IMIA Working Group Paper 100(16)

Support for excavations

49th Annual IMIA Conference – Doha, Qatar

Working Group

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INTRODUCTION

The ever-growing demand for construction works in urban areas, combined with deep excavations, poses geotechnical design and construction / execution challenges, to ensure proper foundation works and not to damage the surrounding buildings, utilities and environment.

For a lot of projects these deep excavations are required that might be overlooked because they do not form part of the final visible construction.

Usually specialised contractors are used and special knowledge and techniques are required to manage the specific challenges of these works.

The following article is focussing to give an overview on types of excavations, soil conditions, impact and influence of deep excavations on the neighbourhood and also offers recommendations for the underwriting.

1. TYPES OF EXCAVATIONS

1.1 GENERAL

1.1.1 Situations requiring designed excavation supports

Excavations require a ‘designed’ support where:

- The ground is weak and the excavated sides are not self-supporting.
- There is a high water table with resultant hydrostatic pressures on the sides and invert of the excavation.
- There are surrounding buildings and other sources of vertical load that ‘surcharge’ the sides of the excavation.
- The stability of surrounding structures and services could be undermined by any significant movements of the excavation.

1.1.2 Size & depth of excavations requiring designed supports

Excavations with depths in excess of some 3 metres will always require a designed support system. The precise depth will be governed by local regulations but, in general terms, designed support systems are required where there would otherwise be a risk of damage or injury.

Any size of excavation might require a designed support system, from a narrow trench excavation to a substantial underground shaft or basement structure.

1.1.3 Shapes of excavation requiring designed supports

The most statically efficient shape for an excavation is a circle as this provides both the minimum cutting edge length and the minimum wall area in contact with the soil in terms of plan area. Other possible shapes are however square, rectangular or elliptical.

If the plan shape is rectangular, it is often advantageous to use longitudinal or cross-walls to divide the excavation into approximately square plan areas for ease of construction.

1.2 TOP DOWN CONSTRUCTION

Top-down basement construction is a construction method whereby the permanent works are constructed in tandem with the excavation process. The permanent works provide most of the required strutting in place of temporary supports.

The walls are constructed initially followed by the roof slab, through which access openings are provided for the excavation work to proceed downwards. The floor slab at the next level down is then constructed, again with access openings, once sufficient additional soil has been excavated.

This sequence of work is repeated until the excavation of soil is complete and the base slab constructed.

Images from 'Land Transport Authority' paper on "Top-Down Construction"

The requirement for temporary strutting depends upon any potential short-term deficiencies in the strutting capacity of the permanent works whilst access is provided for the lowering of construction plant, equipment & labour.

This method of basement construction is generally less expensive and faster than the more conventional bottom-up construction. There are other risk factors to consider, however, as the permanent works are constructed in more confined and challenging conditions with access to critical areas being more restricted.

The connections to the roof, floors and base slab can be particularly challenging and more difficult to form. There is also a higher risk of water leakage at the joints between the slabs and the walls.

There are a large number of concurrent construction activities with top-down construction that require particularly careful coordination. The risks associated with the confined spaces in which the labour & plant need to operate also require close attention.

1.3 BOTTOM UP CONSTRUCTION

Bottom up construction is a method of basement excavation whereby the entire basement area is excavated and supported by temporary works prior to the permanent works being constructed. It is the conventional method of basement construction in which the walls are constructed initially, and internal temporary strutting installed until the excavation reaches its final depth or formation level.

The walls are of reinforced concrete construction generally comprising diaphragm walls or piles. Two or more levels of temporary strutting are usually required to ensure that adequate resistance is provided against soil and ground water pressures acting on the basement walls.

Cross section through basement excavation showing all the soil having been excavated down to formation level with the walls and temporary strutting having been installed but prior to any permanent works having been constructed

Cross section through basement excavation showing the base slab having been installed prior to the remainder of the permanent works (the floor slabs, roof and walls) being constructed and the temporary strutting removed

Images from 'Land Transport Authority' paper on "Construction of Secant Pile Wall"

After installation of the strutting system is completed and the soil has been excavated to formation level, the basement slab is then constructed as the first item of permanent works. The remaining items of permanent works, including floor slabs, roof and walls are then constructed allowing the temporary struts to be removed. Waterproofing is applied to the walls and roof, as required, and backfilling to the final levels undertaken to complete the basement.

In the event of particularly deep excavations, sometimes involving several levels of basement construction, the adequacy of the temporary struts to withstand substantial applied active pressures is of particular importance. Ground water control is also important in order to minimise hydrostatic pressures and to reduce the loads in the temporary strutting as much as possible. This can either be achieved by pumping water out from the excavation or by an external pumping arrangement to lower the water table in the vicinity. Particular care needs to be taken that the dewatering does not have adverse effects on surrounding infrastructure. See also 'Third Party Liability' section of paper.

1.4 BORED PILES

Bored piles are generally constructed using a crane mounted auger or a drilling rig to remove the soil and replace it with concrete. There are two principal categories of bored pile in supported excavations; namely, 'contiguous piles' and 'secant piles'.

Images from ‘Land Transport Authority’ paper on “Construction of Secant Pile Wall”

Conti[illegible]mprise interlocking piles whereby a gap is left between consecutively installed primary piles that is filled with a secondary pile cut into the primary piles on either side.

Cross-section through secant piling in which the primary piles are shown to be cut into by the secondary piles. The primary piles generally comprise a weaker concrete so the secondary piles can readily cut into them whilst also maintaining their verticality.

A wall formed from contiguous piles is suitable to retain stiff and cohesive sub-soils where ground water levels are below the depth of the basement construction. The small gaps between the contiguous piles can be grouted to form a watertight retaining wall. It is normally the most economic and fastest construction option.

A secant piled wall is however the appropriate form of construction where there is a high water table in that the interlocking piles form a more effective barrier against the passage of water.

The exposed piles, whether contiguous or secant, exhibit a fairly rough appearance as the soil is excavated from their face. Therefore, in most cases, an inner wall, which may or may not be structural, will be constructed or some decorative surface applied such as sprayed concrete or cladding. A drainage system will generally need to be installed between the piles and any inner wall.

1.5 DIAPHRAGM WALLS

Diaphragm walls are of in-situ reinforced concrete construction, typically between 20 and 50 metres deep. The walls are constructed in discreet panel lengths, generally between 2 and 7 metres, using either cable-suspended or mechanically operated grabs, and can be up to 1.5 metres wide.

A ‘guide wall’ is initially constructed at ground level to ensure the diaphragm wall is accurately located. A panel length of soil is then excavated under a bentonite slurry to prevent the excavated soil faces from collapsing. Vertical excavation tolerances are very important to ensure that the connections with the floor and basement slabs at the lower levels can be accurately made at the intended positions.

Bentonite is a ‘thixotropic’ material such that it is a highly viscous material in a static state that is capable of supporting excavated faces. When vibrated however, it is transformed into a fluid enabling it to be pumped from the bentonite plant into the panels.

‘Stop-ends’ are inserted to form the joints between adjacent panels, and water bars can be incorporated at these joints (alternatively known as a ‘water-stop joint’) where there is a risk of water ingress. A reinforcement cage is then lowered into the excavated panel, and concrete is poured using tremie pipes to avoid segregation. As the concrete is poured, the bentonite is displaced as it is of lower density than the concrete. The bentonite is then collected and re-used. The bentonite slurry requires the careful management and use of specialist plant, including de-sanding equipment.

The diaphragm wall becomes the permanent wall once it has been connected to the roof, floors and base slab of the basement construction. It is therefore important that the concrete achieves the required strength and does not segregate when poured.

1.6 SHEET PILES

Sheet piling provides earth retention and excavation support using steel sheet sections with interlocking edges. Sheet piles are installed in sequence with a Sheet Pile Driver to form a wall for permanent or temporary earth support resulting in reduced groundwater inflow. Where they are being used in a temporary capacity thought has to be given to their eventual removal and possible localized settlement.

Sheet Pile Installation Process - Image from Hayward Baker paper on Sheet Piles

Vibratory hammers are used to install sheet piles or if soils are too hard or dense an impact hammer can be used. At sites where vibrations are a concern sheets can be hydraulically installed by the use of water jets at the base of the pile supplied through small pipes welded to the sheet pile.

1.7 GROUND ANCHORS

Ground Anchor Installation Process - Image from Hayward Baker paper on Anchors

To counter the soil and water pressure behind the excavation walls ground anchors can be utilized. To achieve this, an anchor rig is used to drill a hole through the retaining structure into the soil or rock using a casing if necessary. Threadbar or strand tendon is inserted into the hole and the hole is filled with high-strength grout. Any casing used is then extracted. The length of bar or strand above the bond zone is covered by a bond breaker to eliminate load transfer above the bond zone. The anchor head is then generally tensioned and connected to the structure requiring the support. In this way anchors stabilize and support the excavation walls by transferring the tension loads through the threadbar or strand tendons.

1.8 STRUTTING

Excavations may require struts to be installed during excavation to meet soil and water pressures exerted on the walls of the excavation.

As well as fixed struts hydraulic struts are available which have a larger degree of adjustability and can be preloaded to minimise deflection and settlement during excavation.

It is possible to fit load monitoring equipment within or to the struts which helps to determine trends and give warning when struts are becoming overloaded. Load cells are incorporated within the

Wale Strut

Strut

Sebdier beam

Lagging

Lagging

Wale

Wedge

Elevation

Struts and associated Structural Members

struts, in series, so the loads pass through the cells whereas strain gauges are fixed to the struts. Alternatively, if the struts are hydraulic, the hydraulic fluid pressure can be measured to monitor pressure. Both alternatives measure extensions and compressions of the struts.

The design must look at not only the loading on the struts, but also constructability while allowing space for equipment and materials entering or exiting the excavation.

Consideration has to be given to redundancy within the design so if a strut is unable to take its load due to damage, failure of the whole system will not occur. Adequate drainage provisions also need to be incorporated into the design to prevent failure due to water pressure.

1.9 INVERT TREATMENT

Invert treatment refers to how the bottom of the excavation is constructed. Where groundwater is present several alternatives may be employed. One method is to install a temporary well system which pumps out groundwater to lower the level to below that of the excavation invert.

The well system design is dependent on factors such as the normal groundwater level and the level it has to be reduced to (below the invert of the excavation) for the works to take place as well as characteristics of the soil layers, such as its permeability.

Lowering the groundwater level causes settlement and therefore subsidence of the neighbouring area. This is a major consideration not just for the contract works site, but also for Third Party assets in the vicinity. For this reason, it is desirable to have not just impermeable walls to the excavation, but also a horizontal sealing blanket on the bottom of the excavation below the water table.

Lowering the Groundwater through the well system 1). Note ground anchors 2). Image from Munich Re paper on 'Excavation pits below groundwater level'

One method is to extend the walls down into a natural layer of impermeable material such as silt or clay. Excavation then follows groundwater removal within the walls. Sump drainage pumps then remove any water which may enter the excavation during construction.

If there is no natural sealing blanket, one has to be constructed under water which remains, after excavation has been completed, down to the required depth. This is an activity which requires precise planning and previous experience. The concrete sealing blanket is reinforced and tied down to resist hydrostatic pressures by bracing or grout anchors which act under tension when the excavation is dewatered.

Concrete blanket construction with tremmied concrete from a Concrete Pump 1) to form a Concrete Sealing Blanket 2).
Image from Munich Re paper on 'Excavation pits below groundwater level'

Grout sealing blankets can also be constructed where underwater concreting is not appropriate. This method also requires a high degree of contractor expertise and experience. Depending on the subsoil geotechnical conditions, grouting can be either injectable, which is approriate when the subsoil is granular and homogeneous, or jet grouting where it is not. Jet grouting replaces the subsoil, whereas injectable grouting fills void space in granular material. The grout sealing blanket is also tied down to resist hydrostatic pressures by bracing or grout anchors.

Another method that is employed when instead of granular material the subsoil is fine sand and silt, is jet grouting a sealing blanket. This involves sinking a drill pipe fitted with lateral jets to the level of the proposed sealing blanket. The pipe is then rotated while grout is injected under pressure into the surrounding soil. The drill pipe is then removed and the process is repeated until all the grout 'discs', that make up the sealing blanket, are constructed.

Image from Munich Re paper on 'Excavation pits below groundwater level

2. GEOTECHNICAL CONSIDERATIONS

2.1 SOIL TYPES

2.1.1 General Description

To the civil engineer, soil is any uncemented or weakly cemented accumulation of mineral particles formed by the weathering of rocks, the void space between the particles containing water and/or air. Weak cementation can be due to carbonates or oxides precipitated between the particles or due to organic matter. If the products of weathering remain at the original location they constitute a residual soil. If the products are transported and deposited in a different location, they constitute a transported soil, the agents of transportation being gravity, wind, water and glaciers. During transportation the size and shape of particles can undergo change and particles can be sorted into size ranges.

The destructive process in the formation of soil from rock may be either physical or chemical. The physical process may be erosion by the action of the wind, water or glaciers, or disintegration caused by alternate freezing and thawing in cracks of the rocks. The resultant soil particles retain the same composition as that of the parent rock. Particles of this type are approximately equidimensional and are described as being of bulky form, i.e. the particles may be angular, sub-angular or rounded. The particles occur in a wide range of sizes, from boulders down to the fine rock flour formed by grinding action of glaciers. The structural arrangement of bulky particles is described as single strain, each particle being in direct contact with adjoining particles without there being any bond or cohesion between them. The structure may be loose, medium dense or dense, depending on the way in which the particles are packed around.

The chemical process results in changes in the mineral form of the parent rock due to the action of water (especially if it contains traces of acid or alkali), oxygen and carbon dioxide. Chemical weathering results in the formation of groups of crystalline particles of colloidal size (< 0,002 mm) known as clay minerals. The clay mineral Kaolinite, for example, is formed by the breakdown of Feldspar by the action of water and carbon dioxide. Most clay mineral particles are of “plate like” form having high specific surface (i.e. high surface area to mass ratio) with the result that their properties are influenced significantly by surface forces.

In more general terms, a soil is considered to be *cohesive* if the particles adhere after wetting and subsequent drying and if significant force is then required to crumble the soil: this does not include soils whose particles adhere when wet due to surface tension. A soil which does not possess these characteristics is said to be *cohesionless*.

2.1.2 Soil description and classification

It is essential that a standard language should exist for the description of soils. A comprehensive description should include the characteristics of the both soil material and the *in-situ* soil mass. Material characteristics can be determined from disturbed samples of the soil, i.e. samples having the same particle size distribution as the in-situ soil but in which the in-situ structure has not been preserved. The principal material characteristics are particle size distribution (or grading) and plasticity, from which the soil name can be deduced. Particle size distribution and plasticity properties can be determined either by standard laboratory tests or by simple visual and manual procedures. Secondary material characteristics are the colour of the soil and the shape, texture and composition of the particles. Mass characteristics should ideally be determined in the field but in many cases they can be detected in undisturbed samples, i.e. samples in which the in-situ firmness or strength, and details of any bedding, discontinuities and weathering. The arrangement of minor geological details, referred to as soil macro-fabric, should be carefully described as this can influence the engineering behaviour of the in-situ soil to a considerable extent. Examples of macro-fabric features are thin layers of fine sand and silt in a clay, silt-filled fissures in clay, small lenses of clay in a sand, organic inclusions and root holes. The name of the geological formation, if definitely known, should be included in the description; in addition the type of deposit may be stated (e.g. till, alluvium, river terrace) as this can indicate , in a general way, the likely behaviour of the soil.

It is important to distinguish between soil description and soil classification. Soil description includes details of both material and mass characteristics, and therefore it is unlikely that any two soils will have identical descriptions. In soil classification, on the other hand, a soil is allocated to one of a limited number of groups on the basis of material characteristics only (particle size and distribution and plasticity) soil classification is thus independent of the in-situ condition of the soil mass. If the soil is to be employed in its undisturbed condition, for example to support a foundation, a full soil description will be adequate and the addition of the soil classification is discretionary. However, classification is particularly useful if the soil in question is to be used as a construction material, for example in an embankment.

According to the standards of soil description the basic soil types are boulders, cobbles, gravel, sand, silt and clay defined in terms of the particle size ranges given above. In addition organic clay, organic sand, organic silt and peat can be counted. These names are always written in capital letters in a soil description. Mixtures of the basic soil types are referred to as composite types.

A soil is of basic type sand or gravel (these being termed coarse soils) if, after the removal of any cobbles or boulders, over 65% of the material is of sand and gravel sizes. A soil is of basic type silt or clay (termed fine soils) if, after the removal of any cobbles and boulders, over 35% of the material is of silt and clay sizes. Sand and gravel may each be subdivided into coarse, medium and fine fractions. Sand and gravel can be described as well graded, poorly graded, uniform or gap-graded. In the case of gravels, particle shape (angular, sub-angular, sub-rounded, rounded, flat, elongate) and texture (rough, smooth, polished) can be described if necessary. Particle composition can also be described. Gravel particles are usually rock fragment (e.g. sandstone); sand particles usually consist of individual mineral grains (e.g. quartz)

The firmness or strength of the in-situ soil can be assessed by means of the tests given below:

Soil Type	Term	Field Test
Sands, Gravels	Loose	Can be excavated with a spade; 50 mm wooden peg can be easily driven
	Dense	Requires a pick for excavation; 50 mm wooden peg is hard to drive
	Slightly cemented	Visual examination; pick removes soil in lumps which can be abraded
Silts	Soft or loose	easily moulded or crushed in the fingers
	Firm or dense	can be moulded or crushed by strong pressure in the fingers
Clays	very soft	exudes between the fingers when squeezed in the hand
	soft	moulded by light finger pressure
	firm	can be moulded by the strong finger pressure
	stiff	cannot be moulded by fingers; can be indented by the thumb
	very stiff	can be indented by thumbnail
Organic, peats	Firm	Fibres already compressed together
	Spongy	very compressible and open structure
	Plastic	can be moulded in the hand and smears the fingers

Source: R.F. CRAIG, Soil Mechanics, 1994

The information about physical properties of subsoil will be used to analyse new structures, i.e. the prediction of ultimate bearing capacity and settlement, the selection of type and depth of foundation, the locating of ground water table, the evaluation of earth pressure, open excavation for foundation etc. More of these information is also used for controlling nearby existing structures such as actual safety of the structure, expected future settlement etc.

As most of the civil engineering structures are built below the surface of existing ground it's requiring an open excavation. Method of excavation, stability of slopes of excavation, stability of bottom of excavation, earth pressure against bracing systems are among problems to be solved during an open excavation. All these items are directly related to the soil type as well as the type of the civil Engineering structure and its foundation. An excavation for a particular foundation may be made by an open excavation with unsupported slopes, braced cuts, sheet pile walls, cofferdams and caissons.

Open excavation with unsupported slopes:

Temporary or permanent cuts or excavations can be made with unsupported slopes if there's adequate space to establish a proper slope at which the soil material can stand safely with an acceptable factor of safety. The depth of such cut or excavation is directly related to type of soil. The height of the unsupported slopes at bedrocks may reach up to 15 meters. Actually, stability of slopes in soil excavations depends on various factors such as type of material to be excavated, the degree of consolidation of that material, the degree of uniformity of soil layers, the position of ground water table. In non-homogenous soils, for example, the degree and height of the slope is controlled by the presence of an effective layer (loose soil on a firm effective layer or a firm soil on a loose effective layer).

Unsupported cuts in sand:

Sands above water table can be considered stable and they can be excavated using a standard slope. On the other hand, loose saturated sands are not stable and they cause slides during excavations. Fine sands and silts below groundwater table are the worst kind of excavation materials and they flow easily like a liquid. If the lateral confinement of saturated fine sand or silt is disturbed it is almost impossible to prevent slide failure. Therefore, saturated fine sands should not be attempted to be excavated without any lateral supporting systems. But fortunately, most of the sands encountered at the site contain some cementing material or a small amount cohesion and they may be excavated using standard slopes.

Unsupported cuts in soft clay:

If a standard slope of 1,5 horizontal to 1 vertical is used in a thick layer of soft clay, maximum height of unsupported excavation is about 3 meters.

Unsupported cuts in stiff clay:

Actually, stiff clays are stable temporarily and can stand for sometimes up to 10 meters of vertical excavation. It is possible that a deep excavation may be stand without supporting if the required time of excavation and foundation construction is short and the construction works can be completed in dry season. However, stiff clays are weakened by hair cracks called joints and they have a significant effect of stability of soil. When an excavation starts in stiff clay, the lateral stresses will be relieved and consequently the clay mass will tend to expand to create joints. Water may be enter into these open joints and it causes the softening of the clay. This gradual process may cause reduction of the strength of the clay and will cause to failure of the slope at last. As a result, it may be said that stiff clay may stand more than other types of soils when excavated; however, it depends directly on the duration of excavation and climate conditions. Moreover, there may be soft clay layers within soil texture which may cause sudden failure. Therefore, it is necessary to run triaxial tests on large specimens which include a representative number of joints.

Unsupported Cuts in clay containing layers of sand or silt

If a cut is made in a homogenous clay strata containing a layer or pockets of water bearing sand or silt , water seeps out of the slopes at various points. They require special attention, especially if the water-bearing strata slopes down toward the excavation pit as below. In this case, the inclined water-bearing strata works as an effective layer and causes a slide toward the pit.

Excavation in clay including sand or silt strata
Source: I. ORDEMIR, Foundation Engineering, 1984

Braced Cuts:

It's desirable that the sides of temporary cuts shall be made as steep as possible and preferable vertical without using any bracing system. Vertical or steep slopes without bracing will furnish a free working space for construction substructure and foundation , and will be also more economical. Unfortunately most of the soil conditions do not allow deep and wide excavations without any bracing system. It's also desirable to complete the excavation and construction in dry conditions, but it should not be forgotten that in many cases it will be necessary to lower the ground water table.

Braced cuts in clays

It's known that cohesive soils can be cut vertically up to a certain depth without bracing. The approximate values of critical depths for cohesive soils are as below

Soil	Critical depth
Very soft clay	up to 1,5 meter
soft clay	1,5 to 3,0 meter

firm clay	3,0 to 6,0 meter
stiff and very stiff clay *)	6,0 to 10 meter

*) Very deep cuts in stiff clays can be stand safely temporarily, but their apparent stability cannot be considered for permanent cuts.

Additionally, although cohesive soils can stand up to a critical depth without bracing, it should be taken into account that some tension cracks will appear on the ground level near to excavation pit after a certain time. These cracks reduce the critical height and sides of the cut may collapse. In order to prevent such failures upper edges of cuts in cohesive soils should be braced.

Finally, a considerable depth of excavation can be reached by anchored shoring systems with placing rows of drilled tie-backs at different elevations while excavation proceeds. This system has so many advantages that it can be successfully used almost under any soil and ground water conditions for almost any depth of excavation with different techniques.

An illustrated example of anchored shoring system
Source: I.ORDEMIR, Pile foundations, 1984

Deep excavation with rows of anchorages

Deep excavation by anchored soldier beam system

2.2 GROUNDWATER

All soils are permeable materials, water being free to flow through the interconnected pores between the solid particles. The pressure of the pore water is measured relative to the atmospheric pressure and the level at which the pressure is atmospheric (i.e. Zero) is defined as the water table (WT) or the phreatic surface. Below the water table, the soil is assumed to be fully saturated although it is likely that, due to presence of small volumes of entrapped air, the degree of saturation will be marginally below 100%. The level of water table changes according to the climatic conditions but the level can change also as a consequence of constructional periods. A perched water table can occur locally, contained by soil of low permeability, above the normal water table level. Artesian conditions can exist if an inclined soil layer of high permeability is confined locally by an overlying layer of low permeability: the pressure in the artesian layer is governed not by the local water table level but by a higher water table level at a distant location where the layer is unconfined.

2.2.1 Ground Freezing

Ground freezing is a construction technique that has been used for over one hundred years to provide temporary earth support and groundwater control. Applications are found in the underground civil, mining and environmental remediation industries.

Artificial ground freezing is used when other conventional methods such as dewatering, shoring and grouting are not feasible. Ground freezing is also used to provide groundwater barriers around mining operations for gold and other minerals, oil sands or oil shales. It is often referred to as ground freezing, soil freezing, or freeze wall. The ground freezing process involves drilling and installing a series of relatively closely spaced pipes and circulating a coolant through these pipes. The refrigerated coolant extracts heat from the ground, converting the soil pore water to ice resulting in an extremely strong, impermeable material. It is the most positive method of ground improvement used in the underground construction and mining industries.

From: *www.moretrench.com*

2.2.2 Dewatering:

Construction of civil engineering structures many times requires excavations below water table. To ensure safe and dry working conditions in the excavated areas the flow of water into the excavation pit must be eliminated or reduced. As a result the inflow of water should be controlled by lowering the ground water below the slopes and bottom of excavation. Ground water lowering operation cannot be standardized; and it is possible to use one or several different types of dewatering systems depending on the size and depth of excavation and hydraulic characteristics of soil. By means of proper dewatering operations, excavation and construction safety requirements can be satisfied; because

a) Stability of excavated slopes will increase
b) Danger of heaving of the bottom of excavation pit will decrease
c) Lateral loads on sheeting and bracing will be reduced
d) Excavation characteristics can be improved

Customary methods for controlling the ground water were to collect the water in the sump in the bottom of excavation and to pump outside of the excavated area. To facilitate pumping from sumps, sheeting was frequently used.

The water management system typically includes alarms and redundancy to avoid pump failure and water table level increase.

The water level has to be determined. Boreholes or trial pits, for example, could be used for this purpose.

On large jobs, evaluation of coefficient of permeability and pumping tests are necessary for determining the quantity of water and the time required for a dewatering process. The amount of water to be removed from the excavated area depends upon the height of water head, the permeability of the soil below level and the size of the area to be dewatered. In general, extensive dewatering is necessary for deep excavation in permeable soils and little dewatering for shallow excavations or excavations in impervious soils.

2.2.2.1. Pumping from sumps

For small excavations in suitable soils, it is possible to permit seepage from the slopes and collect water in ditches and sumps and pump it out of the excavation. A sump is a simple hole in the ground to collect the water for pumping out. For small areas, one sump is enough. But several sumps may be used for dewatering large excavations.

2.2.2.2. Well points

A well point is a metal pipe approximately 5 to 10 cm. diameter and 0.50 to 1.5 m in length which is perforated and wrapped with a metal filter mesh (usually stainless steel mesh). Well points are connected to 5 to 10 cm diameter pipes (riser pipes) and are driven into ground. The upper ends of riser pipes are connected to a header pipe that is connected to a pump.

A well point system is shown as schematically as below:

Well point system
Source: I. ORDEMIR, Foundation Engineering, 1984

2.2.2.3. Deep well pumps:

When great lift and multiple-stages are necessary in well point systems, then deep well pumps may be used. These deep wells can be located at some considerable distance from the edge of excavation and they don't interfere with other construction activities. The deep wells are 15 to 60 cm or larger in diameter and they are formed by drilling operations to the desired depth. Deep wells are furnished by a filter material that prevents loss of fine material in the adjacent ground. A submersible pump is lowered to the bottom of each well. Such wells are capable of lowering a large head of water and are spaced at 8 m to 40 m apart depending upon the depth of water to be lowered.

2.2.2.4. Other dewatering methods:

Electro-osmosis may also be utilized for dewatering excavations. This method is based on the principle that if positive and negative electrodes are installed in the ground, and an electric potential is set up, the water molecules will move toward the negative electrodes (to a well point). This method can very successfully be applied to silts and silty clays. But the method is expensive and requires a special technique and equipment. It is, therefore, not a common method of dewatering.

Ground water may also be controlled by freezing. This is also an expensive method and requires expert design and installation. The basic idea is to form an ice wall around the area excavated. The ice wall formed from the frozen ground should be thick enough to protect the excavation. Circular shaped frozen walls have been very successfully used to protect very deep excavations safely.

2.3 CAVERNS/VOIDS (KARST)

The design and construction of civil engineering structures in karst regions confronts many problems due to the unpredictable location, dimensions and geometry of the karst structure and voids.

Karst terrain is one of the most intricate types of ground to be assessed for civil engineering purposes.

Conventional methods of site exploration like desk studies, borings, test pits, geophysical techniques, have their advantages and disadvantages; none of them are 100% accurate; therefore they should be used in accordance to each project, the available budget and the undertaken risk. As no two sites are identical in karst, site investigation should be tailored to each site. Factors that should be considered when designing site investigation in karst are:

- Maturity of karst landforms
- Depth of the karst features
- Overburden thickness
- Lateral extent of the karst features
- Hydrogeology of the area
- Loading etc.

The main problems confronted by engineers designing structures on or in karst terrain are:

- Difficulties in excavation and grading the ground over pinnacled rockheads;
- Collapse of the roof over
- Subsurface voids, subsidence of cover soil over sinkhole
- Difficulties in founding a structure over an irregular or pinnacled rockhead
- Loss of water from dam reservoirs
- Pollution of groundwater, etc.

A number of solutions have been practiced by engineers to solve these problems like: relocating the structure on a safer site, filling the voids and the fractures with concrete, improving the foundation ground with grouting and/or geogrids, replacing foundation soil, bridging the voids with rigid mats or beams, using deep foundations (piling, drilled shafts, etc.), minimizing future sinkhole development by controlling surface and ground water, etc.

2.4 COMPENSATION GROUTING

Compensation grouting or the use of grouting techniques to control ground settlement during soft ground tunnelling, has become a well-established technique.

Compensation grouting can be described as the introduction of a fluid or semi fluid material into the ground, increasing the local volume at the point of injection. This in turn causes movement by expansion of ground away from the area of injection, either compensating for movement in an opposing sense or causing movement to accumulate in the direction of expansion.

Two processes have been traditionally used:

- Soil Fracture Grouting
- Compaction Grouting

Soil fracture grouting injection relies on propagation of in ground fractures by injection of a neat fluid grout at pressures in excess of the hydro fracture pressure and is demonstrated schematically by **Figure 1**. This technique has generally found a commercial niche in its application in fine grained soils where more positive grouting methods such as permeation and jet grouting are not possible.

Figure 1 Concept of Compensation Grouting by Hydro fracture Technique

Alternatively, a *ction grout* can be injected, generally in granular soils to be propagated. Pressures required to initiate this process are high and the process is shown schematically in **Figure 2 (below)**.

Source: Essler (2000): 'Compensation Grouting, Concept, Theory and Practice'

Unless cementing binder is very weak, this process can't be reinitiated from the same position, as the set grout is almost impossible to break through. While compaction grouting has been used successfully as a method of compensation grouting related to tunnel construction, its inherent high pressure of injection limits its application in close proximity to a tunnel face. Compaction grouting is further limited in its ability to react to settlements quickly because injection pipes are not reusable, thus requiring the installation of additional pipes for added injections.

3. SURROUNDINGS/TERRAIN/LOCATION

3.1 GENERAL

It is very important to analyse the impact that deep excavations can cause into surrounding and existing structures, buildings and underground services.

Location and type of site play important roles in the behaviour of a building not only in an earthquake but also in normal conditions too. Therefore, site for a building should be carefully chosen. The common problem that needs to be kept in mind while selecting sites are below:

Water logged area: Water logged areas should be avoided for building construction. In water logged areas, there may be possibility of flooding, foundation settlement and liquefaction.

Earth filled (back filled) area: - No building foundation should rest on uncompacted filled ground. In a back-filled area, the bearing capacity of foundation sub-soil is low and settlement of foundations may occur. In addition differential settlement may become a big problem at such soil. Also, foundation may be exposed to easy scouring of the backfilled soil. If a building is to be constructed on a filled ground, the foundation should be deep enough so as to rest on the firm ground surface beneath the fill.

Fig 3.1: a typical differential settlement

Waste disposal areas: buildings to be constructed on top of ex – waste disposal areas shall be treated specially, i.e. soil retreatment such as dynamic compaction or, pre-consolidation is needed.

Steep and unstable slopes: - No building should be constructed near to steep and unstable slopes. Steep and unstable slope areas are the potential areas for landslide and rock fall; there are potential dangers of landslides and rock fall due to rain or ground shaking. The simplest indication of sustained stability of a slope is the upright standing of a tree on it. They would be inclined downwards in the case of unstable slopes. These steep and unstable slopes should be avoided. However, buildings can be constructed in such areas after the provision of proper precautions by such as retaining walls and proper foundations. In such case all wall footings should be set back from the edge of slope.

Near River Banks: - River banks should also be avoided for building construction. River banks are susceptible to frequent flooding and also susceptible to liquefaction. Buildings should be far enough from the flooding zone of the river and construction in such areas should be undertaken only after carrying out necessary protection works.

Near to Big Trees: - Roots of the trees may penetrate into the foundation and damage the whole building. Also, if a building is near to a big tree, there is always possibility of the tree falling of tree in strong winds and storms.

Local Knowledge: - It is a good practice during the construction of a building to examine the existing local knowledge and the history of performance of existing buildings. This will assist in identifying whether there is any potential danger from inherent natural susceptibilities of the land to the process of sliding, erosion, land subsidence and liquefaction during the past earthquakes or any other natural/geological processes likely to threaten the integrity of the building. The local practice of managing such hazards, if any, should be judged against the required level of acceptable risk.

Moreover some countries, mostly ones at high earthquake zones , forces the contractors to prepare soil investigation report before commencement of construction works. This also give a chance to contractor / designer a better understanding of subsoil conditions and in turn a proper method of construction may arise.

3.2 THIRD PARTY LIABILITY - SURROUNDING PROPERTY DAMAGE

For the purpose of deep excavations, retaining walls may have been cast, ground anchors placed and dewatering actions were carried out, will there be any effects on the surroundings?

The main damage to the surrounding property are ensuing damage from ground movements, related to multiple sources of the deep excavation works, starting with the construction methods of the retaining walls, followed by the excavations, the insertion of ground anchors and possibly dewatering actions, all of which can affect the surrounding areas in means of soil strength, displacement, settlement, vibration, ground water levels and others.

These issues pose a complex problem in predicting the deep excavation impacts to the near and far vicinity surrounding property. The deep excavation impact to the surrounding property varies from aesthetic damages, serviceability damages and up to structural or stability damage that may lead to collapse.

Therefore, when as part of the construction works, deep excavation will be carried out, third party ensuing damages should be considered as a possible exposure not to be underestimated.

This chapter has 3 sections that will clarify the 3 main factors influencing third party damages to surrounding property, following deep excavations:

3.2.1 Settlement and displacement (this is a consequence)

3.2.2 Ground water pumping

3.2.3 Vibrations

This chapter does not deal with damages that may occur due to a complete collapse of retaining wall, contamination or water resource, impacts and human factors (noise, vibrations, dust, etc.).

The last chapter 6 of this paper summarizes the underwriting expectations and provides risk management recommendations.

3.2.1 SETTLEMENT AND DISPLACEMENT

For clarity the following definitions have been used, in the context of damages to the surrounding structures.

Displacement – ground movement in any direction.

Settlement – the vertical component of ground displacement.

Assessing the settlement and displacement effect to a structure that is adjacent to an excavation involves a combination of structural and geotechnical considerations. The soil displacement affects the adjacent structure in the form of stress, deformation and cracks, but also the presence of the building modifies the soil displacement beneath it.

The main factors influencing settlement and displacement next to excavations:

When one excavates along one side of a retaining wall, an unbalanced load condition is created on the other side, not being excavated, creating several forces on the wall.

Vertical and horizontal earth pressure is created on the retained side, forcing it to move into the recently excavated area. This is due to the fact that, when an area is excavated and the soil is removed, there is zero lateral pressure at the recently excavated areas. As a result, the retained soil, which was in a balance of forces, starts to move towards the excavated area and hence there is a reduction in the lateral pressure, compared to that in the initial state. The lateral force will reduce until it reaches a minimum new value against the retaining wall.

Predicting and monitoring settlement and displacement

Theoretical models use different approaches for predicting displacements and settlements. They are usually numerical or analytical modelling and computing programs. The reliability of the prediction models has uncertainties due to the lack of information regarding the soil conditions, simplified approaches and the influences of other factors.

In order to control the displacements and settlements exposures, it is recommended to use measuring equipment and to implement adequate procedures. There are many types of measuring equipment, which include, among others, laser measurements, sliding micrometers, extensometers, liquid levelling sensors, electrical and vibrating wire crack meters, strain gauges and many others.

3.2.2 GROUND WATER

Deep excavations reaching ground water levels pose another exposure relating to the effect from the lowering of ground water levels, which will increase the displacements and settlements and thus the potential damage to third party property.

Mitigation measures groundwater lowering

Engineering measures can sometimes be applied in addition to the main groundwater control system, to minimize the groundwater lowering impacts. The mitigation measures must be developed on a site-specific basis, and may include:

- **a.** Artificial recharge: Groundwater from the pumped discharge can be re-injected back into the ground, behind the impermeable barrier either to prevent lowering of groundwater levels and corresponding ground settlement, or to prevent depletion of groundwater resources.
- **b.** Temporary cut-off walls: If there is a concern that permanent cut-off walls will affect the long term groundwater flow regime, due to the barrier effect, then it may be possible to use temporary cut-off techniques. For example, steel sheet-piles that can be withdrawn at the end of the project, or artificial ground freezing, which will eventually thaw and allow groundwater flow to pass.
- **c.** Localized groundwater cut-off walls: Where there is a specific receptor to be protected, such as a wetland or sensitive structure, it may be possible to install a localized section of cut-off wall or grout curtain between the dewatering system and the receptor, to reduce the drawdown at the receptor.
- **d.** Protection of individual problematic areas: If there is only a small number of isolated problematic areas, it may be more cost effective to simply fix or prevent the problem directly at the receptor, for example by underpinning the foundations of a sensitive

structure, or by providing a new piped water supply to replace a well where lowering of water levels has reduced the yield.

3.2.3 VIBRATIONS AND DYNAMIC IMPACTS

Pilling works, but mainly sheet pile driving using vibratory equipment, impacts the environment mainly through vibrations. Vibration due to pile driving is a complex process that involves parameters that change during the pilling process. The vibration is generated by the pile driver that hammers on the pile which interacts with the soil, an action which generates a vibration through the ground that interacts with the surrounding structures both underground and above ground and may not only disturb the occupants but may also damage the structures.

If there are sensitive buildings close to the excavation, then it would be necessary to use a technique that does not introduce excessive vibrations.

In order to control the vibration exposures, measuring equipment, such as velocity, acceleration and displacement transducers, may be used.

3.3 CONDITION SURVEYS / DILAPIDATION REPORTS

It’s in the own interest of the principal, that the status quo and condition of existing structures in the vicinity of his/her project is documented before the start of any works on the site.

Depending on foundation level, age, kind of construction (concrete, wood frame, bricks..) and condition, buildings are differently sensitive to adjacent construction works.

It’s highly recommended that the affected structures are identified and surveyed by an experienced and authorised engineer who can issue an expert opinion.

A summary of these reports should be made available to the Underwriter to be aware of the exposures arising out of these factors.

The documents can be used as a base for any later claims issues and negotiations.

4 WORDING CONSIDERATIONS – ENDORSEMENTS

Excavations and excavation supports are probably the single construction work which has most relevant endorsements. They are divided into the following main groups:

Group A endorsements – directly related to the excavation support

Group B endorsements – related to the excavation works

Group C endorsements – related to third party exposures

The underwriter's decision whether to include the required endorsement relates to the type of works and the surrounding area:

4.1 GROUP A ENDORSEMENTS which are directly related to the excavation support:

In general these endorsements provide exclusions to section 1 where the Insurers will not indemnify the Insured in respect of:

i. Loss or damage arising directly or indirectly to foundation piles and/or casings and/or sheet pile constructions which are:
   a. Misplaced and/or misaligned
   b. Lost during driving and/or extraction
   c. Block disconnection or declutching
ii. Cost of repair, replacement, or rectification of piling work necessitated by leakage or infiltration of fluids or material at seams, joints, connections and/or beneath sheet pile constructions or into casings.
iii. Abandoned piling work
iv. Piles which have failed to pass a load test or attain the required bearing load

Related / similar endorsements are:

i. Swiss Re EPI 48 Piling construction
ii. Munich Re Endorsement 121- Special conditions concerning piling foundation and retaining wall works
iii. Munich Re Endorsement 1238- Piling, foundation and retaining wall construction works
iv. LEG Piling clause

4.2 GROUP B ENDORSEMENTS which are related to the excavation works:

In general these endorsements provide exclusions to section 1 where the Insurers will not indemnify the Insured in respect of:

A. Additional expenses related to dewatering costs. In general these endorsements provide exclusions to section 1 where the Insurers will not indemnify the Insured in respect of:
   i. Additional dewatering expenses
   ii. Expenses incurred for additional installations and facilities for the discharge of run-off and/or underground water.

iii. Loss or damage due to a failure of the dewatering system
iv. Expenses incurred for the repair of cracks and to remedy leakage of water into excavations and basements.

Related / similar endorsements are:

i. Swiss Re EPI 46 - Ground water pumping

B. Additional expenses related to the exposures and damages related to natural perils. In general these endorsements provide exclusions to section 1 where the Insurers will not indemnify the Insured in respect of:

v. Flooding and inundation of the excavated area
vi. Removal of debris
vii. landslides

Related / similar endorsements are:

i. Swiss Re EPI 31 - Exclusion of flood damage
ii. Munich Re Endorsement 010 / 1231 – flood and inundation
iii. Munich Re Endorsement 1231 – flood and inundation
iv. Swiss Re EPI 41 - Debris, silt , erosion , landslip
v. Munich Re Endorsement 111 – removal of debris from landslides
vi. Munich Re Endorsement 1235 – removal of debris

4.3 GROUP C ENDORSEMENTS which are related to third party exposures:

In general theses endorsements provide exclusions to section 2 where the Insurers will not indemnify in respect of liability for loss or damage to any property or land or building:

i. Property or land or building only, if prior to the commencement of construction its condition is sound and the necessary loss prevention measures have been taken,
ii. Expense for preparation of a report on the condition of any endangered property or land or building.
iii. Loss or damage which is foreseeable having regard to the nature of the construction work or the manner of its execution,
iv. Superficial damage which neither impairs the stability of the property, land or buildings nor endangers their users,
v. Costs of loss prevention or minimization measures which become necessary during the period of insurance.

Related / similar endorsements are:

i. Swiss Re EPI 07 - Vibration, removal or weakening of support
ii. Munich Re Endorsement 120 - Vibration, removal or weakening of support
iii. Munich Re Endorsement 1231 – Liability consequent upon Vibration, removal or weakening of support

5. LOSS EXAMPLES

5.1 CONSTRUCTION OF UNDERGROUND TRAIN STATIONS CAUSING SETTLEMENTS

During the excavation for an underground station box, water and sand ingressed through the misaligned secant piled wall into the box causing settlement of terrain, cracks and tilting in/of neighbouring surroundings affecting damages to a crane base (for the construction works) and third party buildings.

Inside box –
Clay fill to stop ingress of fine sand, silt and groundwater between two piles into the box.
-
Advanta Global Services

Settlement of surrounding outside the box – not severe but alarming - Advanta Global Services

Repair works:

1. additional piling of station box and micro piling of most affected areas to stablise the crane foundation
2. low pressure jet grouting, high pressure jet grouting to mitigate the loss of sub-surface material and piling to the crane base.
3. additional ground improvement with Tube-a-Manchette (TAM) grouting in order to reinstate the pre-loss settlement readings.

5.2 COLLAPSE OF DIAPHRAGM WALL OF SUBWAY TUNNEL

Collapsed lateral support system of the cut and cover tunnel - http://failures.wikispaces.com/Nicoll+Highway+-+Subway+Tunnel+Collapse

Situation:
Open trench construction runs through 2 reclamation zones. (50/20 years old). Top soil with fill material (low compression)
below zone with soft clay, silts and sands to a depth of 40 meters. Groundwater table about 2 meters below surface. - https://www.yumpu.com/en/document/view/15629804/the-nicoll-highway-collapse/5

Diaphragm walls divided in 40 wall sections. Each section construction based on worst soil parameters. The temporary retaining system of diaphragm walls and struts was designed with geotechnical simulation software using finite elements. Continuous monitoring with inclinometers, settlement markers, piezometers etc.

What led to the failure of the construction?
The collapse did not develop suddenly – during the excavation process several diaphragm walls started showing cracks and ground settlements occurred.
The waler-strut connection was completely under designed.

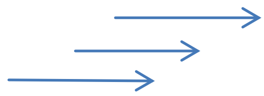
Conclusion:
The excavation was under-designed. The geotechnical circumstances (soft soil filled with water) had been misinterpreted. The mathematical method to prove the stiffness of the soil was not adequate for excavations in that soil with that depth. Tracking the break even points to receive a working mathematical evidence led to an overestimation of the construction method.

5.3 FALLEN OVER "BUILDING NO. 7"

http://www.telegraph.co.uk/news/worldnews/asia/china/5664043/Shanghai-building-collapse.html

The collapse of a nearly finished 10 story high-rise building was caused by earth excavated to make a 4.6-metre deep pit for an underground car park alongside the building, being piled to depths of up to 10 metres on the other side of the structure. The weight of the pile created a pressure differential which led to a shift in the soil structure, eventually weakening the foundations and causing them to fail.

This situation has been aggravated by several days of heavy rain leading up to the collapse, but investigators would not say whether this was a crucial factor. The construction company did not consider clearly that the earth pile could have such a devastating effect.



http://www.hoax-slayer.com/13-story-buliding-collapse-china.shtml

1. An underground garage was being dug on the south side, to a depth of 4.6 meters.
2. The excavated dirt was being piled up on the north side, to a height of 10 meters.
2. The building experienced uneven lateral pressure from south and north.
4. This resulted in a lateral pressure of 3,000 tonnes, which was greater than what the piles could tolerate. Thus the building toppled over in the southerly direction.

5.4 Excavation Support fails (most recent case Oct. 2016 in Turkey)

the side wall secured by anchors collapsed probably due to insufficient length or faulty workmanship considering the soft conditions of the soil behind the wall.

See more of the case by use of this link which may be available for limited time only:

https://www.reddit.com/r/civilengineering/comments/551wib/retaining_wall_collapse_caught_on_camera_in_turkey/

6. SUMMARY

6.1 UNDERWRITER'S GUIDANCE (Works, TPL & Existing Property)

- Ensure competent designers & contractors – they need to have relevant experience & specialisms. Check the internet for a list of projects they have undertaken. Size of companies is important to ensure they have adequate resources.
- Soils report with recommendations about the foundations – must ensure that a soil-report has been produced by a competent company, that it is sufficiently detailed with an adequate number of boreholes taken to the necessary depths. Should highlight similar projects undertaken in the neighborhood to compare equivalent ground conditions.
- Construction method – Need to determine the type of wall & floor construction and the sequence of installation, such as a top down or bottom-up construction method. Is the construction method reasonable for the depth & size of the excavation?
- Monitoring of movements (works & TPL) – Layout of monitoring points required to ensure the movements are adequately assessed, and that there are adequate personnel to take the readings at the required frequency. Request a plan of what emergency measures the contractor would take in the event of significant movements. Who is measuring the movements? Are they separate from the contractor?
- Level of supervision – who is performing the supervision? Is there a separate consultant engaged by the Employer to undertake this role?
- Ground water treatment, drainage, flooding, water table – Is the excavation situated in an area prone to flooding? The pumping capacity and controls, the water management regime and the adequacy of the installed drainage. Seasonal deviations may occur in the water levels related to the program of basement construction.
- Sensitivity & proximity of third party assets – these include utilities, buildings with a required knowledge of their construction. Any dilapidation reports produced?

6.2 RISK MANAGEMENT RECOMMENDATIONS

1) When as part of the construction works, deep excavation will be carried out, third party damage should be considered as a possible exposure not to be underestimated.
2) It is often not a question of IF but rather of HOW MUCH settlement and displacement, groundwater level changes, vibrations will be created on site.
3) Often the preconstruction survey, monitoring and protection measures are not well budgeted. The responsibility for the surrounding structures is often unclear or not well communicated between the project's parties: designers, special consultants, contractors and subcontractors, so that at the end of the process they will look to the insurance company to settle the damages.
4) Numerical and analytical methods and available computing programs allow engineers to quite accurately predict the influences on the surrounding areas.
5) As a thumb rule, underwriters should consider the ratio between the excavated depth to the surround property, a ratio of 1D:1H (the Distance of the surrounding property to

excavated Height) requires the underwriters' attention, ratio of 2-3D:1H is less exposed and over that can be regarded to be in a safe zone.

6) Require preconstruction surveys and documentation of the surrounding properties, including dates and measurements. This will reduce litigation since once damage is alleged, it seldom goes smoothly.
7) Monitoring will provide early warning, reveal unknowns, and minimize damages to surrounding structures. Require a well-defined monitoring plan, including threshold limits, that includes monitoring of settlement and displacement, groundwater levels, vibrations and site observations visits.
8) There are many types of measuring equipment, which include, among others, laser measurements, sliding micrometers, extensometers, liquid levelling sensors, electrical and vibrating wire crack meters, strain gauges, tilt meters, velocity, acceleration and displacement transducers, seismographs, piezometers to measure vibrations and many others.

6.3 CONCLUSIONS

Excavation construction is a form of temporary works whereby the contractor may take risks not normally associated with the construction of the permanent works. The construction may not receive the same level of scrutiny by the professional team as might otherwise be the case for permanent works. The exposure arising out of these works is very often underestimated.

The Underwriter therefore has to be especially cognisant of these risks and the problems that might arise.

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