (usually the center) of the wall, perhaps fastening it to a nail in a floor joist overhead, about 4" in from the wall. Measure from the string in to the wall at various heights up the wall. You'll be able to easily pinpoint the height of the most bulge or lean. This is *not* engineering. It's simple a simple mason's method to measure a wall or chimney during construction to keep it plumb.

- Wall most-bulged in near the surface (most common, in the upper 1/2 of the wall), perhaps at a depth equal to the frost line in climates where freezing occurs - we suspect water or frost loading on the wall, possibly vehicle traffic
- Wall most-bulged in at its center (common) - we suspect vehicle traffic or possibly water/earth loading
- Wall most-bulged in near its bottom (unusual) - we suspect earth loading or wet earth loading.

Questions about active (dynamic) foundation movement

- Constant rate?
- Accelerating?
- Decelerating?
- Seasonal or intermittent?
- Related to ongoing site work?

NOTE: without historical data these causes can be difficult to confirm without monitoring. Active movement requires a monitoring; present or future repair steps likely.

EVALUATE MOVEMENT - How to Evaluate the Significance of Foundation Movement

- *Historical data is a key observation or data that needs to be collected*
- recent, sudden: serious, prompt action needed
- recurrent: action probably needed
- long term, continuing: action may be needed

- initial damage at backfill: may be ok
- struck: may be ok
- initial settlement: may be ok

NOTE: ANY crack associated with significant displacement of original structural or mechanical (gas/sewer lines) components is likely to be significant. Even slight displacement is significant if mechanical systems may be unsafe (earthquake).

Amount, type, & direction of foundation movement

- Bulging brick - if broken bond courses, very serious/dangerous (1/3 "rule"-A. Carson; author opinion: this needs clarification. 1/3 of wall thickness looks like much too much movement to allow--DF.)
- Bulging masonry block - risk of collapse
- Vertical & horizontal dislocation - depends on amount

The importance of the amount of foundation movement varies

- Wall height, type of construction, materials
- Implications for building: structure-pulled framing apart?
- Site factors which increase risk: earth loading, water

Climate, seismic, & other local foundation structural requirements

Earthquake design requirements for reinforcement

Cold-climate design requirements for reinforcement, drainage, frost protection

Storm/High-wind (and earthquake) design requirements for connections to framing (not considered here)

Other Expert Views regarding Evaluating Foundation Crack Size or Extent of Movement

British Royal Institute of Chartered Surveyors, RICS - Degree of Damage - per W.H. Ransom (RICS)

- Very slight/slight single, isolated cracks - Fine cracks, <5mm (.3") wide, slight sticking windows/doors
- Moderate - 5-15mm (.2"-.6") wide, point up brick, some local replacement, doors/windows stick, pipes may break, not weather tight
- Severe/very severe - > 15mm (.6") to > 25mm (1"), walls likely to lean, bulge, may require shoring; beams may lose bearing; windows distort, glass may break, pipes probably break. External repairs needed, partial or complete rebuild.
- Multiple small cracks, leaning, shifting can be serious too.