UTILIZING PILES TO REDUCE DIFFERENTIAL MOVEMENT IN RESIDENTIAL STRUCTURES WITH STRIP FOOTINGS

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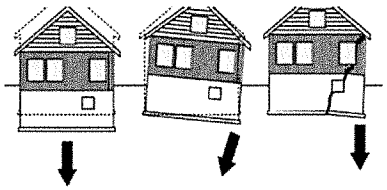

One of the scariest issues a homeowner can face is a foundation problem. It can be as minor as simple concrete shrinkage and as major as a structural foundation failure with significant financial implications.

For the purposes of limiting this discussion, I will restrict the scope to residential structures in the Edmonton area with strip footings, which are considered shallow foundations. By nature of their depth, shallow foundations are in what is considered the most dynamic region of a soil profile, which can extend to a depth of 10 feet or more.

In the Edmonton area, the most common soil in the dynamic region of the soil profile below the organic topsoil (0 to 3 feet) is lacustrine clay from the ancient glacial Lake Edmonton. This soil contains large amounts of high swelling clay minerals and can have shrinkage rates in excess of 40% of bulk volume. This is known as a "high activity clay" (derived from Atterberg limits). The Lake Edmonton deposits range from 15 to 32 feet thick with SPT's of 15 to 25 (standard penetration test-general strength characterization of soils). The Lake Edmonton deposits overly the glacial till deposits left behind after the glaciers retreated. These tills can be 25 to 100 feet thick with SPT's of 25 to 200. The till with its higher strength is the ideal layer into which residential end bearing piles should be founded. Beneath the till is the Empress Formation of sands and gravels, which overlies the Horseshoe Canyon formation, which is our Cretaceous Bedrock. These lower levels are only applicable for founding very large structures.

One of the common types of problems encountered in residences is differential movement. The movement may be either a differential settlement or lifting or a combination of the two. It may be due to simple differential consolidation of the soil beneath the footing or a change in the soil moisture in different areas.

Changes in soil moisture conditions may be caused by either extended periods of drought or periods of heavy rain. With periods of low precipitation a relatively common accelerated cause of differential foundation settlement occurs when mature trees or large bushes are located adjacent to homes.

Through evapotranspiration they remove moisture from the soil through their leaves at a rate of 150 to 380 litres per day (warm day during the growing season). During this process the plants are capable of generating 10 to 20 atmospheres of tension (negative pore pressure) in the water phase of the surrounding soil, the net effect of which is to create a bubble of reduced moisture content far greater in depth and radius than the root system itself. Within this bubble of reduced moisture the soil will consolidate or shrink depending on the specific properties (activity) of the soil.

It is also possible under certain conditions to have frost heaving in areas of unheated crawl spaces with improperly installed or non-existent perimeter insulation and certain moisture conditions.

Other causes of differential movement can include:

- Different soil conditions such as part of the house being constructed on fill material or if the house is completely constructed on engineered fill that has not been evenly compacted properly.
- Undermined sections of strip footings caused by sewer or water-line failures or by flowing water from surface flooding finding a "path" under footings.
- Issues can arise when excavations have occurred under footings for utility repairs or other reasons.

Wood frame houses and their foundations are not designed to handle excessive differential movement. It would be prohibitively expensive to design and construct the basement or crawlspace walls or grade beams to act as a rigid structure capable of spanning large distances theoretically up to the size of the house. Instead we rely on the soil to provide a relatively even support under the strip footings.

Building codes and standard practices will accept overall settlement of up to 50 to 135mm (in clay) and L/1000 to L/1400 for differential settlement (called angular distortion) where L is the distance between measurement points (for a wall 6 meters long the maximum allowable differential settlement could be 4.3 to

6mm). These limits were established to limit the amount of cracking acceptable in a residence relating to new home construction warranties.

These limits clearly show that some settlement and even some differential settlement is expected in residential structures over time. As far as the homeowner is concerned what is tolerable is subjective.

Engineers have a variety of foundation types available for building new homes as well as for remediation of existing foundations with problems such as differential movement. Each type of foundation has its "pros and cons".

I will limit this discussion to the use of piles (underpinning) to remediate the problem of differential settlement in residences, as this is the most common and economical solution for most situations.

Example

A residence is exhibiting differential settlement in several areas of the house. The house is of medium age approximately 60 years old. The region it is located in has been experiencing a long-term trend of reduced moisture. Within the past couple of years the house is showing signs of differential settlement in the form of cracks in the interior walls at various locations with some corresponding cracks in the foundation.

The house is a split level with the mid level floor over a crawl space. The foundation in this area is a half height basement wall on a strip footing. This footing is at the same elevation and is continuous with the strip footing for the lower level of the remainder of house that also has the top level above. The whole strip footing is only 3 to 4 feet below the exterior grade (typical residence 5 to 7 ft). There is an attached garage, which is likely founded on a grade beam with cast-in-place piles.

This main area of the house is considered a very shallow foundation and even more susceptible to differential movements both from settlement and possibly frost heaving (low probability as structure is heated). This house is located in Edmonton (northern climate) with a typical soil structure consisting of; a highly active clay (volume sensitive to moisture content), overlying a glacial till deposit. At that level in the soil profile there is very little overburden pressure to help confine the expansive forces of the expanding clay fraction in the lacustrine clay.

It was also noted that several large mature spruce/pine trees were located in the immediate vicinity of the house, which could be aggravating the soil moisture conditions.

It is decided that the best way to support this house is to add piles around the perimeter in the areas exhibiting differential movement. Measurements have been taken over a period of time (1 year) identifying the areas of movement, which correlates to the pattern of cracks that have developed in the walls.

What happens when piles are retrofitted to a house?

- First the existing basement is excavated to a level sufficient to allow for the mounting bracket (or concrete haunch) to be installed beneath the existing footing. Depending on the site conditions the excavation may be localized to the pile locations or be continuous.
- Piles are installed. In the case:
    - For **cast-in-place concrete piles**, the holes have to be augured to a sufficient depth to develop the required load carrying capacity and the tailings need to be removed. (Note: experience has shown that most pile failures involving cast-in-place piles are caused by insufficient depth of installation and diameter due to use of a generic pile design instead of a site specific design based on actual bore hole data). The augured hole for the pile has to be competent with no sloughing and the bottom cleared of any loose material prior to installation of reinforcing steel and concrete. Preferably, the foundation-loading stratum should be assessed by a qualified professional with pocket penetrometer checks of the undisturbed tailings to ensure the soil is comparable to the design criteria. Upon initial curing of the pile the concrete haunch needs to be formed, reinforced and poured connecting the pile to the house structure. Note: this method does not easily lend itself to preloading or lifting of the structure if that is the objective of the remediation and because no measurement of the pile capacity can practically be made a higher factor of safety (3.0) must be used in the design.
    - For **helical pipe (screw) piles**, the starter helical section is set below the level of the foundation and screwed into the soil using a hydraulic drive head mounted on a small skid steer or utilizing a portable unit with torque bar. Extension sections are added as required as the helixes are advanced down into the desired bearing soil. The torque values are monitored along with the depth to

ensure that the bearing helixes are founded at the correct level with the corresponding minimal required torque. (Torque values provide an indirect measurement of the ultimate capacity of the pile). Once that is achieved the mounting bracket is attached to the bottom of the foundation wall. Typically the footing is removed at that point to allow direct mounting of the bracket to the foundation wall for better load transfer (Less eccentricity-offset load transfer). With this pile type it is also possible to pre load the pile and even lift the structure if that is desired as part of the remediation. Due to the indirect measurement of the piles' ultimate performance, a lower factor of safety (2.0) can be used. In certain rare circumstances such as extremely soft soil conditions above the helixes the design may require the stiffening of the pipe that is acting as a column for load transfer. This can be achieved by filling of the pipe after completion of the pipe install with concrete (increases pipe capacity by 75%).

- For **pipe push piles (friction)**, a mounting bracket is mounted on the foundation wall. Typically the footing is removed at that point to allow direct mounting of the bracket to the foundation wall for better load transfer (Less eccentricity-offset load transfer). The starter push section with shear reduction ring (if end bearing only) is set below the level of the foundation and pushed into the soil using a hydraulic ram. The pipe becomes plugged at 10 to 20 pipe diameters (approximately 3 ft. for a 3" diameter pipe) so there is no need for the pipes to be close ended for full end bearing capability. Extension sections are added as required as the pipe is advanced down into the soil. The hydraulic jacking pressure values are monitored along with the depth to ensure that the bearing end is founded at the correct level with the corresponding jacking force (jacking force values provide a direct measurement of the ultimate capacity of the pier). With this pile type it is also possible to pre load the pile and even lift the structure if that is desired as part of the remediation. Due to the direct measurement of the piles' ultimate performance, a lower factor of safety (1.5) can be used. A limiting factor for the use of these piles is the condition and weight of the existing structure itself since the process of installation requires the pushing up against the existing structure to advance the piles into the soil. If the available weight of the structure at the point of installation is insufficient or if there exists distress or damage to the structure near that location it may not be possible to utilize a push pier. In certain circumstances such as extremely soft soil

conditions the design may require the stiffening of the pipe that is acting as a column for load transfer. This can be achieved by filling of the pipe after completion of the pipe install with concrete (increases pipe capacity by 75%).

What happens after piles are retrofitted to a house?

What happens after the piles are installed in a house is very important and in fact governs several key design decisions before the piles are installed.

- In the case where the building structure is lifted (if leveling is a design objective) using either the helical pile system or push pile system all the loading is transferred to the piles with the foundation walls and grade beams acting as beams supporting the structure above. This means the existing concrete walls will govern the spacing and locations of the piles.
- Ideally, retrofit piles should be preloaded to the predicted dead loads to minimize any future movement
- In the case where the pile systems are either only partially preloaded or not loaded at all, the existing strip footing foundation is still carrying the loads **UNTIL.....THERE IS FURTHER SETTLEMENT !!!!**
- When there is further settlement the loads will shift from the strip footings to the piles, which will load the piles according to their design parameters. When those values are reached any further settlement of the structure supported by piles is halted while areas not supported by piles will settle. The impact of this is that the spacing and location of the piles still needs to be based on the case that the piles will carry all the loads. Failing to follow this puts the structure at risk of unsupported differential movement between supported and unsupported areas, which could cause even more severe damage to the structure.
- Additional piles may also be required for a proper repair if it is found that there are discontinuities (large cracks that require support on either side of the crack). Some of these conditions are not visible until excavation is underway or the inside of the exterior wall is exposed.

Attached Garages

Attached garages present a unique problem for several reasons;

- Attached garages are typically founded on grade beams with cast in place piles using generically sized piles (diameter and depth not specifically designed for the actual site soil conditions).

- On rare occasions the garage may be founded on strip footings at an extremely shallow depth (less the 2 ft.).
- A high percentage of garages are unheated.
- The garages are usually tied into the house foundation by dowels and concrete pockets

The most common configuration, concrete piles supporting a grade beam, which is dowelled into pockets on the main house foundation, presents a problem due to the combining of different foundation types.

Remember that earlier in the paper, I mentioned that a certain amount of settlement is expected in a residence. It is a normal consequence of placing a structure on top of soil. Unfortunately different foundation types have different settlement characteristics. So even without any moisture issues or uneven soil settlement conditions there can still be differential settlement between a house and the attached garage. In addition, it can also be subject to the other causes of differential settlement mentioned previously.

A specific problem relating to the fact that most garages are unheated is frost heaving which can cause differential movement, in this case an upward movement. If void forms (crushable cardboard or Styrofoam) have not been installed or installed properly under the grade beams, the upward forces from freezing soil can actually pull the piles upward out of the ground (called frost jacking).

One area that is common to see this problem is at garage door openings. In severe enough cases the garage doors may be damaged beyond repair. Attached garages also typically have a natural connection of different roofs. The impact of garage differential movement from the house can in many cases cause a displacement between the house roof and the garage roof.

The three options for remediating any differential settlement in terms of piles remain the same. If however, the garage is to be lifted or lowered (in the case of frost jacking), the connections between the existing concrete piles and the grade beam need to be severed when the new piles are installed to facilitate the realignment. Helical pipe piles and pipe push piles are better suited when realignment of the garage is desired. If push piles are used the existing concrete piles are not severed until the piles have been installed as the concrete piles' skin friction and weight will assist in driving of the push piles.