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Research Article

Interactions in Subterranean and Surface Structures

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Abstract

Underground spaces have been in use throughout human history and their usage is accelerating due to convenient transportation and living space excavations. Subterranean tunnels in urban areas have provided so much efficiency that crowded city governing bodies are gradually pushed to handle metro and other underground facilities in traffic jammed cities. Caves, historic tunnels and underground cities are not new phenomena and they have been in human usage since the early times. However, designing and excavation of subterranean spaces including metro tunnels currently have come together with unexpected dilemmas related with land ownerships and structures' stabilities in/on the earth crust. In addition to the context of foundation stabilities of surface structures which have been main concerns in rock/soil mechanics, extra concerns have recently been added including paradoxes in land/space ownership rights (legislative right/responsibility/taxation issues) and induced stress & displacement complexity which could only be handled by proper engineering designs/plans for urbanisation. Improper settlements could be rehabilitated and redesigned without large scale destruction of rock/soil masses in urban areas according to revised city plans. However, this is not the case for underground spaces. Thus excavated subterranean spaces influence the stress & displacement and groundwater distribution surrounding themselves. Therefore, they must be designed according to mandatory city development plans. Additionally, underground spaces affect surface structures and vice-versa. These subjects are supplied here to present the importance of the context which should be handled together with adequate engineers, in groups of mining, civil, geology, geophysics, environment, surveying, and other related engineers.

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Yeraltı ve yüzey yapılarında karşılıklı etkileşimler

Özet

Yeraltı boşlukları insanlık tarihi boyunca kullanılmış olup, yeraltından yapılan ulaşımın kolay olması ve yeraltına kazılan ek yaşam-alanları nedeniyle kullanımı giderek artmaktadır. Kentlerdeki metro sisteminin sağladığı faydalar, yöneticileri kalabalık şehirlerde trafik sıkışıklığının olduğu semtler için giderek artan oranda metro ve diğer yeraltı tesislerini planlamaya zorlamaktadır. Mağaralar, tüneller ve yeraltı şehirleri daha önceden bilinmeyen konu başlıkları değildir, çok eski zamanlardan beri insanlar bunlarla beraber yaşamaktadır. Ancak, metro tünelleri dahil olmak üzere, artan oranda, yeni yeraltı boşluklarının tasarımı ve kazısı, yerkabuğu içindeki/üzerindeki mülkiyet haklarını/sorumluluklarını da beraberinde getirmiştir. Bununla birlikte ilgili yeryüzü ve yeraltı yapılarının karşılıklı duyarlılık durumlarıyla ilgili tanımlanmayan şartlar (karışıklıklar/açmazlar) da vardır. Bu konuyla ilgili olarak, kaya/zemin mekaniğinin önemli konularından olan, yüzey yapılarının temel/zemin duyarlılığı bağlamına ek olarak, mülkiyet tanımındaki "yüzey-arazi" & "yeraltı-hacim" hak tanımlamalarındaki *(kanuni haklar/sorumluluklar/vergi mükellefiyetleri)* kargaşaya (paradokslara) da dikkat çekmek gerekir. Uzman mühendislerin tasarımlarına/planlarına uygun olan yeryüzü/yeraltı yapılarından dolayı gelişen ikincil gerilmelerin-deformasyonların karmaşıklığı da ekstra endişelere neden olmaktadır. Kentsel alanlarda, kaya/toprak kütleleri tahrip edilmeden yapılmış, eksik uygulamalı yerleşimler, şehir planlarının revizesiyle tekrarlanabilir. Ancak, yeraltı açıklıkları için durum böylesine kolay değildir. Yeraltı boşlukları kendilerini çevreleyen kayaçlar içindeki gerilme & deformasyon ve yeraltı su dağılımını etkilerler. Bu nedenle, yeraltı yerleşimleri şehir planlarına göre uygulanmalıdır. Yeraltı boşluklarının, yüzey yapıları üzerindeki etkileri ve tersi durumlar, maden, inşaat, jeoloji, jeofizik, çevre, harita ve benzeri alanlarda uzmanlaşmış mühendislerce oluşturulan çalışma gruplarında, birlikte ele alınması gereken bir konudur. Konunun önemi ve içerdiği paradoks bu çalışma kapsamında araştırılarak vurgulanmıştır.

Anahtar Kelimeler
Yeraltı boşlukları
Yeryüzündeki yer değişim
Zemin yer değişimi
Tünel & bina etkileşimi

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1. INTRODUCTION

Requirements of human societies have been gradually expanding as the urban settlement areas and their populations are increasing. According to Broere [1] half of the world population lives in cities. After United Nation data [2], he stated that city populations will reach around 10 billion in the next 40 years. Humans' societies are directly dependent on what the earth crust has supplied to them. Direct or indirect natural resources of earth should strictly be observed to keep their controls on their sustainability. In this content, the usage of minerals, water and energy resources have already been researched & analysed for years. But subterranean space positions have recently been considered as valuable resources as well. Broere wrote that, "*underground development is an important tool in developing and reshaping urban areas to meet the challenges of the future*". Subterranean supply systems in urban areas for; domestic & irrigation water, natural gasses through pipelines and urban collecting systems for rain water and waste water (sewer) have been positioned below the urban roads. Recently electric power supply lines in urban areas have also been put into subterranean canals to secure them from extreme weather influences. However, urban people have realised the importance of subterranean spaces after the increase in subway (metro) lines and their subterranean stations. Some of the stations have even been organised as pedestrian passages through heavy traffic areas. Subterranean car parks & shopping centres are starting to be common features in crowded cities. These spaces also have advantages for cities which have extreme climate conditions (high/low temperature locations etc.). Governing bodies in cities have also realised the efficiency and opportunities of underground spaces, especially for metro line concerns. Fast public transportation through metro systems has provided traffic jams decline in some locations of cities. They connected the urban locations through subterranean tunnels which could not pass through by the surface roads due to natural and historical heritages. Similarly, Broere stated that *"Placement of infrastructure and other facilities underground presents an opportunity for realizing new functions in urban areas without destroying heritages or negatively impacting the surface environment*". Meng etal. [3] also pointed, metro systems' fast and convenient characters have impulses on new subway constructions for "*the stage of rapid development in recent years*". Moreover, increasing the number of subterranean passages and tunnels for roads & rail lines furthermore brings convenient opportunities for city planners.

Beside subway activities in different cities, there are also new underground space excavations, subterranean renovations & rental projects, rehabilitations of abandoned mines, caves and historic underground cities for the purposes of urban activities, (living spaces, museums, depots etc.). They have gradually brought new understanding to subterranean spaces together with their stability concerns in rock/soil mechanics, [4]. Living spaces defined here can be volumetric spaces in subterranean structures, constructions. After human societies organised as nations their governmental bodies have gradually introduced taxations and responsibility procedures for land and property ownerships. Settlements in two dimensional, 2D, urban plans have currently included mainly surface structures as; roads, bridges, dams, parks, buildings, high-rise constructions, houses, industrial & agricultural sites etc., on earth surface. Some of the buildings and houses have also basements and they could be planned as sublevel parts of the surface structures. Beside the convenient use of basements, there are also caves, historical tunnels, underground cities in urban areas of some cities and they are included in available 2D city plans with special codes for their protections. The practices of other types of underground spaces in urban areas are recently expanding and need legislative regulations. As the lengths of metro lines are increased yearly bases in the world, more subterranean spaces are supplied to public usages, (as; shopping centres, depots, shelters, social-sportive-cultural activity centres, hotels, living spaces etc.), their locations in the rock masses should be officially recorded. Today, due to lack of legislative definitions, some of the historical subterranean spaces, caves, tunnels, sinkholes have no ownership records. They are usually mapped for positioning or (related) project purposes. Layouts & dimensions of all natural subterranean features for instance are not legally validated yet. New excavations for subterranean spaces and the ones already existing (underground spaces as; caves, historic tunnels & passages, historic underground cities, abandoned stable mine openings etc.) in urban areas should evidently be recorded and their features ought to be handled through city-plans. Their locations, positions, dimensions, stabilities and safety features originated due to their usages have included potentials for further paradoxes & disputes, if the ownership rights & liabilities have not been defined properly through legislative rules. Vertical extensions of surface land ownerships have already been in discussions for engineered structures [5, 6] besides underground mineral, energy, and groundwater related regulations. Comprehending economic potentials of the subterranean spaces in time [7, 8], subterranean spaces already existed have been engineered to rehabilitate while the new ones are steadily required to be projected. Legislative land registry systems are mostly in 2D parcel configurations. Individual units in surface structures (houses, apartments, high-rise buildings, etc.) constructed on these parcels could also be registered with "apart-property ownership" rights which have the same land parcel registry (reference/base serial number(s)). In order to define ownership rights in 3D, surface land ownership rights and related vertical (above-*sky* / below-*subterranean*) extension limits should sensibly be handled according to national legislative acts/codes differences. Definitions of subterranean urban spaces in 3D have already been legitimate in Malaysia by introducing the "stratum" term in 1990. According to the Federal Department of Lands and Mines (JKPTG) in Malaysia, stratum is "*the underground land which has been identified for the purpose of disposal as an independent use and not related with the above usage*", [9].

Likewise, increasing subterranean space volumes possibly led the Republic of Singapore to issue a legislative Act in 2015 to systemise subterranean spaces. This Act pointed that; "*if no such depth is specified, subterranean space to -30.000 metres from the Singapore Height Datum.",* [10]. Introducing 3D land ownerships including dispersed surface and subterranean parcels require not only 3D digital modelling but also adequate level of information related to rock/soil masses at the focused local areas. These cover regional data related to; geology, geophysics, earthquake statistics, rock/soil masses & their mechanical behaviours, in-situ stress field, etc. To gather data linked to subterranean rock/soil masses, diverse data-sets have been collected (through the field & laboratory observations and tests) for new subterranean excavation projects. These records and earlier data collected for different surface/underground projects on the other hand will also be valuable assets for further urban activities including subways, tunnels, subterranean spaces etc. Therefore, these data have gradually been enquired by countries for their national data-banks (i.e.; UK has *"Assessing Subsurface Knowledge*", ASK, network procedures in this context, [11]). Beside these data gathering efforts, it is also obvious that government bodies in urban areas have spent their time to organise underground space ownership procedures according to available 2D land ownership registry systems, (if there is no specific legislative act/code for subterranean spaces). Countries which have land legislation systems based on historic "Latin Maxim" rules [12], have previously provided certain limitations (restrictions) over the ownership rights described there. Actual "Latin Maxim" rule stated that "whoever owns lands, owns the underground and sky (below/above) of the lands". In reality, restrictions on this rule were already defined for "below the registered lands" to exclude rights of *mineral, energy, groundwater resources* from surface land ownership rights. There are also available right restrictions for "above (sky) the registered lands" to coordinate man-made flying objects (balloons, planes etc.), [13].

The land/property ownership right procedures defined by legislations in countries have their influences on the future paradoxes among the owners of the engineered structures in/on the earth crust. Land ownership registration for surface and underground spaces are legislative procedures which countries can select (decide) to follow. This part of the land registry concept is related to countries' citizenship rights. However, supplying restrictions for land ownership rights for below/above the registered lands as strata/layers for diverse economical assets has already provided layered procedures into the concept. Therefore, layered, (Fig.1), 3D land/property ownership procedures might have been defined in future *(Malaysia were already issued an Act to define subterranean "stratum", [9])* to eliminate paradoxes & dilemmas introduced through subterranean spaces below the registered surface land parcels.

However, there is another side of land ownership concept which is related directly to induced stress & displacement formed due to the usage of surface and/or underground land parcels. Surface and underground structures are also the reasons of induced stresses & deformation besides other natural causes, actors. These influences might cause unrequired damages in the focused private land parcels (and its neighbouring parcels in/on earth crust). At this point type of land registration procedures (2D/3D) play an important role. Owners of surface land parcels could influence neighbouring parcels through their activities in/on earth masses. They might disturb neighbouring surface structure foundations' stabilities while excavating foundations at their surface land parcels.

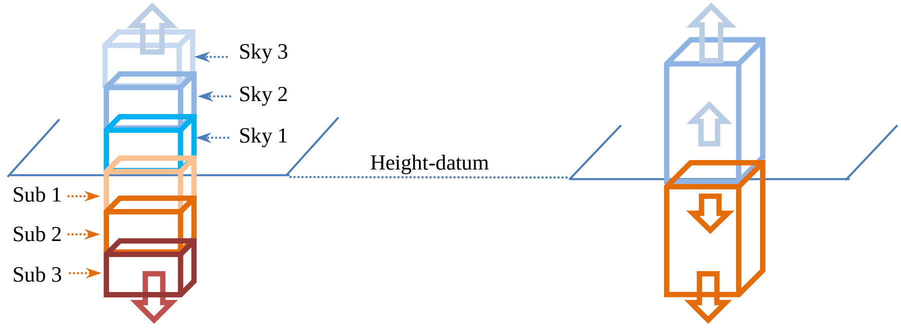


Figure 1. a) Layers which could be defined below/above the height-datum level, (Layers' registry in 3D procedures should be followed after clear descriptions of layers' rights and liabilities through legislative Acts/Codes). b) Land ownership phenomena in "Latin Maxim", "the ad coelom" doctrine.

There can also be induced vibration influences on surface and subterranean spaces due to engineered activities in/on earth crust. Mining and industrial activities might have machineries which originate these ground vibrations. Rock mass blasting, for instance, may introduce a high level of ground vibration if it is not handled in engineering manners. Engineered structures in/on earth crust can also be influenced by weight of neighbouring structures. Due to additional weight put on structures' (high-rise buildings, dams, bridges, etc.) foundations might cause induced stress & displacement on nearside parcels. Mining and urban metro constructions have supplied their turmoil to modern urban life. However, positive contributions of these activities cannot be oversighted. New development in urban life and increase in underground spaces usages have forced engineers to evaluate rock/soil mechanics context for more sustainable ways to access natural resources including underground space opportunities.

2. EFFECTS OF TUNNELS ON SURFACE STRUCTURES

Gravity is the main struggle at excavated space stabilities in/on rock/soil masses. Mining engineering experiences have presented that excavations cause redistributions of overburden loads/stresses. This fact causes strain eventually displacements at rock/soil masses. Landslides, slope failures, roof span failures, gallery-tunnel collapses etc. might be the final stage of these micro scale movements originated due to earth gravity *(lunar gravity may be in these influences as well).* Earth gravity influences all materials, so rock masses in/on earth crust are forced downward direction into the centre of the earth. When a space is opened in rock/soil masses, primary stress fields handled in geological eras are disturbed and new equilibrium cases (secondary stress fields) have started to be developed. Stresses (vertical and horizontal) originated due to overburden and tectonic pushes/loads cannot pass through open spaces, they re-distribute around these surface/subterranean spaces. Any increase in tectonic forces or overburden loads cause supplementary strains in the surrounding rock/soil masses of the spaces. This fact, in some way, is similar to the stress-strain distributions around a circular hole of machine parts. For uniform material characteristics, stress-strain re-distribution cases were analysed by Kirsch [14] for a circular hole. Rock/soil masses can be uniform (massive) in structures but they are usually heterogeneous in characters. Excavating a space forms a 3D influence zone around them and secondary stress fields & directions are started to be formed. Their impact on surrounding rocks/soils may create displacements which cannot be required in engineering designs. Design expectation could be different for diverse circumstances, therefore, in rock engineering projects, there are always specific data collection activities and stress & displacement analyses and eventually failure evaluation steps for good design practices. Therefore, excavation performed in/on earth crust for surface foundations or subterranean spaces cause changes in primary stress & displacement fields in 3D. Ground movements, (settlements / subsidence) observed on ground surface due to any excavations in/on earth crust or displacements of tunnels due to other underground spaces can then be evaluated through that induced stress conditions. These factors have long been research subjects in rock and soil engineering. For example, Rampello etal. [15] stated that some metro tunnels in Rome, Italy, "*Contract T2 of the new line C* " run under the historical centre of the city. The centre has historical masonry buildings which reportedly built between the 15th and 19th centuries. The authors wrote that "*a reliable evaluation of potential damage induced by tunnel excavation to the* *existing buildings was then essential*". Therefore, design efforts of the tunnels had then been realised accordingly. Similarly, Wang, [16], noted that even shield tunnelling methods (which *"has less influence on ground disturbance than other tunnel construction methods")* influence surrounding rock masses. If excavation of tunnels is inevitable, expected displacements around tunnels are the main engineering concern. Wang wrote also that; "*necessary, relevant treatment measures should be supplemented to control the influence of disturbance on stratum and adjacent buildings within a safe range".* In this content, the works performed by Shahin etal. [17] provided results that show the importance of the interactions of influences between tunnelling and existing structures need to be emphasized. They wrote that numerical simulations may provide predictions of ground movements and related stress conditions around tunnel lining, "*if the mechanical properties of the ground material and the interaction of soil and structure is treated properly*". Zheng, etal. [18] stated also that works performed for new tunnel construction passing near the existing structures cause deformations. They analysed deformation characteristics of existing subterranean upper structures due to the new tunnelling efforts below them to provide safe design options. There are studies to predict ground surface subsidence based on empirical approaches, and their selection was also studied by Peck, [19]. This study was a 3D numerical simulation and performed at Qingdao, China, for; "*the double-line tunnels of Qingdao Metro Line-4 passing under the Cuobuling station*". They evaluated displacements around the new tunnels in two model cases (with or without upper subterranean stations) by simulating tunnel excavation cycle as well. In the first step, displacements due to the first tunnel were analysed (Fig. 2a), then a second tunnel of this twin-tunnel model was added to the simulation and displacements were re-evaluated again (Fig. 2b). According to their simulation (without a subterranean station case), after the excavation of the first tunnel, the maximum displacement occurred at the top of the vault. They wrote that, *"the vault of the tunnel settled obviously, the settlement reached 2.24 mm, and the bottom of the arch was uplifted, and the uplift amount reached 1.10 mm".* The results presented in Fig. 2 show that deformation at ground surface is inevitable, therefore the amount of displacements and their effects on surface structures are analysed according to city plans and land ownership rights. The shapes and dimensions of the surface structures are also important when the influences of subsidence are considered due to tunnels and mining activities. Subsidence prevention precautions defined in mining engineering contexts & experiences *(which cover distinct chapters in mining related books)* could be introduced here (tunnel driving sequences) to control the ground surface deformations (subsidence) and its unsafe disturbances.

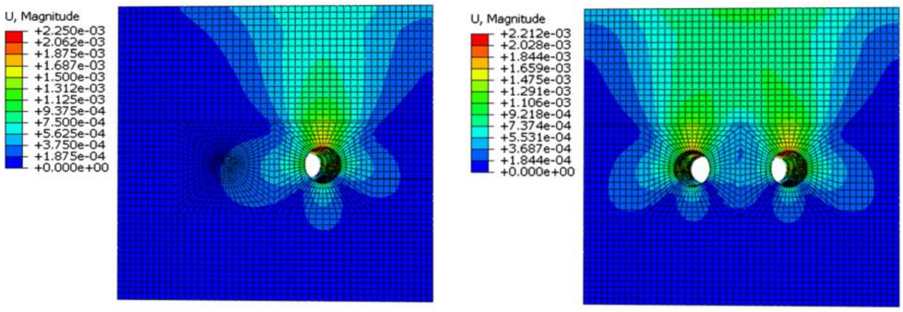
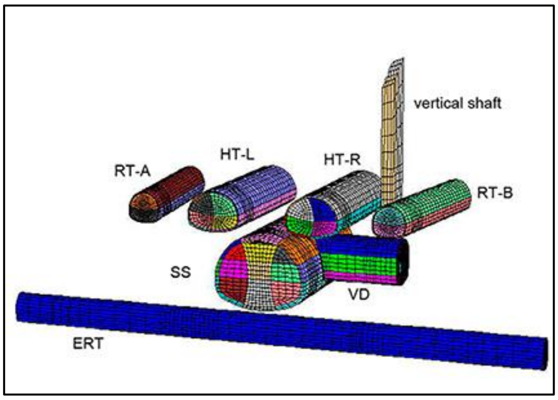


Figure 2. Model simulation; a) Displacement (m) distribution around single-line tunnel model, Zheng, etal., [18], b) Displacement (m) distribution around double-line tunnel models [18].

Franzius, etal. [20] stated that during performances of 2D plane-strain finite element analyses for shallow tunnels, stress & displacement evaluation could also be performed by considering the weight of surface structures as well. Because they thought that the weight of buildings influenced the stress & displacement distributions surrounding the shallow tunnels. They showed that *"how the application of building load changes the stress regime in the ground and how this stress change alters tunnelling induced ground and building deformation"*. Tunnels are essential parts of intercity roads and rail networks if the surface morphology is irregular like in mountainous regions. Likewise, there are several twin-tunnels in mountainous regions of Turkey which were excavated mainly in the last 3 decades. One of them is called Cukurcayir-II twin-tunnel in Trabzon, and passes through (below) residential areas as well. This tunnel project has two tunnels, *(excavation width/height: 16.5m/13.5m, overburden thickness; 25m)*. Aygar & Gokceoglu [21] supplied details and displacement distribution surrounding these tunnels through numerical analyses. The sequential analyses reported for these tunnels revealed that displacements due to the first tunnel excavation could be 13cm around the tunnel and this value was estimated at 9.96cm (maximum) at the earth's surface over the tunnels. After the first tunnel, the second tunnel was excavated and the reported numerical analysis displacement results were 13.6cm at the second tunnel roof and 11cm at the earth's surface. These results clearly demonstrated also that tunnel driving influences the surrounding rock masses' stress & displacement conditions.

If there are one or more underground spaces/tunnels around the projected subterranean space, engineers should also think about their interactions. The distance among the subterranean spaces and ground surface are main design concerns to decrease displacements tempted by individual subterranean spaces. Their induced effective stress & displacement fields should be kept away from each other, (overlapping cases should be eliminated, which cause extra deformation at ground surface and spaces' surrounding rock masses). Multiple underground spaces and their interactions were analysed by Gao, etal. [22] too. They described the stability of a large transportation tunnel-complex under populated urban areas. This construction complex has 7 shallow tunnels (with large cross-section areas, Fig. 3a) at Hongyan village, Chongqing, China. First, they analysed the stability of these tunnels and their surroundings rocks through FLAC3D numerical analyses software. The researcher said that, *"results showed that the tunnels were subjected to heave and crown settlement induced by adjacent excavations*". Their results also showed deviatoric stress distributions around the tunnels (Fig. 3b). Studies including numerical analyses and field measurements have obviously presented that subterranean tunnels influence the ground surface as well as the neighbouring engineered structures. If the influences focused on certain surface locations which underlined historic buildings (mostly masonry structures) and natural heritages, the ground deformations should be defined undoubtedly to evaluate their disturbing impacts. Likewise, influences of tunnelling on a surface masonry structure, (Hoca Pasha Mosque, built in 1868), were analysed by Dalgic, [23], in Istanbul, Turkey. Sirkeci (Istanbul) Metro Station's and related shaft's influences on this building were evaluated for further engineering decisions. In addition to these cases, there is another factor which engineers should consider for settlements of surface structures due to the neighbouring excavations in/on earth crust. That is the interactions between "ground surface settlements" and "displacements occurred at the surface structures' foundations". It is evident that downward displacement occurred at a ground surface area ("dx" mm for example) due to underground spaces not directly considered as descending displacements of the foundations located above them. Stiffness values of foundations are one of the governing factors here to control movements of surface structure foundations [20, 24, 25]. For instance; Uzay [26] analysed one building at Esenler, (Istanbul, Turkey), which had cracks due to underground metro tunnel excavation. He evaluated ground surface displacements and the building's cracks by including particular structure's properties. The cases presented earlier lines (above) cover single, double, three or more tunnels' excavations at particular locations. Surveyed studies reported about the changes occurring in stress & displacement around the tunnels. The authors also wrote the ground surface downward displacements, which should be evaluated for structures in/on earth crust to secure mechanically stable living environments.



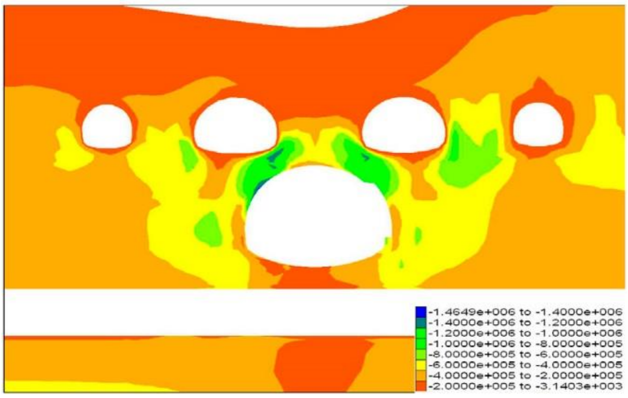


Figure 3. a) Shallow tunnels' positions at Hongyan village, Chongqing, China, [22], b) Deviatoric stress distribution surrounding these tunnels, (- values: comp. stress, + values: tensile stress), [22].

3. EFFECTS OF SURFACE STRUCTURES ON TUNNELS

Surface structures have their weights depending on their volumes and material contents. When there is a plan of a high rise building, (skyscrapers), its weight with their long subterranean piles at their foundation have to be considered also by the owners of neighbouring land parcels. Foundation engineering contents have descriptions how surface structures' weights are supported by different design of foundation models on soil/rock masses. Soil/rock masses' mechanical properties and their internal defects like discontinuities are also certain influences on their load resistance (support) capacity (load bearing capacity). Surface structures' weight influences on subterranean spaces (tunnels) are analysed by several studies to estimate risks related. In this content, the study given by Guo, etal. [27] can be presented here. They firstly mentioned the demands for surface structures which are growing in urban cities with population increase. That means, some surface constructions somehow have to steadily be planned above the underground spaces, (tunnels, depots, car parks etc.). These researchers analysed the impact of surface structures on metro lines at (Liangmaqiao Road, Chaoyang District), Beijing city, China, in their study. They performed numerical analysis models to estimate the resultant influences of surface structures on tunnels in 4 main design options. These options include primarily the features of surface structures, *(like; a) "unloading stage": construction of surface structure has a foundation excavation (shallow or deep) stage, and "loading stage": surface structure building stage (low or high rise building), b) These unloading & loading stages of surface structures can be at different levels of influences according to the amount of mass removed from earth crust for foundation and amount of mass built to construct the structures. Unloading and then loading stages are almost compulsory for each surface structure at a construction site. c) New surface structure positions can be planned according to the locations of underground tunnels if there are some opportunities, d) these surface and underground structures can be in the same vertical axis, or they can be in different vertical axis together with different depth & horizontal differences).* Guo, etal. [27] wrote that the result they obtained had evidences of impact on tunnels by adjacent surface construction processes.

Similar study had been performed by Mirhabibi & Soroush, [28] to understand surface structure and underground tunnel interactions in urban areas. These interactions are vital considerations for local people who have land & property ownerships above the planned or already excavated tunnels. These authors wrote that, *"interactions between buildings and tunnels can have major effects on the settlement trough. Therefore, the factors involved in this interaction need to be assessed prior to construction*". They collected data related to the Shiraz Metro Line, Iran, to analyse different positional differences between double-line metro tunnels and surface structures. The analyses were 2D numerical simulation and they noted that the influences of different design factors (such as; tunnels' depth, distance between tunnels' centre, surface structures': stiffness, weight, width and location) were considered during their analyses. Their results illustrated that; "*stiffness of surface buildings has a great effect on ground settlement, and it must be considered in simulations for realistic predictions of tunnelling induced ground deformations"*. According to their results; surface structure width *"is a major geometrical parameter which controls the overall tunnelling-building interaction behaviour*". They also warned about the weight and bending stiffness of the surface structures. These factors also have important possessions on the tunnelling–building interaction behaviour. They wrote that, "*the increase of tunnel depth, centre to centre distance of tunnels and surface distance of buildings from the centre line of twin tunnels decrease the effect of buildings on settlement curve*". Another significant numerical analysis research in this issue was performed by Meng, etal. [3] and they obtained influences of foundation excavation on underground tunnels in Quingdao, China. Their results showed that the existing tunnel could move towards the foundation excavation of the new building. Horizontal displacement (0.47mm) was estimated greater here and this movement towards the side of the foundation pit (Fig. 4a). The researchers also pointed out the effects of wind-loading on high-rise buildings which influence the induced stress & displacement distributions around the existing tunnel below the surface buildings. Their statement was as follows; *"the results show that the tunnel is obviously affected by the building wind load by different wind directions*".

Induced displacements in/on earth crust originated by surface structures have gradually become important for urban areas while the weights of the structures are increased due to high rise buildings.

Therefore, surface and subterranean structures are constructed according to city plans. Thus it is also vital to have official records for surface and subterranean spaces (including ownership & liability rights) to continue any new excavations & structures in/on earth crust.

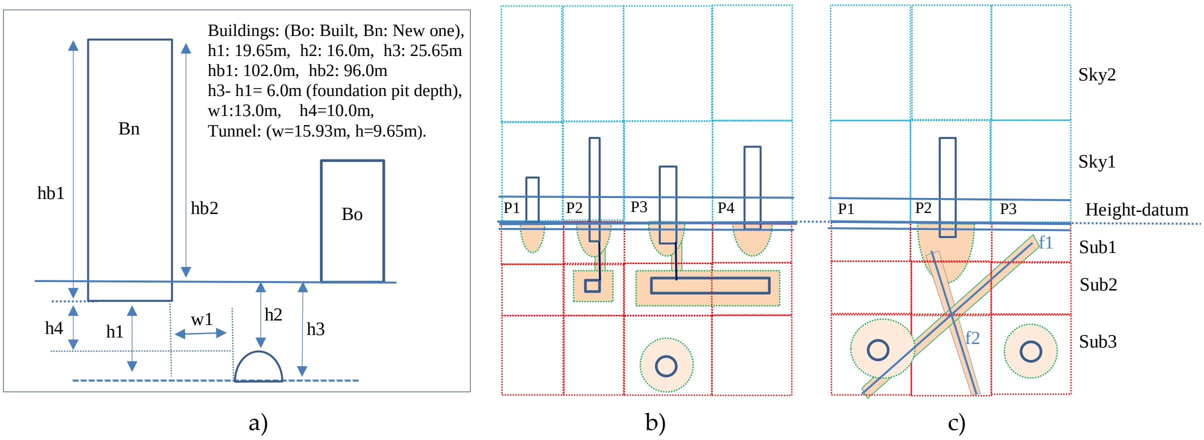


Figure 4. a) Positions between planned surface building (Bn) and the existing tunnel in Quingdao, China, (after, Meng etal. [3]), b) Layered land parcels *(below/above the surface lands*) with engineered structures. c) Layered land parcels *(below/above the surface lands)* including natural faults and man-made structures together.

4. DISCUSSIONS ON SURFACE & SUBTERRANEAN STRUCTURES

Surface land ownerships defined by unrestricted "Latin Maxim" rule covers "the rights" below and above the surface land parcel. In this land concept, defining any surface and underground spaces can be rapid, (reasonable through surface land's boundaries), and covers less complexity. This rule theoretically embraces the rights of surface land parcels and additionally covers the rights below (underground) and above (sky) parts as well. For example, if one has land ownership rights of P2 parcel in Fig. 4b, on the basis of the Latin Maxim rule (unrestricted), that owner has full rights on all the layers below and above. Thus, supposedly there are no defined layers in the original Latin Maxim land ownership concept. However, layered concept which have predominantly been defined for different economic aspects *[groundwater-(agriculture-environment-domestic sectors); minerals-(mining sector), energy resources-(coals, oils, natural gasses, geothermal waters, deep hot-rock masses related mining & petroleum sector); sky layers in different height limits-(for domestic houses, apartments, high-rise buildings); high attitude sky layers-(for balloons, aviation flights)]* in time periods. These layers have introduced restrictions applied to the original Latin Maxim land ownership concept. Due to recent economic considerations in the world, subterranean spaces have also been started to be designed gradually for different underground projects. The "stratum" definition, [9], by Malaysia can be considered in this context. It is vital here to point out the following facts related to hypothetical layered land ownership phenomena, (which certain modifications have already been in applications as the defined restrictions on the original Latin Maxim rule. Layered conception in 3D land ownership procedure might be accepted by different government bodies in time (if there will be reached consensus among shareholders of land ownership and the States). The following hypothetical case examples are supplied here to present the paradoxes which will appear eventually for the cases of assumed layered land ownership concept. As it is presented in Figure 4b, in this phenomenon, there are layers below/above ground surface height datum, *(their validity and vertical extensions, thicknesses, need to be discussed in the national decision consuls, parliaments, in detail).* Thus, these layers' ownership rights could possibly be held by different owners. For example, ownerships of surface land parcels *P1* and its adjacent *"P1-adjucent Sub1 & Sky1"* layered parcels could be held by a particular owner. This holder has 3 ownership certificates in this example, one for *P1* (*land surface usage rights with limited sky height and limited basement depth*), one for *"P1-adjucent Sub1"* parcel and one for "*P1-adjecent Skyl"* parcel. This holder does not have rights to construct high rise surface structure with these 3 certificates, (*there is no rights here to extend the building height into "P1-adjecent Sky2" parcel layer)*. The limits of layers and their rights then should be clearly defined (including restrictions) in legislative acts, if the countries agree to continue with this layered land ownership procedure. There are also paradoxes when considering land ownership rights if the actual rights *(based on the original Latin Maxim rule)* on surface land parcels are diminishing by introducing layered land concepts. These facts need to be conferred at the

Parliaments of countries.

In order to demonstrate problematic cases in layered ownership concept, following examples can be given. Consideration of two land owners who have different land ownership certificates is taken into account here. One owner holds *[P2 and "P2-adjacent Sub1&Sub2&Sky1"]* parcels, the other owner holds *[P3 and "P3-adjacent Sub1&Sub2&Sky1"]* and *[P4 and "P4-adjacent Sub1&Sub2&Sky1"]* parcels (Fig 4b). In this example engineering structures (shown in Fig. 4b) and land surface usage are clearly defined and ordered according to parcel holders. There is one subterranean space located along the "*P3-adjacent Sub2*" and "*P4-adjacent Sub2*" parcels. Since the owners of these two underground parcels are the same holder, then there is no conflict here. The problem in this example might have arisen due to induced stress & displacement originated due to the surface structures or/and subterranean spaces. In order to provide protection for induced stresses and their resultant displacements, scheduled surface structures & subterranean spaces should be designed according to the rock/soil mechanic rules (*engineered structure related influences should be decreased up to acceptable disturbance levels inside the specified parcels according to indicated engineering standard. This fact is illustrated hypothetically with shaded areas in Fig. 4b & 4c).* Because of this precaution, surface land parcels and underground parcels at sub layers cannot be facilitated in full manner. Engineering structures cannot be positioned at that parcels by using full boundary limits. That means, engineering structures in/on earth crust at defined parcels should be carefully designed so that their stress & displacement influences *(in short / long terms)* should be diminished up to certain limits in their own parcel's boundaries.

Another case example can be defined also as follows. If the owners of the parcels are shaped in a way that; one landowner has *[P3 and "P3-adjecent Sub1&Sub2&Sky1"]* and *["P4-adjecent Sub2"]* parcels; Another owner has *[P4 and "P4-adjecent Sub1&Sky1"];* That means these two owners have different layers' ownership rights, (Fig. 4b), when the land parcel *P4* is in the consideration. In this hypothetical case, *[P4 and "P4-adjucent Sub1"]* parcels and *"P4-adjucent Sub2*" parcels have different owners, (shareholders). If there is an underground space excavation as illustrated in Fig.4b for Sub2 parcels underlying *P3* and *P4*, its disturbances can affect overlying layers up to ground surface. Actual excavated or planned tunnel cases presented through the earlier sections in this paper showed that induced displacements are inevitable, in this case example, at *[P3 and "P3-adjucent Sub1"]* and *[P4 and "P4-adjucent Sub1"]* parcels. If there is no defined allowable limit for induced stresses and displacements for similar short & long term induced stress & displacement cases, the owners of related parcels in this example will end up in legal disputes. The decision supports data and results of analyses based on criteria and numerical & empirical solutions *(which ground engineers have to supply*) include uncertainties due to rock/soil masses' natural characteristics. Therefore, decisions to solve those legal disputes require more rock/soil mechanics research to decline a little more (further) uncertainties. In other words, supplying decision support data & results on the base of numerical analyses which might be based on only empirical solutions seem to be scanty. In addition to this paradox, the ground conditions in defined surface parcels can be heterogeneous in characters (Fig. 4c). The rock/soil masses here in the considerations, might have faults (discontinuities), caves etc. which have their own induced stress & displacement influencing areas around. Induced stress & displacement caused by foundations of surface structures and tunnels might be overlapped with these naturally formed induced stress fields to cause further stability problems.

There is another point to be mentioned here that, if there are surface structures with minimum disruption at their foundations *(due to low unloading/loading rates),* these structures could be diminished to be re-constructed in better manners (to obtain much safer & stable structures for earthquakes for instance). On the hand, if there is a deep foundation excavation at a surface parcel, (covers surface land ownership rights and Sub 1 parcel rights, Fig. 4b, 4c, for example), its disturbances on neighbouring parcels cannot be totally eliminated and these influences are effective for some more years. Therefore, surface structures with deep foundation excavations and underground spaces have their influences on rock/soil masses and this cannot be eliminated totally by diminishing these structures. Thus, they should be planned in the first place carefully with the official city plan concept.

The influences among the underground spaces and surface structures are not limited to induced stress & displacement cases and related land ownership dilemmas. Ground vibrations originated by blasting, machine working, loading & dumping operations can also influence surrounding structures harmfully. Different researches have already performed to measure vibration effects of surface open pit blasting, (in Peak Particle Velocity, PPV), on surface and underground structures. Besides there are also works to determine influences of ground vibration originated due to underground space blasting & operations. The results of studies presented that horizontal-vertical particle vibration travels more easily in massive rock/soil masses. Heavily fractured rocks (heterogeneous soils) with higher porosity contents are mediums where vibration has gradually lost its energy to travel more distances. There are engineering standards about vibrations and the levels of allowable PPV levels were already listed accordingly. Disputes occurring among surface land & property owners and companies performing excavations have been settled by measuring their operational vibrations and evaluating them if the data coincides with the allowable vibration levels in the standards. Moreover, the procedure [29] supplied by "Strathclyde Partnership for Transportation" Company, (SPT), in Glasgow, UK, could be an example for protective actions for underground metro tunnels from man-made vibrations. The company developed charts including vibration precaution categories for engineering operations *(planned to be completed neighbouring their tunnels under their obligation)* in Glasgow city. Surface or underground excavations, constructions, or any other operations which create vibrations near SPT-Metro tunnels are enquired to be observed with instrumentation. The vibrations here should follow the supplied "special vibration limits" which are in different PPV levels. The limitations provided in this application in Glasgow can be a good example for the governing bodies on the other side of the world to define their precautions to facilitate safer surface and underground spaces for future usages.

5. CONCLUSIONS

Underground metro lines are versatile transportation manners in modern urban life. Increasing subway networks and other subterranean spaces have introduced a new understanding of underground spaces. Ownership rights paradoxes among surface land parcels and underground spaces have not totally solved for most of the countries. Layered parcel phenomenon (definition) below/above the surface land is one solution some countries may apply. Disputes possibly arose due to the layered parcel ownership implications are not the only cases for subterranean spaces, they have diverse induced stress & displacement and ground vibration influence cases which cause instabilities of surface & subterranean structures. Therefore, these influences' allowable limits should be defined in legislative acts with land ownership descriptions. Any gap in the rights and liabilities will end up with paradoxes of disputes in near future. Ground engineering including rock/soil mechanic cases have supplied solutions for induced stress & displacement predictions. However, uncertainties arose due to rock mass discontinuities have forced ground engineers to research more deeply in actual rock/soil masses' behavioural characteristics. These works in rock/soil mechanics gradually provide more efficient explanations for induced stress & displacement fields and their stability cases.

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