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Underpin Restoration Methods: Stabilization, Restoration and Preventative

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Abstract- This paper presents a review of commonly encountered deleterious soil conditions, their respective impacts on existing structures and currently employed methods used to remediate them. After discussing common forms of damage and distress resulting from these conditions, three underpinning methodologies intended to address structurally related displacement are presented. The first two methodologies include Stabilization and Restoration for cases where the supporting soils can be remediated and their damaging effect arrested. The third methodology, Preventative, is used in cases where damaging effects form supporting soils cannot be arrested. Each methodology is present along with design considerations and actual examples of their application.

Keywords**:** Underpinning, Micropiles, Pin Piles, Foundation Restoration, Slab Restoration, Displacement

1. Introduction

When evaluating an existing structure for damages related to deleterious soil conditions, it is important to consider not only the type of structure and the type of damage manifest but the type of deleterious soil conditions and whether they can be remediated so as to prevent further damages. In cases where the supporting soils can be remediated and their damaging effect arrested, partial underpinning can be effectively used to stabilize or restore damaged structures. In cases where damaging effects from supporting soils cannot be arrested underpinning is often the only economically viable solution to isolate the structure from its supporting soils and prevent further damage.

Within this paper three underpinning methodologies are presented. The first two methodologies include Stabilization and Restoration for cases where the supporting soils can be remediated and their damaging effect arrested. The third methodology, Preventative, is used in cases where damaging effects from supporting soils cannot be arrested. Each methodology is present along with design considerations and actual examples of their application.

2. Deleterious Soil Conditions and Remediation Measures

For the purpose of this paper three basic types of deleterious soil conditions are discussed. The three deleterious soil conditions are discussed in general terms and include non-cohesive subsidence, organics and shrink swell clays.

2. 1. Non-Cohesive Subsidence

Subsidence of non-cohesive soils poses the greatest threat to structures built atop shallow foundations. Subsidence of non-cohesive soils is the process where by non-cohesive soils migrate or vacate from beneath the structure sitting atop them. This subsidence of soils can result from any one of a number of sources including sinkhole activity, erosion, collapsed subsurface features or collapsed subsurface structures. The result of this subsidence is a general downward movement of the land surface along with structures sitting atop them. As the subsurface loses its ability to support the weight of a structure, the foundation, at grade slabs and structure will experience displacement and displacement related damage or distress.

Of the three deleterious soil conditions discussed in this paper, non-cohesive soil subsidence is perhaps the easiest to remediate. Typically, the soil remediation process involves two steps. First the mechanisms facilitating or causing the migration or vacation of the soils is arrested. In the case of a sinkhole, arresting the mechanism is accomplished by grouting the throat of the void or cap grouting the surface of the rock below. In the case of erosion, the mechanism is arrested by redirecting surface water flow. The second step involves backfilling the vacated soils and densifying the originally disturbed soils along with the backfilled soils.

These processes do not however address any displacement or displacement related damage and distress to the structure sitting atop the soils.

2. 2. Organics

Organic laden soils can be detrimental to the support of both shallow and deep foundations. The soils under many structural foundations contain buried or neglected items that were left to decompose. Soils that include a substantial amount of decayed or decaying plant matter, wood, peat, and roots are considered organic. Over time, the soil, acid and moisture can break down these items and the organic matter will continue to decay and the soil will experience a decrease in volume (Brown, 1997). If organic laden soil is under a structure or concrete slab, the decrease in soil volume may cause settlement or subsidence. Similar to the previous case, as the subsurface loses its ability to support the weight of a structure, the foundation, at grade slabs and structure will experience displacement and displacement related damage or distress.

Of the three deleterious soil conditions discussed in this paper, remediating organics has the greatest degree of variability. If the organics are contained to a limited area or are found well above the water table, it is possible that they can be treated similar to non-cohesive soils that have subsided. Specifically, the void can be backfilled and the originally disturbed soils densified. If however the organics are not contained to a limited area or are found within the water table, remediation becomes significantly more difficult and in a number of cases not economically feasible. In these cases the voided areas and soil instability can result in either localized displacement or global displacement.

These processes also do not address any displacement or displacement related damage and distress to the structure sitting atop the soils.

2. 3. Shrink Swell Clays

Shrink swell clayey soils, often referred to as expansive soils poses the greatest threat to structures built atop shallow foundations and deeper foundations that do not serve to isolate the structure from the soils. Shrink swell clayey soils behave similar to sponges: expansive clay soils shrink when they become dehydrated, due to the lack of moisture from the surface or from a decrease in the groundwater table, and they expand or swell when fully saturated. Structures that are built within or atop these soils are subject to upward and downward movement as the soils moisture levels fluctuate (Das, 1999). This movement can vary from heave in wet conditions to settlement in dry conditions. Swelling clays derived from residual soils can exert uplift pressures of as much as 5500 psf, which can do considerable damage to lightly-loaded structures. Similar to the two previous cases, as the ability of the subsurface to support the weight of a structure fluctuates, the foundation, at grade slabs and structure will experience displacement and displacement related damage or distress.

Of the three deleterious soil conditions discussed in this paper, remediating shrink swell clayey soils has the greatest degree of difficulty. If the shrink swell clayey soils are not contained to a limited area or are found to extend to greater depths, remediation becomes significantly more difficult and in most cases not economically feasible with respect to existing shallow foundations. In this case the instability often results in both localized displacement and global displacement.

These processes also do not address any displacement or displacement related damage and distress to the structure sitting atop the soils.

3. Deleterious Soils Impacts on Existing Structures

The impact that deleterious soil conditions can have on an existing structure can be classified into one of three categories: type of displacement, type of damage and type of occurrence. Given that each of these can occur in any order or combination, each potential impact is to be investigated and considered.

3. 1. Type of Displacement

Displacement due to deleterious soil conditions can cause either uniform displacement or localized displacement depending on the area of the soil that has been affected.

Uniform Displacement: when the displacement encompasses or affects the entire structure it is referred to as Uniform Displacement. Uniform displacement is most common in shrink swell clayey soils and large areas of submerged organic laden soils. Uniform displacement has a tremendous impact on the structure but often results in the least amount of notable distress. Figure 1 shows the ground floor topography of a building that has experienced large scale uniform displacement. A review of the topographic lines superimposed on the building's footprint show a uniform displacement from the front left corner toward the rear right corner on the order of approximately 4 inches.

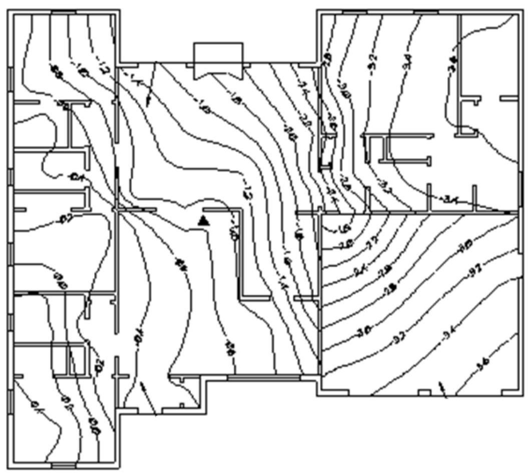

Fig. 1. Uniform Displacement

Differential Displacement: when the displacement is isolated to a portion of the structure it is referred to as localized displacement or more commonly differential displacement. Differential displacement is most common in subsidence of non-cohesive soils but can also occur in shrink swell clayey soils and organic laden soils. Differential displacement can have a more limited impact on the structure as a whole but often results in the greatest amount of notable displacement related damage and distress. Figure 2 shows the ground floor topography of a building that has experienced significant differential displacement on the order of approximately 3.5 inches.

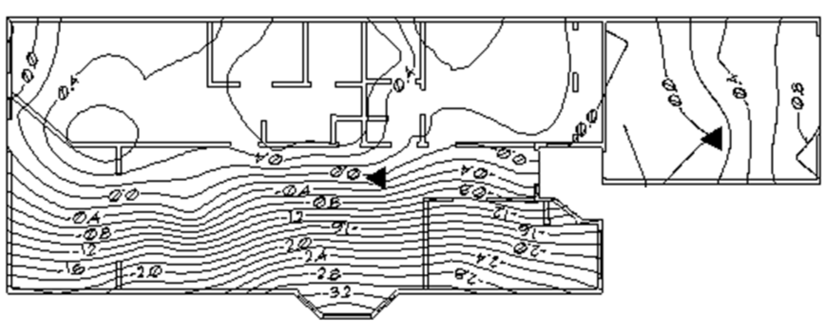

Fig. 2. Differential Displacement

3. 2. Type of Damage

Both uniform and differential displacement can cause displacement related distress. Part of the evaluation process is determining whether the distress attributed to the displacement is structural or non-structural in nature (Gilbert, 2001).

Non-Structural Damage: when distress resulting from displacement of the structures is evident, it is classified as non-structural if the integrity of the structural system has not been compromised. This type of damage is often referred to as “cosmetic damage” or “architectural” in that only the finishes or fixtures have been effected and require repair. This type of damage is found in both uniform and differential displacement and typically manifest first in rigid or brittle finishes and features.

Structural Damage: when distress and damage have risen to the level where the integrity of the structural system has been compromised it is classified as structural damage. Specifically, damage is classified as structural damage when the damage has been found to alter the load path resulting in an increase in stresses or serving to prevent the structure from performing as designed. This type of damage occurs primarily in differential displacement.

3. 3. Type of Occurrence

Part of the evaluation process also includes determining whether the displacement resulted from a single occurrence or is an indication of an ongoing or cyclic mechanism. A single occurrence would most likely result from subsidence of non-cohesive soils in conjunction with sinkhole activity, erosion, collapse of a subsurface features or collapse of a subsurface structure. A single occurrence event in non-cohesive soil is the easiest soil condition to remediate and the simplest structural condition to address.

Ongoing cyclic occurrence events are the most common and typically result from shrink swell clayey soils moving the structure up and then down repeatedly over an extended period of time (Bullivant, 1996). These types of events also result from organic laden soils shifting and settling over an extended period of time. The greatest challenge in repairing existing structures subject to ongoing cyclic occurrence events is the need to isolate the structure from the problematic soils so as to break the cycle.

4. Methodologies

Once the soil mechanism responsible for the displacement of a structure has been identified and remediated if possible, then an appropriate foundation restoration technique can be designed and employed. In cases where the structure has been affected and stabilizing or lifting of the structure is desired, this paper proposes three methodologies to utilizing micropiles or underpins. The three methodologies are identified as stabilize, restoration and preventative.

4. 1. Partial Underpinning

In cases where the supporting soils can be remediated and their damaging effect arrested partial underpinning can be effectively used to stabilize or restore damaged structures. There are two methods that can be used when developing a partial underpin design: stabilization or restoration.

Stabilization: the first foundation restoration methodology is a stabilization method. The stabilization method is intended to stabilize the affected portion of the structure in its current position while relieving displacement related distress to the affected portions. This method is typically performed in conjunction with other structural measures for the purpose of supplemental strengthening or to prevent further displacement related distress. This method underpins the load bearing components of the affected portions so as to transfers the load through the piles to a more competent end bearing strata.

This method does not lift the structure and is not intended to restore the structure to a pre-event state. The stabilization method is typically utilized when repairs or modifications have been performed prior to the underpinning, most often in an attempt to conceal displacement related damage, and lifting or releveling of the structure is anticipated to cause excessive collateral damage. Complex structures are another example where the stabilization approach would be optimum due to irregular stress distribution and stress concentration.

Once the structure is stabilized, any remaining cracks and separations can be cosmetically addressed subsequent to the stabilization process. This includes the floating of the floors to regain the levelness desired (ACI, 2005). It is important to note that a period of time should be allotted for the structure to redistribute internal stresses prior to completing cosmetic or architectural repairs.

A limitation to the stabilization method is that it does not prevent those portions of the structure not supported by underpins from responding to possible future movements due to dynamic changes. Dynamic changes within the soil can result from improperly remediated subsurface mechanisms, particle redistribution, consolidation, changes in pore pressure and movements due to shrink-swell clay soils.

Figure 3 shows a partial underpin plan utilizing the stabilization method. This figure depicts the underpin locations as solid black dots along the lower wall. This plan also depicts boxed shaded regions within the footprint of the structure where leveling agents were to be used so as to re-establish a level floor since the floor was not lifted.

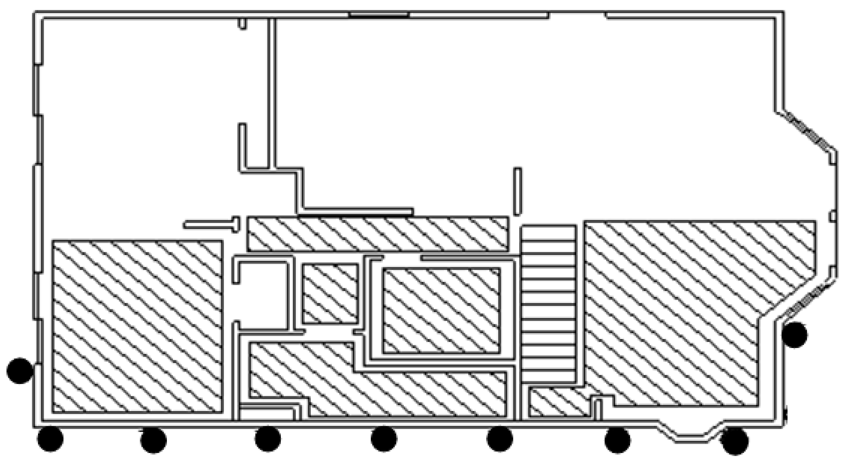

Fig. 3. Stabilization Underpin Plan

Restoration: the second methodology that can be used is a restoration method. The restoration method, similar to the stabilization method, is to be implemented once the mechanism driving the differential displacements has been arrested. The restoration method utilizes underpins to lift and restore the displaced portions of the structure to a pre-event state while addressing and relieving displacement related distress. The restoration method not only addresses the load bearing components but also addresses the slab of the structure. This method is capable of restoring structural integrity to those portions of the structure affected by the displacement.

It is common for existing cracks to be sealed during the lifting process; however, it is not unusual for collateral cracks to occur. It is important to note that a period of time should be allotted for the structure to redistribute internal stresses prior to completing cosmetic repairs. Given that the structure has been altered from its previous position, the time period warranted to redistribute internal stresses will exceed that of a stabilization method.

A limitation to the restoration method, similar to the stabilization method, is that it does not prevent those portions of the structure not supported by underpins from responding to possible future movements due to dynamic changes. Another limitation to the restoration method is the amount of the structure that can be underpinned. Depending upon the configuration of the structure's foundation and the type of structure being underpinned, this method would limit the percentage to less than 50% of any contiguous structural system. In this case, the integrity of the entire structure is taken into consideration. Given that underpinning changes the foundation system from soil supported to pile supported, underpinning more than 50% and less than 100% of a contiguous structural system will serve to concentrate stresses resulting from future movements.

Figure 4 shows a partial underpin plan utilizing the restoration method. This figure depicts the underpin locations as solid black dots along the exterior walls. This plan also depicts underpin locations as solid black dots within the interior of the structure's footprint. These interior underpins were used to lift the interior slab along with the exterior walls so as to re-establish a level floor.

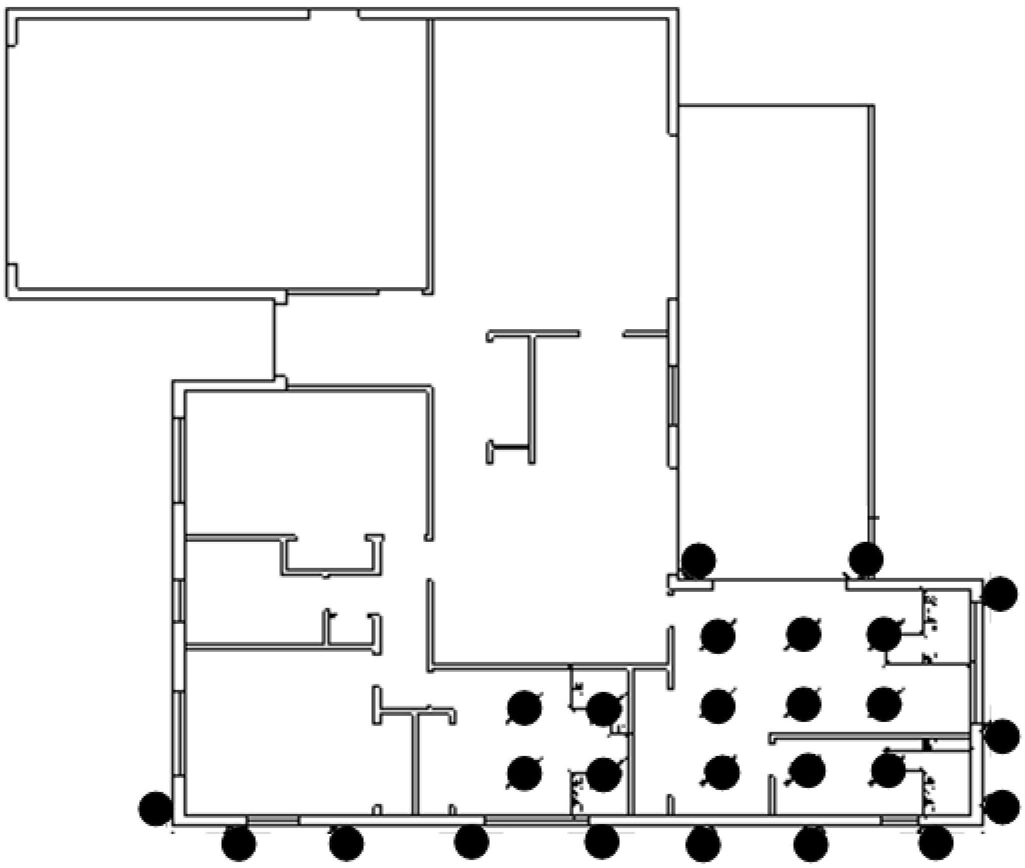

Fig. 4. Restoration Underpin Plan

4. 2. Comprehensive Underpinning

In cases where the supporting soils cannot be remediated or their damaging effect arrested, comprehensive underpinning is often the only economically viable solution to isolate the structure from its supporting soils and prevent further damage.

Preventative: the third foundation restoration method is the preventative method. The preventative method is to be used when dynamic changes within the soil, such as changes in pore pressure and/or movements due to shrink-swell clay, are present or anticipated. The preventative method is also recommended when the subsurface soils affecting the structure cannot be effectively remediated. In this case underpins are used to isolate the structure from the problematic soils. This isolation is accomplished by transferring the loads from the structure through the underpins to rock or more stable soils below the problematic soils.

Within the preventative method, there exist two approaches; a structural preventative approach and a comprehensive preventative approach. A structural preventative approach is utilized when the subsurface mechanism cannot be remediated; however, the movement is not expected to be significant. Therefore, only the load bearing components (exterior walls, interior bearing walls, columns, etc.) require isolation through underpinning.

A comprehensive preventative approach is warranted when the subsurface mechanism cannot be remediated and is susceptible to causing significant differential displacement. In this case, the entire structure will require underpinning, including the interior slab. When this method is being employed to isolate the structure from expansive clays, this method is most effective when implemented when the clays are at their greatest volume. This will help to prevent the structure from being lifted off of the underpins once the clay rehydrates and expands.

Figure 5 shows a comprehensive underpin plan utilizing the preventative method. This figure depicts the underpin locations as solid black dots along the exterior walls and within the interior of the structure's footprint. These interior underpins were used to lift and isolate the entire structure from their supporting soils.

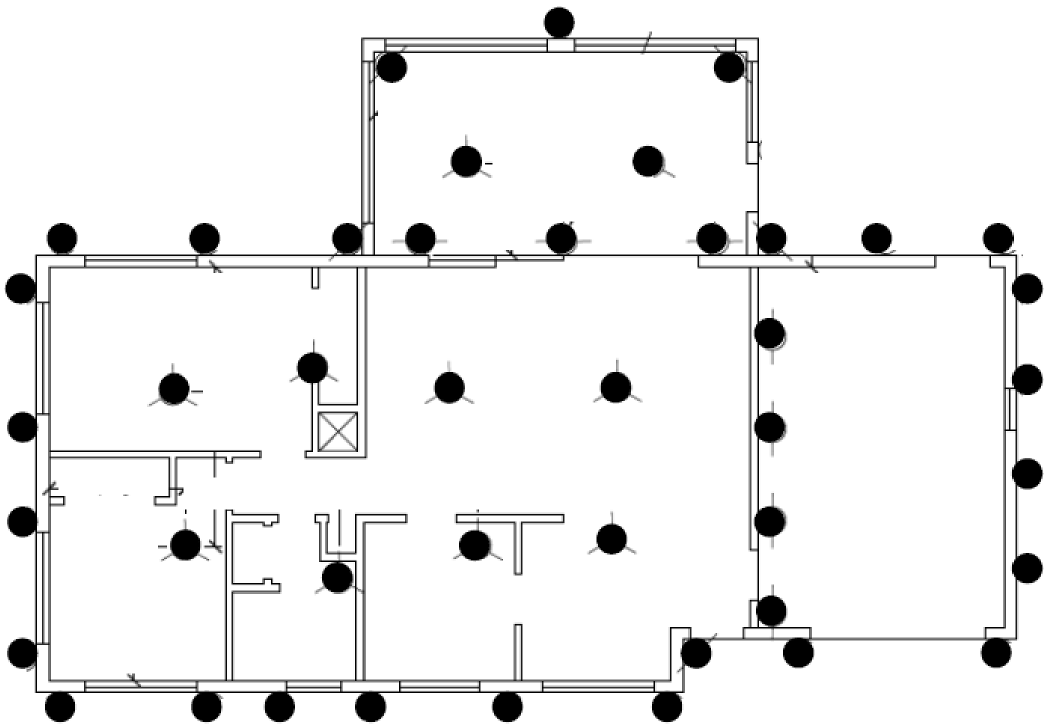

Fig. 5. Preventative Underpin Plan

5. Conclusion

When addressing displacement related damage and distress, in cases where the supporting soils can be remediated and their damaging effect arrested, partial underpinning can be effectively used. The two partial underpinning methodologies include the Stabilization method and the Restoration method. However, in cases where damaging effects form supporting soils cannot be arrested, comprehensive underpinning can be used to isolate the structure from its supporting soils and prevent further damage. The comprehensive methodology is the Preventative method.

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