

***“Improving Safety In Geotechnical Engineering
By Avoiding Common Mistakes”***

By

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Improving Safety In Geotechnical Engineering By Avoiding Common Mistakes

INTRODUCTION

While most people measure experience by the number of years in practice, I personally prefer to measure it by the number of projects encountered where problem solving was involved. This is particularly true in engineering. As civil engineers, we were taught to design correctly, but also solve problems as they occur, thus gaining experience to be implemented in projects to come...

During my years of practice in Lebanon since 1995, the geotechnical problems I encountered were often the results of common mistakes! Unfortunately, these mistakes lead to failures, accompanied in some instances with loss of life and property. What is even more dramatic is seeing these mistakes being repeated while in fact we should be learning from them.

Soil conditions are never identical from one project to another, so copying rather than designing also lead to problems, let alone copying the mistakes. Should we wait for the problems to occur before we start avoiding them? It is in the objective of this paper to answer (even partially) this question. These common mistakes are hereby presented according to the different types of geotechnical works. Hopefully, this article would interest young engineers, as well as more experienced colleagues, and help in improving the safety of our projects.

SOIL INVESTIGATIONS & GEOTECHNICAL REPORTS

Requiring a soil investigation as part of the construction permit for all sizable constructions in Lebanon was a very important and wise decision. Like any law, advantages and disadvantages exist, but in my opinion the advantages dominate in this case. Investing 2 to 5 per thousand of the project budget on soil investigation will benefit all parties involved. Much more dollars would be saved this way, and more importantly the safety during and after construction would be improved.

The purpose of the geotechnical report, as envisioned by engineers, is to reduce the uncertainty of the subsurface conditions. The goal is to avoid over-design but also eliminate under-design! In this regard, orienting the investigation towards design recommendations is important, and will serve better the purpose of the future construction. If this is currently performed for large projects, it should as well be applied to small projects that are often ignored.

Selection of Soil Parameters: the c & ϕ Magic

This has been the subject of numerous articles and papers. It is discussed at every public occasion or conference related to geotechnical engineering. As Professor W. Lambe and others proved, the soil strength depends very significantly on the effective stress path to failure.

The soil parameters that describe the shear failure criterion introduced by Coulomb in 1776 are still taught today but often misused. The cohesion c , and the angle of internal friction, ϕ , are the most common soil parameters utilized in present theories of soil mechanics and geotechnical engineering related to bearing capacity, earth pressures, soil improvements, pile behavior, and others.

On numerous occasions I have encountered very detailed designs with precise calculations relying unfortunately on c & ϕ that were selected magically with little or no testing! I personally prefer to guess a solution based on precise soil data, rather than detail a design based on a pure guess of c & ϕ .

It is a common belief among engineers that sand has a friction angle close to 30° and zero cohesion, and that clay is cohesive with zero friction! Well whether you are a geotechnical engineer or not, the truth is that effective cohesion in soil often doesn't exist. That is right. Cohesion could be present only in over-consolidated or cemented soils, and only for small strain shear prior to any failure. For this reason, I would like to divide cohesion in 2 types: Apparent Cohesion & Adhesion.

The apparent cohesion is the one relying on the suction of partially saturated soils, or exhibited by clays subjected to fast shearing conditions. Even sand when partially saturated becomes cohesive as felt when building a sand castle on the sandy beaches of Byblos or Jyeh. This apparent cohesion should not be relied upon in real life since it can lead to drastic reduction of safety. Soil cohesion could drastically decrease or even disappear with time and with the increase in moisture, after a rainstorm for example...The sand castle collapses when saturated by an approaching wave. For this purpose, I recommend relying solely on the effective internal friction of the soil rather than its cohesion when solving long term and large strain problems such as soil stabilization, shoring, and earth retention, be it in sand or clay.

The adhesion, on the other hand, is the cohesion due to over compaction of the soil or even chemical cementation. Such cohesion is barely affected by moisture variations or time. Over-consolidated clays for example (rare in Lebanon) would exhibit cohesive behavior even under slow shearing rate. Cemented soil such as sandstone or shale has a cohesion that can also be considered during design. Even then, the applied stresses should not lead to large strains since the brittle cementation gets broken, and the strength is reduced to residual friction only. Sedimentary rocks are in fact soil particles that have been cemented with a very large cohesion by the geological phenomena of mother earth. Along a fracture in rock, only friction resistance is relied upon.

However, cohesion > 0 with the $\phi = 0$ concept, may still be the right selection to determine, for example, the allowable bearing capacity of a foundation on saturated clay. The undrained condition would be the governing criterion in this case. What is most important is to select the least "error carrying" parameters for solving the problem in question!

To determine c & ϕ : *"Of course, the test conditions should be chosen to reproduce natural conditions as closely as possible" p362, Fundamentals of Soil mechanics, 1948, by Donald Taylor.*

Uncover the Enemy: H₂O

As recognized by most of us, the most serious enemy of the geotechnical profession is water. So, look for it, try to find it, and...drain it away.

It has been shown that the most critical path to failure is building up pore pressures thus reducing effective stresses. Exploring the subsurface strata helps predicting seepage of underground water. Standpipe piezometers are simple and inexpensive tools that could be installed within the soil investigation boreholes. They allow monitoring the presence of any water head and its seasonal fluctuations. This is particularly required when planning deep excavations below the water table or where perched water exists. Soil parameters such as permeability become very important in that case. Estimating the permeability in the lab, and even in-situ within the borehole by using the Ernst or Houghout equations, require little extra effort.

Rock = Safe Foundations?

“My villa in Feytroun doesn’t require any investigation since it is just a 3 story structure resting on rock...” told me Mr. X. Well, Mr. X, may be right since the bearing capacity on rock could theoretically reach more than 100 kg/cm² ! But what if he is wrong? How? Cavities, fractured matrix, nearby quarries, and other defects would weaken the rocky stratum. It should be noted that lowering randomly the bearing capacity to improve safety of the foundations is not always a solution even on small size projects. I have witnessed excessive settlements of a footing bearing on rock with an applied pressure as low as 1.5 kg/cm². As shown in Fig. 1, if the cavity is right underneath the column of this footing, punching failure with large settlement is still probable. Hence, it is always recommended to conduct a cavity search under each column, particularly if it is individually founded on rock. Also, determine the strength parameters of the rock matrix and design accordingly: Highly fractured rock behaves like gravel. So, look for any nearby void, fill it up if it exists, improve the bearing capacity for design, decrease the size of the entire foundation system, and thus save money!

BUILDINGS ON SLOPES

A large portion of the Lebanese territory is sloping terrain and mountains. The construction of large buildings on slopes has multiplied during the Lebanese war and after it ended. Building on slopes is a little bit tricky and requires some attention to avoid serious mistakes. Figs. 2a and 2b show some of these mistakes that are discussed in the following paragraphs.

Nature Heals Itself

Natural processes, like erosion, earthquakes, frost, and others, give a mountain its shape over the centuries. If a man made cut is created to accommodate the building, nature will try to bring it back to its original shape. Consequently, leaving a vertical cut behind your building without any support is not recommended. The cut may be unstable particularly if it isn’t solid rock or if the rock layers are dipping unfavorably. With time the cut may fail and present danger to the building, its tenants or nearby structures.

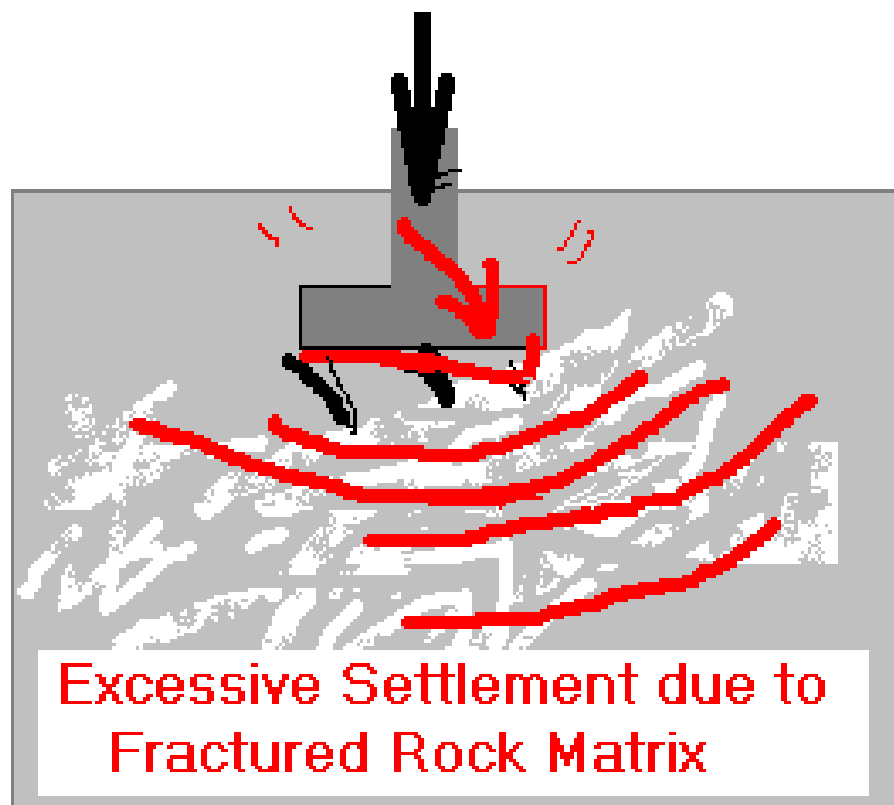
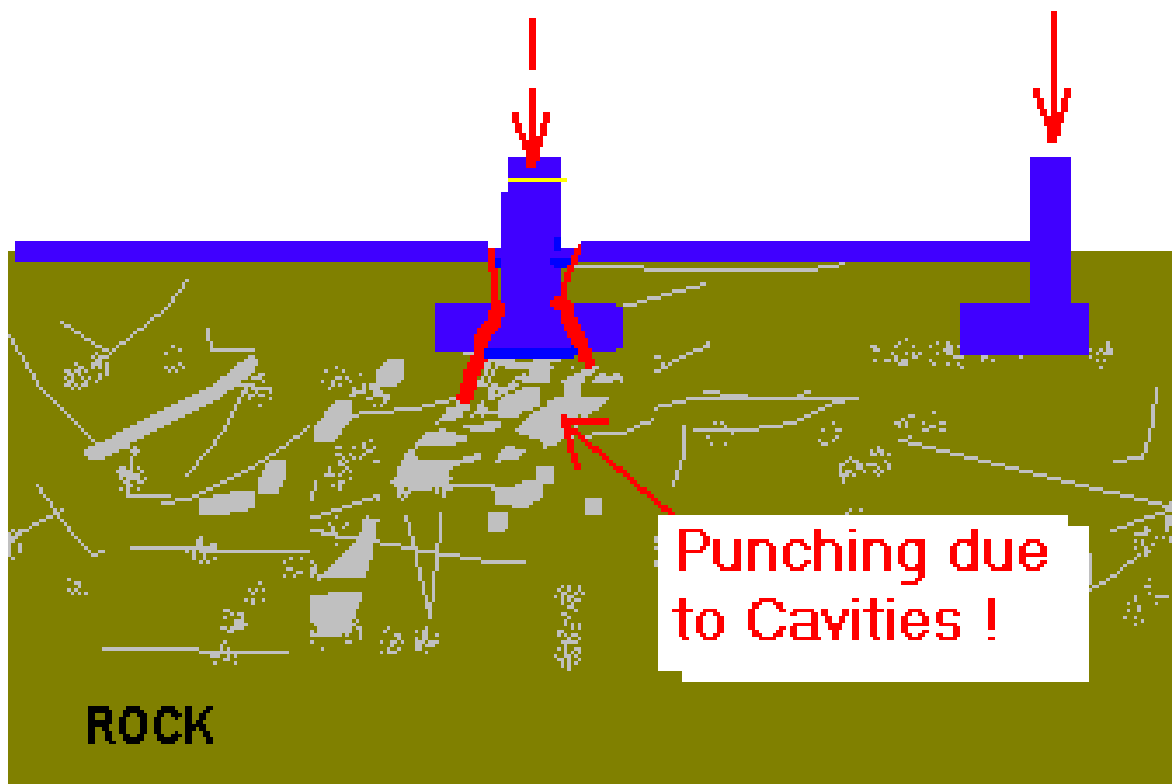


Fig 1. Foundation Mode of Failure due to Cavities

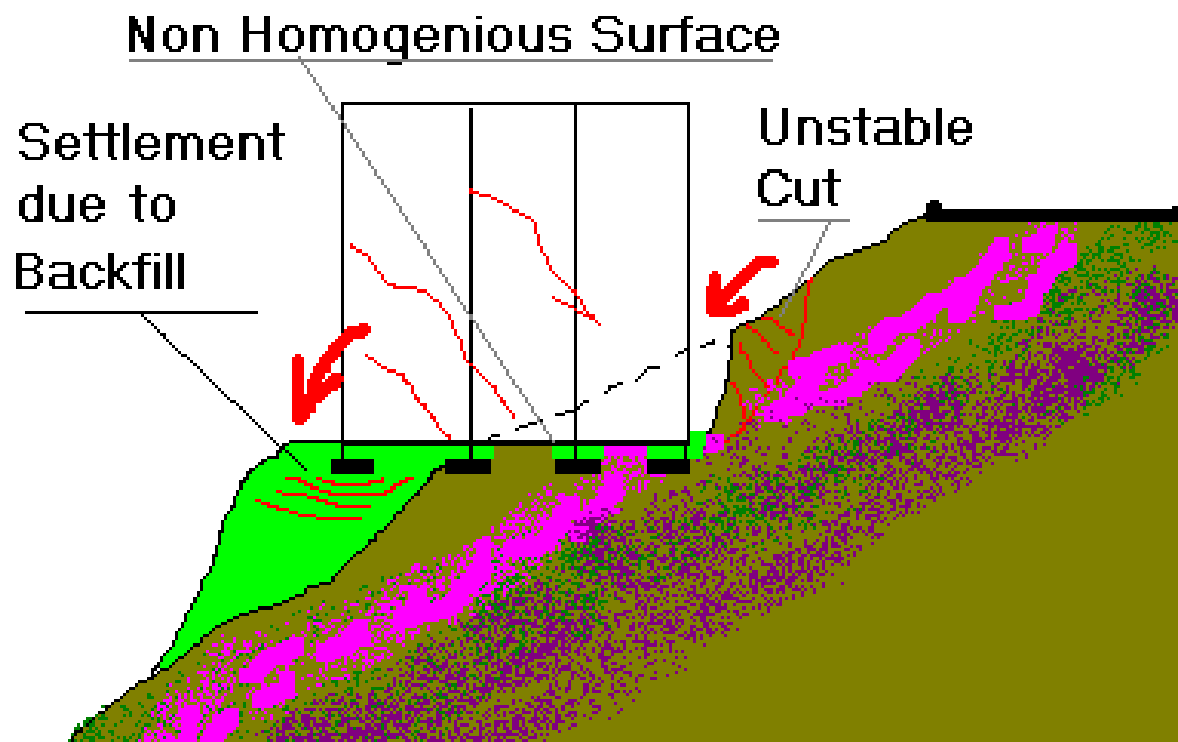


Fig 2.a. Weak Foundation Soil and Unstable Cut

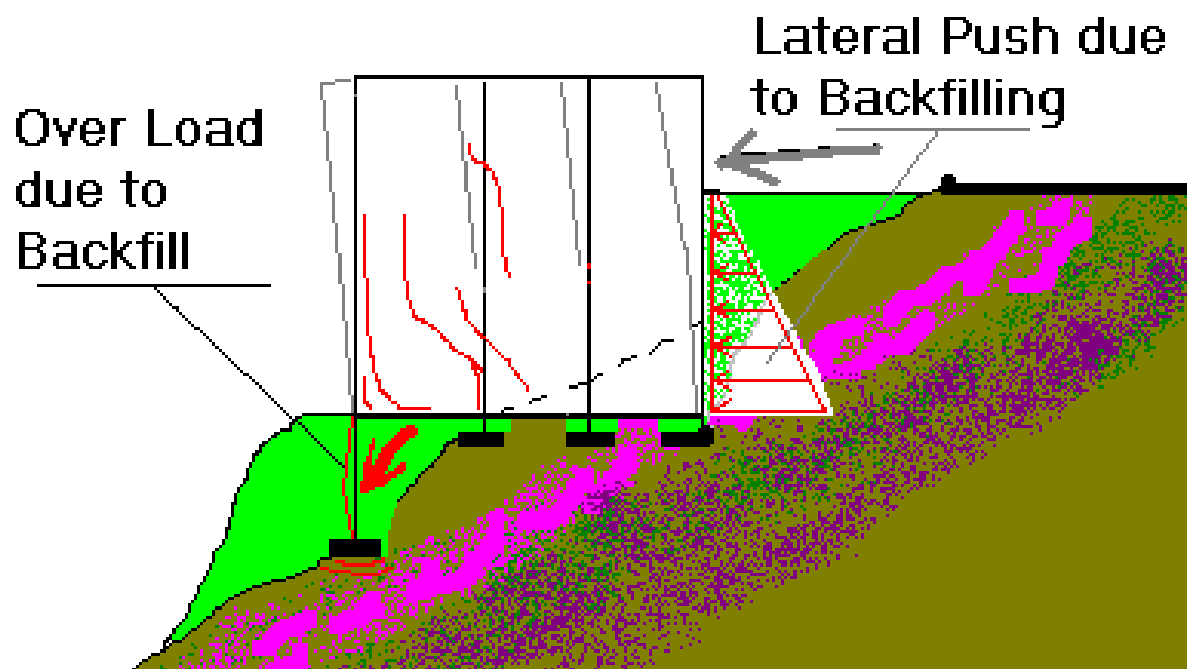


Fig 2.b. Backfilling the Front and the Back

Non Homogeneity

A horizontal soil surface created on a slope to lay the foundations is surely not homogeneous, yet on most projects I have examined, the bearing capacity was assumed constant over the entire foundation system. Even if theoretically determining the settlement of a footing is a separate calculation from its bearing capacity, yet in reality it should not be so. The foundation soil that has been additionally pre-consolidated by the overburden on the uphill side will resist the applied pressure more and will surely settle less. Thus, it is recommended to correct the bearing capacity by the difference in the overburden removed: The frontal (downhill side) footings should proportionally be larger than the uphill ones no matter what the soil type is, even if it is rock.

Founding on Backfill

Backfilling the downhill side to level the terrain is common practice. What is most dangerous is placing the footings on this new unstable backfill. Even if the backfill material is suitable and well compacted, differential settlements are still expected (see Fig. 2.a). In addition, a new backfill on a slope presents a hazard of slope failure when subjected to lateral loads such as earthquakes. The key is to provide an even foundation support and soil-structure interaction under the same building.

Backfilling the Front

On steep slopes, sometimes, deeper excavations are needed to reach the foundation soil on the frontal footings (see Fig. 2.b). Backfilling above the footings to level the terrain may also lead to problems. This extra load on top of the foundation system is often ignored. Remembering that 3m of backfill are equivalent by weight to a 6 story building, should make one think twice prior to backfilling. I have seen this problem on multiple occasions with backfills exceeding 7m in 3 cases! The solution is to keep the empty space empty. Do not backfill the front. Even if the construction permit requires backfilling the front to create a “basement”, safety should not be compromised and an alternate solution should be adopted.

Excessive Lateral Pressures

More than often, buildings that are built on slopes are backfilled on the mountain side. If the structural designer is not aware of these lateral loads, the structural integrity becomes critical. Whether a void of 1 meter or 10 meters (between the cut and the building) is backfilled, a lateral earth pressure proportional to the height of the backfill would be exerted. This lateral load would jeopardize the safety of the structure, unless it is taken into consideration. This reminds us of the importance of visiting the site during the design phase and after, during construction, in order to evaluate in-situ all scenarios and loading behaviors, thus dynamically modifying the design. In addition, since weep-holes are not present in a basement (foundation) wall, and a good French drain is rarely installed, hydrostatic pressures are often added as a bonus to the problem, with consequences shown in Fig.3.



Fig. 3. Failure of a Building Skeleton due to Excessive Lateral Pressure

RETAINING WALLS

Retaining walls, by definition are structures built and backfilled to raise the natural level of the ground. In Fig. 4, the different types of retaining walls are presented. Cantilever retaining walls are the most common in Lebanon. Unfortunately these reinforced concrete walls often lack important details. Missing such details leads to problems. Good detailing, in both design and construction, should at least address the following issues:

Drainage

It is definitely the number one cause of problems in retaining walls. As a first measure, weep-holes through the wall (usually 4" PVC tubing for every 5m²) are a must. These holes should be protected against clogging by a well-designed gravelly filter on the backfill side. This is particularly true if the backfill material is not well selected. A French drain accompanying the weep-holes is an added value to the wall. The French drain consists of a large (>6") perforated tube placed behind the wall. This drain should be well protected by a filter (or better yet a geotextile + Filter) and should be sloped, leading to a free drainage path. In engulfed spaces like a deep excavation, a sump & pump technique could be used to automatically drain the water out by pumping.

Vertical Joints

A vertical expansion joint (full separation with Styrofoam or asphaltic spacer) every ~20m, is common practice in Lebanon. This method is no longer recommended. Current thinking is that with the large shear + friction resistance existing between the soil and the concrete surface (back-face and the base), the joint is useless.

Nowadays, for large walls, a simple contraction joint every 10m would be more efficient and less cumbersome than expansion joints. A contraction joint can be installed by just providing a groove in the concrete surface (say 50x50mm) and stopping one of the two layers of the horizontal steel reinforcement. The groove produces a plane of weakness to locate (and hide) tension cracks during concrete setting and temperature extremes. Concrete pouring is not necessarily stopped at the joint, and if so it would be for aesthetical reasons.

Shear Keying at Construction Joints

Any time old concrete is to receive fresh concrete; a shear key must have been installed. A shear key would ensure that the cold joint is not a weak (smooth) plane through which shear resistance is weakened. An S shaped or V shaped joint would behave against shear much more efficiently than a straight separation. This situation is particularly common in retaining walls where the wall is poured on top of a smooth foundation. The shear force cannot be fully resisted by the concrete section and gets transferred to the steel reinforcement, which is intended for bending moments. In practice, a simple groove during concreting can do the job. A typical groove size is about 100x100mm, or more for heights exceeding 6m, and is placed between the 2 steel layers extruding from the footing.

RETAINING WALLS

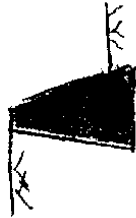

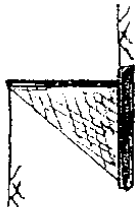


| <u>System</u> | <u>Vertical Element</u> | <u>Lateral Element</u> | <u>Illustration</u> | <u>Remarks</u> |
|------------------------|--|-----------------------------|---|--|
| Gravity Wall | Wall | Wall |  | Nowadays gravity wall need to be built with some cementation and drainage considerations. They are still used specially where material is readily available. Other types like Gabion ... |
| Cantilever Wall | Wall | Strip Footing |  | Most common type of wall. They are many modifications in shape that could be made depending on site conditions. Practically, limited to 10m in height |
| Counterfort Wall | Wall with Counterfort Elements | Strip Footing |  | Financially Attractive for heights of 9m and above. Wall becomes thinner & attached to counterfort elements. Geotechnically same desing as cantilever wall; but structurally different |
| Crib Wall | Caissons with Prefab Elements | — |  | It is basically a gravity wall made by locking together prefab concrete elements. Its advantage is speed (no wait for curing) and use of in-situ material for backfilling. Ecological. |
| Reinforced Earth Walls | Prefab Elements, concrete or others...tires! | Metal Strips or Geotextiles |  | A new system, quick but limited in height and site constraints |

Fig. 4. Common Types of Retaining Walls

Steel Overlap

The steel overlap locations for the reinforcement against bending moment should be staggered. A common mistake has been seen when the steel dowelling at the bottom of the wall is arranged at equal length. The development length when pulling a single steel rebar from a concrete mass can be obtained from the available theories. It is a common rule of thumb to take it as $50 \times \text{Bar Diameter}$. However when many bars are pulled at the same time from the same concrete mass, this theory no longer applies! For this reason the steel overlap should never be congested in the same area to avoid creating a weak zone. A serious failure proving the weakness of this steel overlap is shown in Fig. 5. The practical solution is to alternate the steel length and place the overlap in a staggered (zig-zag) arrangement.

Unyielding Condition: Watch the Structural Design

Walls that are generally assumed to be unyielding include basement walls braced by floor slabs, walls placed on rock, or connected to rigid piles. In these cases, rotation and/or sliding of the base would be insufficient, leading to an “at rest” condition. If an active condition (small movement) is assumed behind the wall, the geotechnical design requirements may be satisfied by checking safety against sliding, overturning, bearing capacity, and global failure. However, if this active condition is not developed, the structural integrity of the wall may be jeopardized. Therefore, it is recommended to use the “at-rest” condition for lateral earth pressure when structurally designing unyielding walls.

SHORING & STABILIZATIONS WITH LATERAL SUPPORTS

Shoring in Lebanon is considered a new “thing” in engineering practice. In fact all of geotechnical engineering is a recent science that is believed to have started only 77 years ago, with the “Erdbaumechanik” book by Karl Terzaghi. Shoring systems for deep excavations and slope stabilizations, utilizing nails and anchors, have been implemented on a regular basis in Lebanon since 1993, with the launching of construction and rehabilitation projects requiring such techniques. Earlier techniques including cast in situ walls, or strutting or others do not meet anymore the project’s requirements in size, depth, and time for execution.

Choices Available

While there exists many types of shoring systems as presented in Fig. 6, sometimes only one of them is applicable on a particular project...and sometimes none! Remarks about each type are also given in this figure. Continuous research and innovations are being introduced in the market. Every project offers an opportunity in designing a new system that is more technically and financially adequate. Copying one shoring system and “pasting” it onto a new project is a major mistake that is often done.

Anchors and Nails: What is the Difference?

Anchors and nails are designations interchangeably used to indicate lateral supports. While both are intended to overcome the shearing stress activated by gravity, these two support systems should be clearly distinguished. Anchors are actively tensioned to



Fig. 5. Total Collapse of a Cantilever Wall due to Steel Congestion and Pull out, With Foundation on Unyielding Piles and Poor Drainage

SHORING SYSTEMS

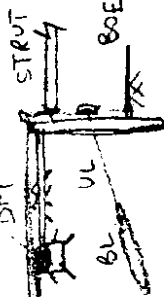
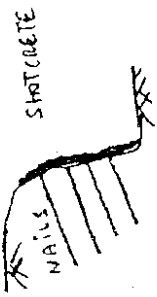
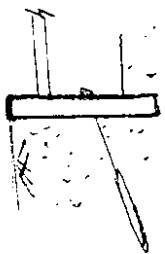
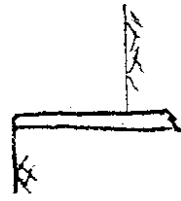
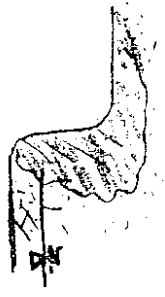
| System | Vertical Element | Lateral Element | Illustration | Remarks |
|------------------------------|--|---|---|--|
| Pile / Anchors | Piles or Micropiles (done prior to excav) | Anchors (active) or inner Struts, or DM anchor |  | Most common type of shoring in Lebanon & Europe. It is very efficient in most soil types. It is necessary where adjacent structures are jeopardized. |
| Shotcrete/ Nails | Reinforced Shotcrete (done during excav) | Nails (passive anchors) |  | Most common and Economical where Movement on the Upper side is permitted. Protection of cuts, tunnels, excavations, etc.... |
| Slurry Trench "Paroi Moulee" | Conc. Wall in the Ground, (done prior to excav) | Anchors, or inner Struts, or Slabs in TopDown technique |  | Expensive method. Financially Attractive When the excavation extends below the water table. Not very successful in Lebanon except on seashore in sandy and clayey soils. |
| Sheet Piles | Steel Sheets of different shapes, (driven by hammering prior to excav) | Anchors or inner Struts |  | Most economical for shallow excavations <6m since sheet could cantilever and its removal for salvage is easy. Beware of rocky and gravelly formations. For deep excavations > 12m sheetpiling is not practical |
| Grouting ! | Cement Grout Injected in the ground (prior to excav) | Cement Grout Injected in the ground |  | Applicable and Financially viable in sand and under the water table. Done prior to excavation. |

Fig. 6. Common Types of Shoring Systems

improve the strength by increasing the effective normal stress along the failure surface. However, nails rely more on its capacity in shearing resistance to increase the strength. Fig. 7 shows an excavation with a shoring system utilizing piles and anchors to support temporarily adjacent structures and infrastructures.

Anchors minimize ground movements when tensioned against a solid vertical wall, thus they are selected when little or no movement is required. i.e. excavation next to an existing building.

Nails on the other hand may require some ground movements before they start acting properly. If some movement can be tolerated, a nailed wall could be the most economical solution.

Inaccessible Data

It should be noted that, in an excavation for example, the soil to be stabilized where the anchoring is done, is different than the one described in the original soil report written based on boreholes within the site that is now excavated! So care should be taken, and soil data from the soil mass that is shearing around us is needed. Since it is rarely permitted to conduct soil investigations in the adjacent lot, some data must be collected during drilling of the planned lateral supports, thus refining the design.

In addition, data of the adjacent structures and infrastructures, such as the depth of foundations, the presence of trenches and pipelines, and other important data should be collected prior to finalizing the design of shoring systems.

Temporary versus Permanent

Most common shoring systems are temporary systems for buildings in deep excavations. Such systems are required for a relatively short period of time, say 6 months, in order to accommodate a future construction that will be the final support. However, when designing a permanent system, extra care and additional considerations should be taken into account such as: permanent and extra loads like earthquakes should be added, safety factors raised, construction procedures improved, and the quality better controlled. Unfortunately, this extra care leads to larger budgets and often is not implemented. The safety of the intended “permanent” system is endangered, and long-term behavior is placed at stake. A slope stabilization system with permanent anchors is shown in Fig. 8.

Monitoring

It is worth mentioning that monitoring should be part of every shoring job. It consists of installing devices that measure any movement during the different phases of the construction. These devices can be installed on the face of the cut and on adjacent structures, or even within the shoring wall (like inside the pile). Monitoring allows controlling the performance of the shoring system, evaluating the design, and detecting early on any anomalies in order to take corrective actions before it is too late. Monitoring methods are numerous utilizing devices like tiltmeters, strain gages, inclinometers, or a surveying “total station”. It is essential to request monitoring as a regular safety measure in future contracts of shoring works.



Fig 7. Temporary Shoring of a Deep Excavation



Fig 8. Slope Stabilization with Permanent Anchors

CONCLUSION

Even though it may sound like an oxymoron, geotechnical engineering is an “artistic science” combining well-established theories with judgments based on experience and analogy. It is a continuous and dynamic science that poses a new challenging problem for every situation. Care should be taken not to fall into the trap of photocopying, or copying solutions.

In conclusion, I would like to stress that this article provides recommendations from a personal point of view. It was written at a short notice, and presents a brief overview on some important issues related to safety in geotechnical engineering, hoping to be of benefit to interested readers.

Worldwide, geotechnical engineering is currently a well-defined discipline within the civil engineering profession complementing other disciplines such as structural, environmental, hydraulic, and bridge engineering. Future developments, research, and lessons learned should continuously emanate as improvement to the geotech discipline; particularly from our beloved country, Lebanon.