STUDY TUNNELLING EFFECTS ON LATERAL BEHAVIOR UNDERGROUND BUILDING

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ABSTRACT

The issue of interaction between tunnel and adjacent structures is of major research for tunnelling in metro cities, because of the high interaction between tunnelling and existing structural components of building. A foremost problem during the planning and execution of underground construction is the influence of construction related ground movements on adjacent structural components of building. During excavation and support of tunnels and open-cuts, changes in the state of stress in the ground mass around the excavation and loss of ground occur. These deviations in stress and ground losses are normally expressed in the form of vertical and horizontal ground movements. The ground movements, in turn, will cause any structures supported by the affected ground to translate, rotate, deform, distort, and possibly sustain damage. As a result, important tasks facing both the engineer and the contractor are the estimation of the magnitude and distribution of the ground movements to be caused by the construction procedures and the tolerance of the structures and utilities to the deformations and distortions sustained as a result of the ground displacements.

Keyword: - *Tunnel 1, Building 2, Ground Movements3, and Urban Environments 4.*

1. BACKGROUND

For hundreds of years, our natural dominion has been the surface of the ground. Insisted by necessity and curiosity, we have always tried to escape from this space, by searching for utilization of the remaining dimension, upwards or downwards. In these struggles, we have always encountered great difficulties, especially in the downward direction. Only the underground space can provide us the site for activities or infrastructures that are needed in the populated metro cities. Human activity and population growth, however, are transforming the nation and planet. Long-term challenges for society include learning how humans can prosper without continued degradation of Earth and how to make suitable and sustainable adaptations. Improving or even sustaining current standards of living in the future will place more stress on earth systems, especially in urban environments where population increases are expected. Approximately 80 percent of people living in the United States live in urban areas. Approximately 53 percent of the American population lives within 50 miles of a coast at a time when global climate change is predicted to have significant coastal impacts including sea level rise, changes in weather patterns, and degradation of drinking water supplies. Meanwhile, some suggest short-term focus needs to be on design and adoption of community-based strategies to reduce vulnerability to the potentially destructive impacts of climate change throughout the nation.

Intensive and well-coordinated use of underground space may be a key component of the sustainability solution. Engineers of underground space will have a vital role in planning, designing, constructing, operating, maintaining, and regulating underground space as well as in informing the social, economic, and even political decisions related to underground space and urban development. Increased interest in underground construction and development is evident throughout the world. Underground engineering can provide a means to reduce energy use, increase green space preservation, sustainably process and store water and wastes, securely and efficiently site critical infrastructure, prevent and reverse degradation of the urban environment, and enhance quality of life. Many urban areas already enjoy the benefits of using underground space.

An integrated three-dimensional approach to infrastructure design and management that considers and values space usage and human and social needs over time benefits all sectors of the community by protecting public health, reducing risks, maximizing reliability and long-term performance of urban infrastructure systems, and minimizing long-term costs. The underground is a valuable resource. Urban planning too rarely takes a systematic account of the space both above and beneath Earth's surface on a coordinated basis at any large scale, and rarely incorporates infrastructure lifecycle planning or long-term infrastructure sustainability when deciding a future course.

Underground construction works have always been very difficult. However, rapid economic development in recent century made us dig in to the soil deeper and deeper, encouraged by numerous reasons. Today, the main reasons which justify use of the underground space can listed as follows.

A. Land use & location

Presently, every mega city is fighting a losing battle for open spaces over the last few years. In fact this lack of space above the surface is not only the case in metro cities but in almost all cities around the world. It leaves us no option but to make use of the underground space in a more thoughtful and a well-organized way so that the advantage of location can be utilized.

B. Isolation considerations

The soil is almost infinitely spaced, fully opaque and gives us many advantages in terms of isolation. It can provide protection against extreme climate, earthquakes and other natural disasters.

C. Environmental preservation

Recent research suggests that a variety of the underground building cases the annual energy demand is below 10 kWh/m2, so we can almost consider such buildings as zero energy buildings. . This is notably important aspect in designing facilities with a low environment impact. The ground can also provide us a variety of rewards in terms of safeguard of the surroundings, such as Aesthetics or ecology.

D. Topographic reasons

Tunnels have been made in undulated surfaces, mainly to dig through mountains for both roads and railways. The use of tunnel advances or makes it possible several transport options, like roads, railways, canals, etc. in hilly and mountainous areas.

E. Economic reasons

Because the initial construction cost of underground buildings is generally higher than those of building in the open air, underground buildings are in a way "punished" when linked to open air buildings. Therefore, the economic paybacks of an underground structure should be evaluated by estimating the life-cost impacts of the reimbursements provided by such structures. Additionally, the evaluation should take into consideration the various indirect rewards they offer, especially in terms of low environmental impact. If executed systematically Initial building costs can be made low, as underground building is largely subtractive rather than additive, and because the soil displaced by the excavation can be used again as building materials.

1.2 Foundation

In general, the term foundation can be defined as the part of the structure which bears the weight of the structure as well as several direct and indirect loads, and transmits them to the underlying soil or rock. The process of designing a foundation involves geology, soil mechanics, rock mechanics and structural engineering. (Day 2005.) A Foundation is the connecting link between the structure proper and the earth. A foundation can also be defined as an artificially laid base on which the superstructure is built (Jumikis, 1971.) The principle aspect of foundation design is to identify the most suitable type of foundation, such as whether to use shallow or deep foundation for the proposed structure. Another fundamental aspect is to develop and understand the governing parameters such as the bearing capacity of the soil or rock underneath and the estimated set- tlement of the foundation over time.

The design of a foundation structure also involves the reinforcement detailing which includes the diameter of the reinforcement bar, the steel grade and the spacing between the reinforcement bars. In most cases, the design of a foundation involves both a geotechnical engineer and a structural engineer. In the initial phase, the geotechnical engineer provides the details regarding the soil bearing capacity and the structural engineer performs the actual design of the foundation. The fundamental structure of the foundation can be divided into two broad categories i.e. shallow foundation and deep foundation. Further, these two types can be divided into several sub-categories depending upon their physical form and structural properties. The geotechnical works and initial planning phase depend upon factors such as the surrounding structures, previous history of the site, and corrosively levels.

The first step in the design of a foundation requires some basic knowledge about the location of the site, known geological hazards, fault lines, landslides or deposits of liquefaction prone sand which is not common. The knowledge about the projects size also helps in the initial planning phase to avoid budget over-runs. The determination of the scope of the work, such as possible subsurface exploration, laboratory testing to determine the feasibility of the project and compaction testing, minimizes any possibility of surprise shortcomings during the actual design and construction phase. For a simple structure, the design and construction could be fully based on the preliminary design in most cases, but for large scale projects, the initial design and plan could be optimized as design and construction progress.

The most usual concern while designing the foundation used to be the frost protection. Since the bedrock level can be found within a very comfortable piling range, the load bearing issues are usually simple. Primarily, the foundation is done to mitigate the effects of frost penetration adequately. If this problem is ignored, it may cause damage under and around the foundation, which could require a costly repair procedure. In general, the depth of the foundation should extend well below the depth of frost penetration level in frost-susceptible soil.

1.2. Types of Foundation

A. Shallow Foundation

A shallow foundation distributes the load of the structure to the upper surface of the ground. The precise definition and range of the depth for a shallow foundation may vary from region to region, but in general, the depth from the field level to the underside of the foundation is less than five times the thickness of the foundation is deemed as a shallow foundation. If the soil layer at shallow depth usually less than 3 m can support the structural load and the action forces without exceeding the critical settlement level, then a shallow foundation is constructed. Shallow foundations are to be avoided when the surface soil is highly compressible. Shallow foundations are vulnerable to three general failure modes, namely general shear failure, local shear failure and punching failure. In the design of the shallow foundation, the possibility of the failures must be taken into consideration. It is worthwhile to note that shallow foundation can be susceptible to any seismic action that changes the contour of the ground. A change in the settlement and a lateral translation may alter the bearing capacity of the upper strata of the soil, or result in soil liquefaction causing grave consequences to the structure. In countries like Finland and other countries with a harsh and long winter, shallow foundations must be protected against freezing. The water in the soil near the foundation can freeze and expand causing damage to the structure. So, to mitigate this problem, the foundation must be built below the frost line protected by insulation, whichever is feasible and cost effective. There are several types of shallow foundations. The best one depends upon the project requirements, the soil bearing capacity of the building site, the cost and the efficiency of the construction project. Some of the shallow foundations types are introduced briefly below.

B. Pad Foundation

A Pad foundation is usually used to support a single point load coming from a support column. The geometrical shape of the padding could be anything circular, square or rec- tangular depending upon the requirements. The pad could either be of uniform thickness or stepped or hunched if it is required to spread the load from a large column to the maximum surface area underneath. There could be several singular paddings below the structure each supporting a load from a single structural column. Pad foundations are usually considered a very efficient shallow foundation type. The thickness of the paddings should be enough to distribute the load across the planned surface area. Pad foundations in general, are reinforced on all except small structures. The reinforcement allows the structure to take on a higher imposed load. A higher load bearing capacity permits to the construction of shallower pads which involves less excavation and uses less concrete. The arrangement and placement of the paddings depend upon the nature of the structure, the type and magnitude of the im- posed loads, the bearing capacity of the ground and the space available at a constructions site.

C. Strip Foundation

Unlike the pad foundation that supports a high-intensity point load, a strip foundation supports line load which may or may not be high in intensity. The strip foundation can be used in most sub soils, but the better a result is yielded if the subsoil has a relatively good load bearing capacity. The depth of the and width of the strip foundation can be changed per the intensity of the line load on it, but the width of a strip foundation that is always either equal to greater than the thickness of the wall it is supports. A strip foundation is very common in cases where structural load bearing wall is used as the load bearing structure instead of the column. A strip foundation is also used if the column to column distance is small, and a pad foundation is not a feasible option. A strip footing is also known as continuous foundation due to the continuous nature of the footings, unlike pad foundations.

D. Mat Foundation

A mat foundation can be defined as a large slab, which supports the columns and walls transferring the load from the structure. This type of a foundation is usually used when the allowable soil pressure is too low and exceeding pressure could result in a major settlement with severe consequences to the structure. This type of a foundation is useful when columns have significantly varied loadings or when the column to column distance is too small for a pad foundation. The construction of a raft foundation can be fast and very inexpensive compared to other types of shallow foundations. The ground slab and the foundation are combined, resulting in less use of material. These types of foundations are suitable for structures with a uniform load distribution. When the load is a concentrated high-intensity line load, the area can be thickened, and further reinforced to avoid cracking.

E. Deep Foundation

A foundation is classified as a deep foundation if the depth of the foundation. (d) is greater than twice the width. (B) of the base of the foundation footing i.e. if, d>2B. This type of a foundation is usually used if the load bearing capacity of the underlying soil layers is very poor and a shallow foundation would not be a viable option. Pile foundations are the part of a civil structure designed to carry and transfer the load and other forces arising from the superstructure above, to the bearing ground. The same pile also helps to transfer the forces to the ground surfaces around as friction forces, if the pile is a friction pile. These are mostly seen in desert structures where there is no bedrock available. The primary component in this type of a foundation is the pile, in some cases a pile cap and a slab on the piles. The most used piles are wooden piles, concrete piles and steel piles depending upon the size and other factors involved in the project. The piles are driven, drilled or jacked into the ground, and the top of the pile is connected to the pile cap. A pile cap is not required with the use of additional reinforcement or several custom components available to avoid the punching shear failure. Piles can be categorized into several types depending upon the type of soil, pile material, and load transmitting characteristics of the pile. Cases where the settlement of the soil is high, bearing capacity is low and it is difficult to build heavy structures which require transfer of loads underneath, require a pile foundation. The versatility of a pile foundation makes it possible to design pile foundations of different mechanical characters like end bearing, friction or combination of both depending upon the site.

Pile foundations have been in use for several hundred years. The documented history shows that the use of the piling technique can be traced back to the 4th century B.C. When Greek and Roman Engineers utilized the piling technique to build structures on the banks of the Mediterranean coast. Though undocumented, there are references of piling techniques adopted by Swiss lake dwellers to elevate their dwellings to protect the occupants against attacks. In the early days of civilization, most villages were situated near rivers for defence, strategic, communications or transportations purposes. Therefore, it was important to strengthen the bearing ground with piling. The only types of piles available were the timber pile which was driven to the ground by manual Labour, or by first digging a pit, planting the piles, and strengthening the base with sand and stones. A breakthrough in modern piling technique can be attributed to Christoffer Phloem, who in 1740 invented pile driving equipment. There are several types of pile foundation based on the material properties of the piles, action on the ground, and the load transfer behaviour of the piles.

1.2.1 Classification of piles based on load transfer

Piles can be classified per the effect of the pile on the ground for load transfer mechanism. The ground bearing capacity and other specific requirement of the project site, dictate which types of piles can be used with and what load transfer method. The different types of piles are introduced below.

A. End bearing piles

In general, end-bearing piles have their bottom on a layer of heavy soil or rock. In this system, the load of the superstructure is transferred to the bearing layer through the pile. In a way, the piles act as columns for load transfer, avoiding the instability of the weaker layer upon the solid layer. Even in scenario when the soil or rock layer is weak, the pile does not fail by buckling. For the pile, not to fail, a part of the pile needs to be unsupported. A layer beneath the pile is then either water or air. The only way to transmit the load to the layer underneath is through either friction or cohesion. In some special cases, the soil around the pile may adhere to the pile surface causing negative skin friction on the pile. This phenomenon may weaken the bearing capacity of the pile substantially. The pile length is determined with the site investigation and soil test.

B. Friction piles

Contrary to bearing piles, friction piles do not transfer the load of the structure to the underlying bedrock. Instead, the support capacity develops from the resistance of the soil friction and adhesion mobilized along the pile. A friction pile is mostly used where the ground beneath is mainly soft clay where it is difficult to find stable bedrock at a plausible depth. Such piles are also known as a floating pile foundation. In sites with medium to low-density sand layers with less cohesion friction piles are often used. The use of friction piles in such circumstances increases the density, which results in the increase of shear strength. At the sites with no bedrock layer at a reasonable depth, end-bearing piles can be extremely long and excessively costly. In such cases, friction piles are driven through the softer layer to a specified depth with enough skin friction required for the desired load bearing capacity.

C. Combined end-bearing and Friction pile

Combined end-bearing and Friction Pile is a pile where, the bearing capacity is developed from combined end-bearing resistance at the bottom tip and adhesion resistance between pile surface and surrounding material surface. In most cases, piles are driven deep enough to gain sufficient frictional resistance. In some cases, the bearing area at the bottom is increased by forcing a bulb of concrete just above the tip to enlarge the area around. In this kind of a pile foundation, the total load carried by the pile equals to the sum of the load carried by the pile end and the load carried by the skin friction against the ground. This type of a pile is used when the soil test result show dense soil or bedrock at a feasible depth and the layers above support skin friction. The ultimate load bearing capacity for this type of pile a can be expressed using the equation below.

$$(QU = QS + QP)$$

where QU is the ultimate load capacity of pile QS is the load carried by the friction pile and QP is the load carried by the end bearing pile.

D. Batter pile

When a pile foundation is inclined against the vertical, such a pile system is called a batter pile. In a batter pile system, the piles are driven into the ground making a certain angle with the vertical axis so that can provide high resistance to the lateral loadings. Within a group of piles consisting of batter piles, the distribution of load can be determined analytically as it is a hyper static structure. When the fill is, loose and has a considerable settlement, the batter pile is laterally loaded. Normally, there are 1-5 inclined piles to 12 vertical piles in each foundation deign. During the design phase, it is assumed that the batter pile has the same axial load bear- ing capacity as the vertical pile if they are of the same material and measurement, and driven to the same stratum.

1.3 Tunnelling Effects

Tunnelling in soft grounds inevitably causes ground movements, both vertical and lateral, which may have an impact on existing pile foundations. In such cases, at least two important aspects must be considered by the designer:

The movements of the piles caused by the ground movements in order to ensure structural serviceability;

The additional forces and/or bending moments induced in the piles by the ground movements in order to ensure structural integrity of the piles.

Current analysis methods to evaluate the effects of tunnelling on existing pile foundations belong to two categories:

Simplified two-stage approaches involving the initial separation of the soil and the piles so that the soil movements are first computed and then imposed on the piles;

Complete numerical analyses including simultaneous modelling of the piles, the soil, and the tunnel excavation.

The latter category is generally based on three-dimensional finite element (FEM) or finite difference (FDM) analyses which provide a complete solution to the tunnel–soil–pile interaction. While such solutions are the most powerful numerical tools currently available, they are very expensive in terms of data preparation (pre- and post-processing) and computational time. The cost of such analyses may become prohibitively high if non-linear soil

behaviour and complicated construction sequences are to be taken into account. In addition to the computational requirements, complete 3D numerical analyses are complex when use for design purposes, particularly when non-linear behaviour is to be considered. Major difficulties are related to the construction and the interpretation of the 3D model (modelling errors are easily overlooked), the high mesh dependency, the uncertainty in assigning mechanical properties to the pile–soil interface elements, the interaction with adjacent structures, and the modelling of the excavation sequence . Thus, a complete 3D analysis is more suitable for obtaining the benchmark solutions (against which simpler analyses can be checked) or for obtaining the final design solution for major projects, than for use as a practical tool for less demanding problems or in the preliminary design stages (in which multiple tunnel configurations and scenarios have to be examined).
In order to overcome the above shortcomings, simplified approaches have emerged. Such approaches are based on a two-stage procedure:

- Evaluation of the free-field ground movements caused by the tunnel excavation;
- Analysis of the piles subjected to the computed free-field ground movements.

In simplified approaches, the tunnelling-induced ground movements are generally evaluated in free-field conditions, i.e., in the absence of piles. This generally is a conservative assumption as the presence of piles increases the soil stiffness, thereby reducing the induced ground movements, as demonstrated numerically.

2. TUNNELLING IN URBAN AREA

As tunnelling expenses continue to drop, tunnelling is being considered as the best option to avoid increasing traffic congestion in urban areas. Tunnels can be used to take heavy traffic from one point of city to other so that local roads can be freed up, improving the dependability of bus service, making cycling possible. In practical, tunnels can rebuild the city, generate returns in long term by letting networks of roads to be born-again and collectively improving the livability of whole urban areas.

There are many reasons for which tunnels are being preferred more these days, some of them are mentioned below.
The cost of tunnel construction is falling by about four per cent each year, compared to surface roads in urban area where acquiring land or moving utilities is expensive construction urban tunnels can be considered as a cheaper option.

Technology for tunnel boring and constructing underground structures have made rapid advance as a result of the channel tunnel and other projects which involved new technologies in place of blasting. These new techniques have transformed the economics of tunnelling where the right geology exists. New cross-sections have been developed which carry two levels of light vehicles in a single tube slashing the cost of tunnel provision.

Harmful pollutants in tunnels can now be collected before ventilation and "scrubbed" near clean using new technologies, whereas vehicle emissions on surface streets flow straight into the air.

3. CONCLUSION

The construction and operation of these systems can damage to surface structures or other underground structures. Therefore the prediction of tunnel induced stresses becomes an important issue in the planning and execution process. The current design approaches which we have are very conventional and may cause excessive spending in the design and construction. A better understanding of tunnelling induced deformations could decrease expenditures and help us escape disputes and resolve claims.

Reference

[1] Brinkgreve R.B.J. et al(2003)."The influence of tunnel boring on foundations and Buildings in urban areas – a numerical study", Int. Workshop on Geotechnics of Soft Soils Theory and Practice.

[2] Huang X., SchweigerH. F.(2010)"Study on influence of deep excavations on existing tunnels using PLAXIS-GiD", Plaxis Professional, April 2010.

[3] Jan Niklas Franzius, (October 2003). Behaviour of buildings due to tunnel induced subsidence, thesis submitted to the University of London for the degree of Doctor of Philosophy

[4] Mroueh H. and Shahrour I. (2002). "Three-dimensional finite element analysis of the interaction between tunnelling and pile foundations", 'International journal for numerical and analytical methods in geomechanics', 2002; 26:217–230.

[5] PLAXIS 2D Manual for General Information, Reference and Scientific Manual.

[6] Pornkasem Jongpradist, Trin Detkhong & Sompote Youwai,(2012) "Numerical Simulations of Geotechnical Works in Bangkok Subsoil Using Advanced Soil Models Available in Plaxis and Through User-Defined Model", PLAXIS Professional, October 2012

[7] Rodriguez J.A.(2005)."Deep Excavation in soft Soils And Complex Ground Water Conditions In Bogotá", PLAXIS Professional, March,2005

[8] Schweckendiek(2006). "Structural Reliability Analysis of Deep Excavations Using the Finite Element Method", PLAXIS Professional, March 2006.

[9] R. Cojean and Y. J. Caï, "Analysis and modeling of slope stability in the Three-Gorges Dam reservoir (China) -The case of Huangtupo landslide," J. Mt. Sci., vol. 8, no. 2, pp. 166–175, Mar. 2011.

[10] G. W. Jia, T. L. T. Zhan, Y. M. Chen, and D. G. Fredlund, "Performance of a large-scale slope model subjected to rising and lowering water levels," Eng. Geol., vol. 106, no. 1–2, pp. 92–103, May 2009.

[11] J. Krahn, "The 2001 R.M. Hardy Lecture: The limits of limit equilibrium analyses," Can. Geotech. J., vol. 40, no. 3, pp. 643–660, Jun. 2003.

[12] J. B. Burland and J. E. B. Jennings, "Limitations to the Use of Effective Stresses in Partly Saturated Soils,"

[13] Géotechnique, vol. 12, no. 2, pp. 125–144, Jan. 1962.

[14] D. G. Fredlund and N. Morgenstern, "Stress state variables for unsaturated soils," J. Geotech. Geoenvironmental Eng., vol. 103, no. GT5, pp. 447–466, Jul. 1977.

[15] D. G. Fredlund, "Unsaturated Soil Mechanics in Engineering Practice," J. Geotech. Geoenvironmental Eng., vol. 132, no. 3, pp. 286–321, Mar. 2006.

[16] M. M. Berilgen, "Investigation of stability of slopes under drawdown conditions," Comput. Geotech., vol. 34, no. 2, pp. 81–91, Mar. 2007.

[17] M. Huang and C.-Q. Jia, "Strength reduction FEM in stability analysis of soil slopes subjected to transient unsaturated seepage," Comput. Geotech., vol. 36, no. 1–2, pp. 93–101, Jan. 2009.

[18] V. Galavi, "Internal Report - Groundwater flow, fully coupled flow deformation and untrained analyses in PLAXIS 2D and 3D," 2010.

[19] S. E. Darby, M. Rinaldi, and S. Dapporto, "Coupled simulations of fluvial erosion and mass wasting for cohesive river banks," J. Geophys. Res., vol. 112, no. F3, p. F03022, Aug. 2007.