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Geotechnical modelling and subsurface analysis of complex underground structures using PLAXIS 3D

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Abstract

In this study, analysis of complicated underground structure of Horemheb tomb (KV57) at Luxor, Egypt by using the software PLAXIS 3D is adopted and the deformation that occurs in the body of the underground structure after applied the failure load detected; the failure loads are obtained from the series of laboratory tests. Then, the structure is modelled by using finite element code to perform accurate three-dimensional analysis of deformation and stability in complex geotechnical engineering and rock mechanics. These underground monumental structures have been analyzed by finite element method FEM to obtain the deformation that accrued into the structure and so beneath of the surface and calculated the effective stress, shear stress and horizontal displacements. In order to modeling requires the soil parameters obtained from laboratorial tests. In the analysis elastic–plastic Mohr–Coulomb model is used as material model. It involves five parameters namely, Young's Modulus (E) and poison's ratio (ν) for soil elasticity, friction angle (φ) and cohesion (c) for soil plasticity. To set up the boundary condition, the standard fixities option is used. As a result a full fixity at the base and free condition at the horizontal side of geometry are generated. Numerical Engineering analysis for Horemheb tomb (KV57) in the valley of kings at the west bank of Luxor was carried out through the following four main steps: (1) Evaluation of surrounding rocks (marl limestone and marl shale) by experimental research and Roclab program to obtain the Hoek Brown and Mohr- Coulomb fit classification criterion and rock mass standards in particular the global strength and deformation coefficient. Also to specify the main characteristics of the Esna Shale using different methods such as swelling test, swelling potential, swelling pressure, in addition, discussion of the role of the expansive Esna Shale in the deterioration of archaeological buildings and sites. (2) Quantitative and qualitative estimates of the relevant factors affecting the stability of the tomb, especially overloading, fixed, geographic, and dynamic. (3) Integrated 3D geotechnical modeling of the cemetery environment for stress and displacement analysis and identification of volumetric strains and plastic points using advanced symbols and programs such as PLAXIS 3D. (4) The rapeutic and retrofit policies and techniques and the fixed monitoring and control systems needed to strengthen and stabilize the cemetery, where the rock mass classification refers to the rock mass where KV57 is excavated and it is poor rocks. The mechanical behavior of the rocks is simulated by assuming a foundational model to soften the elastic stress of the flexible plastic that captures fragile failure and the mechanisms of progressive substrate failure. In addition, rock pillar treatments and ground support strategies are discussed. This article represents the second phase of the numerical analysis of KV57 using PLAXIS 3D.

Keywords: 3D geotechnical modeling, Thebes formations, Esna shale, Rock support structure, Horemheb tomb (KV57), Valley of the Kings, Rock cut tomb, PLAXIS 3D

Introduction

In this study, PLAXIS is used for surface and subsurface settlements in underground monumental structures in the valley of kings at Luxor, Egypt; predicting differential settlements of buildings adjacent to excavation; planning for stability and seepage into underground structures or lateral displacements of diaphragm walls; calculating necessary consolidation time for pore pressure dissipation in undrained loading problems; or estimating bearing capacity and foundation settlement analysis for historic masonry structures, and other structures.

Engineering companies and institutions in the civil and geotechnical engineering industry count on PLAXIS 3D's range of CAD-like drawing capabilities and extrude, intersect, combine, and array functions for geotechnical solutions in infrastructure projects. Advanced options consider creep or flow-deformation coupling through consolidation. Ultimate options analyze the effects of vibrations in the soil, like earthquakes and moving traffic loads. The application also simulates complex hydrological conditions through time-depended variations of water levels or flow functions for both saturated and unsaturated soil conditions,[1].

Your safe solutions deserve trusted computation that can be easily shared with project teams and stakeholders. Confidently address the most common or complex challenges with the rich functionality, sound computation, and intuitive digital workflows of PLAXIS[19 23 27, 29 32, 34, 35, 37].

Capabilities

- Accurately calibrate material models.
- Advanced interoperability with the Bentley ecosystem.
- Automate tasks for improved efficiency with Python scripting.
- Import CAD files for streamlined modeling, saving you time.
- Strengthen reliability with preeminent constitutive model library.
- Access more functionality with sensitivity analysis and parameter variation.

Great efforts have been made to preserve the archaeological site of the Valley of the Kings (KV) since UNESCO declared it a World Heritage Area in 1979. Explorations have been made to restore monuments and temples and investigate damage, degradation, and risk structures by many international groups of scientists inside and around KV [2, 4–13, 15, 20–22, 28, 30, 31, 33, 36, 38, 11, 24] summarize that Egyptian monuments mainly fail due to deterioration or cracking of building materials, weak soft soil (for example, clay), and displacement along natural fractures in hard rocks (for example, limestone, sandstone, strong clay), Or falling rock from steep slopes drifts.

The Valley of the Kings was a burial place for Egypt's pharaohs during the reign of the new king from 1550 to 1070 BC. KV is a small valley cut by heavy rain and eroded during several periods of rivers in the Eocene into a thick layer of limestone located around a sliced layer of marly shale. The valley is located at an altitude of 70 m above the level of the Nile River (140 m above average sea level) and the height of the surrounding hills is 80 m above the valley floor. During the late eighteenth dynasty and throughout the nineteenth century, royal tombs were usually located below the valley some distance from the rock walls. Builders often take advantage of their ankle slopes, as in the case of the Horemheb KV57 tomb. Indeed, many other royal tombs in the Valley of the Kings exhibited similar decay and disintegration features. Most of the royal tombs in the Valley of the Kings and the Western Valley were excavated in the limestone of the middle and lower part of the first Thebes, member, the lowest unit of the formation of Thebes. However, many tombs penetrate the rock and interlocking rocks found in the formation of Isna Shale. All show a advanced deterioration in the rock structure that is irreversible due to swelling and contraction. The Horemheb tomb KV57 is clearly more susceptible to the additional geostatic loading of overburden or surcharge heavy rock layers, rock bursts, and structural damage to support pillars and sidewalls and the effects of past/recent rapid floods caused by torrential rains in the valley. Since some of these tombs also come into contact with underlying shale layers, which have the potential to swell and shrink in conditions of variable humidity. Extensive damage to these underground structures was widely observed in the Valley of the Kings. This tomb KV57 tends to be the worst tomb preserved in the Valley of the Kings. The marl shale in the valley is particularly weak and unstable. Not only did the old quarry problem come up, but the modern conservators too. When the marl shale comes in contact with moisture, it expands and can literally rip the hillside. Despite being thin, being strong support elements, these shafts will continue to attract significant loads due to redistribution of stress due to drilling. Insufficient column strength can lead to extreme instability and failure of the adjacent rock mass with potential catastrophic consequences for the associated undergrounds.

The main characteristics of the geo-environmental and geotechnical analyzes conducted in this study are the investigation of the stable stability, safety margins, and engineering failure of the Tomb of Horemheb (KV57) under their current conditions, against the unfavorable environment (i.e. widespread weathering due to the impact of water and sudden floods in the past and present in particular the 1994 flash flood), Complete lack of protection, geostatic overload of structural rock support columns, and severe geotechnical and seismic conditions.

Numerical methods

The analytical solutions are available for underground monumental structures having circular, elliptical, rectangular with rounded corners, ovaloid, spheroidal shapes and for circular opening at shallow level considering rock to be homogeneous, elastic and isotropic and for deep circular and spherical structures excavated in rock medium having isotropic in-situ stresses for von-Mises, Mohr–Coulomb, Hoek–Brown yield. Special and complex structures such as intersections, bifurcations, stacked tunnels and interaction of several tunnels in closed proximity and openings of complex shapes excavated in rock medium with complicated properties cannot be analyzed by simple analytical solutions. Stress deformation analysis and the requirement of supports in such cases can be analyzed only by numerical methods.

Two approaches to numerical modeling of rock masses can be identified, both recognizing geological structures as being discontinuous due to joints, faults and bedding planes. A continuum approach treats the rock mass as a continuum intersected by a number of discontinuities, while a discontinuum approach views the rock mass as an assemblage of independent blocks or particles.

The finite difference method (FDM), finite element method (FEM) and boundary element method (BEM) are based upon the continuum approach. The FEM involves eight basic steps viz., discretisation, selection of displacement model, definition of strain–displacement and stress–strain relations, derivation of element equations, assembly and incorporation of boundary conditions, solutions of primary unknowns, computation of secondary unknowns, and interpretation of results. The FEM can be used to analyze problems with material and geometric nonlinearities, complex boundary conditions and non-homogeneities. The method involves discretisation of the entire region of interest. Boundary element method (BEM) involves the discretisation of the interior or exterior boundaries only and consists basically of definition and solution of a problem entirely in terms of surface values of traction and displacement. BEM is classified as direct and indirect depending on the procedure used to construct relationships between the tractions and the displacements. Indirect formulation is used in rock engineering problems particularly with respect to underground structures. Discontinuum models feature numerical procedures involving the equations of blocks or particles rather than continuum. Cundall [7] was among the first to implement the distinct element method (DEM) to represent rock mass as an assembly of discrete blocks where joints/discontinuities are viewed as interfaces between distinct bodies. This method is based on an explicit time stepping algorithm for the integration of the equations of motion of the system in the time domain. The scheme allows for an efficient treatment of the nonlinear phenomena such as sliding, separation and large deformations occurring in the mathematical model.

State of preservation

The Geotechnical instability problems and degradation phenomena of rock cut tomb of Horemheb (57) in the Valley of the Kings (KV) is likely to be dominated by gravity fall and sliding on structural features, also other factors such as excessively high rock in-situ stresses, creep effect, poor petro-physical and geo-mechanical properties of marly shale structures, weathering and /or swelling rock and flash floods caused by heavy rains in the Valley, vibrations and dynamic loading as well as utter lack of preservation become important and can be evaluated by means of a classification of rock quality. The Esna shale in the valley is particularly weak and unstable. It not only posed problems to the ancient quarryman, but to the modern conservator as well. When the shale comes into contact with moisture, it expands and can literally tear a hill side apart.

The tomb was robbed in antiquity. Since then, it has been hit by at least eleven flash floods caused by heavy rains in the Valley. These have completely filled the tomb with debris and seriously damaged its comprehensively decorated walls and pillars. In October and November of 1994, two flood events occurred in the Valley of Kings, sending a warning to all heritage managers. In both cases, a local desert rainstorm occurred in the vicinity of the Valley of Kings. Storm-water runoff and sediment entered the Horemheb tomb (KV57) and other many o tombs and caused erosion of gully floors.

Short-term effects of rainstorms on Horemheb tomb (57) included damaged wall art due to debris flows and collapsed wall structures due to water saturation. Long term damages, however, are difficult to record, even though, their impact might be more critical. Flooded tombs like KV57 built into the Esna shale Formations, are most susceptible to rock- structure deformations or deterioration due to the physical properties of the Esna shale. Throughout the Theban Necropolis, deterioration due to swelling is a common phenomenon that can be observed in Horemheb (KV57).

The damage in KV57 due to the geostatic stresses, consists of fallen ceiling slabs, a cutout wall and door decorations, the ceiling is extremely fractured, however, crack monitors show few displacements since 1991. Crack monitors show a few millimeter (0–10 mm) horizontal and to a more extent, vertical movements. Some parts of ceiling and walls show heavy deterioration caused by rock instability due to abundant horizontal and vertical cracks.

Figure 1 represents some in-plane deformation patterns of the ceiling and walls like vertical cracks and crown zone rock falling and intensive cracking due to over loading (geostatic loading) and impact of old and modern flash floods in particular the 1994 flood. Extensive structural damage of crown ceiling zones and engineering failure of the structural pillars, sidewalls and Ceiling of the Corridors and Chambers in the KV57. Brittle rock, high stress conditions lead to rock bursting (the sudden release of stored strain energy) bursts manifest themselves through sudden. Extensive rock falls from the ceiling is obvious and cracks are active. Carved and decorated walls in massive Esna shale Member are in advanced state of disintegration. The ornamented plaster on top of the chert lenses and nodules was damaged during the first flash floods that entered the tomb some 3000 years ago. During several restoration projects over the past 200 years,

Fig. 1 In-plane deformation patterns of the ceiling and walls like vertical cracks and crown zone rock falling and intensive cracking due to over loading (geostatic loading) and impact of old and modern flash floods in particular the 1994 flood

cracks were filled with plaster for protection and stabilization of the tomb. The impact of the 1994 flash floods on the mural paintings inside the tomb are severely obvious, as shown in Fig. 2.

Fig. 2 Carved and decorated walls in massive Esna shale Member are in advanced state of disintegration. Showing chert lenses. The ornamented plaster on top of the chert lenses and nodules was damaged during the first flash floods that entered the tomb some 3000 years ago. During several restoration projects over the past 200 years, cracks were filled with plaster for protection and stabilization of the tomb. The impact of the 1994 flash floods on the mural paintings inside the tomb are severely obvious

Materials and methodology

Underground structures of KV57 safety analysis is performed using the finite element (FE) method. The research presents a comprehensive study for the rock cut tombs safety analysis, the safety analysis includes not only a failure analysis but the effect of weathering, in particular the materials wear on the differential settlement have been investigated. The commercial FE package PLAXIS 3D is used for conducting stress, as well as settlement analysis. PLAXIS 3D is a finite element program developed for numerical analysis of geotechnical and underground and subterranean structures [14, 16–18].

The deformation of this underground structure has been computed as realistically as possible, utilizing an advanced nonlinear elasto-plastic material model needs to be utilized in PLAXIS 3D which is capable of utilizing such advanced material models. 3D Plastic model is used for deformation and consolidation analysis in this research.

PLAXIS 3D offers CAD-like drawing capabilities to help with the analysis of subsurface environments for geoengineering projects. From excavations, embankments, foundations, tunneling, and mining, to reservoir geomechanics, users can determine the deformation and stability of geotechnical engineering and rock mechanics to assess the geotechnical risk.

Most geotechnical engineers use FEA software packages for their geotechnical design. It is especially useful for performance-based design or in situations when strong structure interaction is taking place and for which analytical solutions are not applicable.

Geotechnical engineers usually prefer to carry out 2D numerical analyses because FE models are simpler and faster to set up, plus, they are also quicker to run and post-process. On the other hand, 2D models will never fully reflect the true 3D reality of the problem at stake and might often lead to overly conservative results. However, 3D models are more accurate and realistic, but could represent a significantly larger time investment.

Why PLAXIS 3D?

PLAXIS 3D is definitely worth the time investment, especially if users already have some modeling experience with PLAXIS 2D. The modeling workflow and most of the modeling features are identical. It only takes a short time to become familiar with handling the third dimension when using construction geometry components natively.

3D model does not have to be sophisticated, complex, or extensive. In that sense, it is vital to properly use symmetry, optimum geometry, and mesh definition.

What is the difference between 2 and 3D finite element analysis?

2D analyses remain attractive due to the relatively fast model set-up and calculation time. Their simplicity is clearly their biggest advantage and explains their popularity. Although 3D analyses are becoming more popular, many geotechnical engineers are reluctant to invest longer modeling time because they are judged as too costly or simply unnecessary. As a consequence, many users continue to use 2D analysis, even for situations where the real 3D geometries would not satisfy the "extrusion" requirement:

This assumption might still be acceptable, but 3D effects would need to be accounted for empirically by the users in some ways (correction factors, averaging …) unless the 2D model is considered to be delivering conservative results.

The user must bear in mind that 2D analyses cannot take into account the effect of stress rotation along any directions that would be contained in the 2D modeling plane (this effect is often referred to as transversal stress arching). These effects are particularly relevant in tunnel construction and for laterally loaded pile, for instance.

Finally, it is important to realize that only an “average” soil displacement can be obtained from a 2D calculation (always the same value, whatever cross section is being considered) and that this value should remain somehow “meaningful” with respect to the true 3D nature of the problem being modeled. In this context, the detailed analysis of a singularity CANNOT be properly dealt with in the framework of a 2D calculation (for instance, a single laterally loaded pile). Only when singularities are relatively close to one another in the out-of-plane direction would a unique average soil-displacement become physically meaningful and a 2D analysis be considered as acceptable.

Results of the 3D numerical analysis and geotechnical modeling

In this study, PLAXIS 3D was implemented to determine the behavior of shale formations under heavy geostatic pressures. PLAXIS is a commercially available program that uses the FEM Finite Element method. PLAXIS uses various soil/rocks models to determine the soil/rocks behavior such as Mohr–Coulomb model, hardening soil model, soft soil model, soft soil crawl model, common rock model and modified Cam-Clay model. The hardening soil model was chosen for this study.

The hardening soil Model is an advanced model of soil behavior simulation. For the Mohr–Coulomb model, specific stress states are described by the friction angle phi, the cohesion c and the expansion angle psi. However, soil hardness is described more accurately using three different types of input hardness: E50 three-axis hardness, Eur three-axis dumping hardness and Ooed counter load hardness. Unlike the Mohr–Coulomb model, the hardened soil model also explains the stress dependence of hardness standards. This means that all stiffness increases with pressure. Hence, the hardness of the three inputs relates to the reference pressure, and is usually taken as 100 kPa (1 bar).

Besides the above model parameters, primary soil conditions, such as pre-standardization, play a fundamental role in most soil deformation problems. This can be taken into account in generating the initial pressure.

Low-strength shale formations where KV57 is seriously excavated grave safety under static loading and earthquake conditions. PLAXIS 3D was used for three-dimensional numerical analysis of the central main rooms with their structurally supportive rock columns structurally damaged. Vertical cracks due to overload and slope of strength are evident.

The goal of 3D testing is to evaluate the state of pressure in columns taking into account 3D engineering. The issue of 3D effects on a basic design methodology is considered in the following areas. The various reenactments shown are redirected using the PLAXIS 3D symbol (PLAXIS 3D).

The results of the three-dimensional static analysis represented in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 indicate that the rock columns in the main chambers are subject to relatively high pressure pressures.

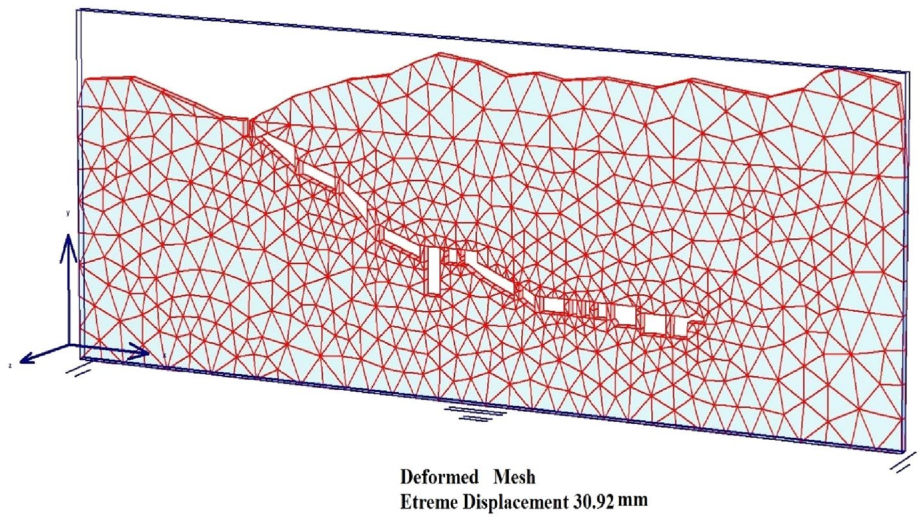

Fig. 3. Deformed Mesh with extreme displacement 3.92 × 10^{-3} m

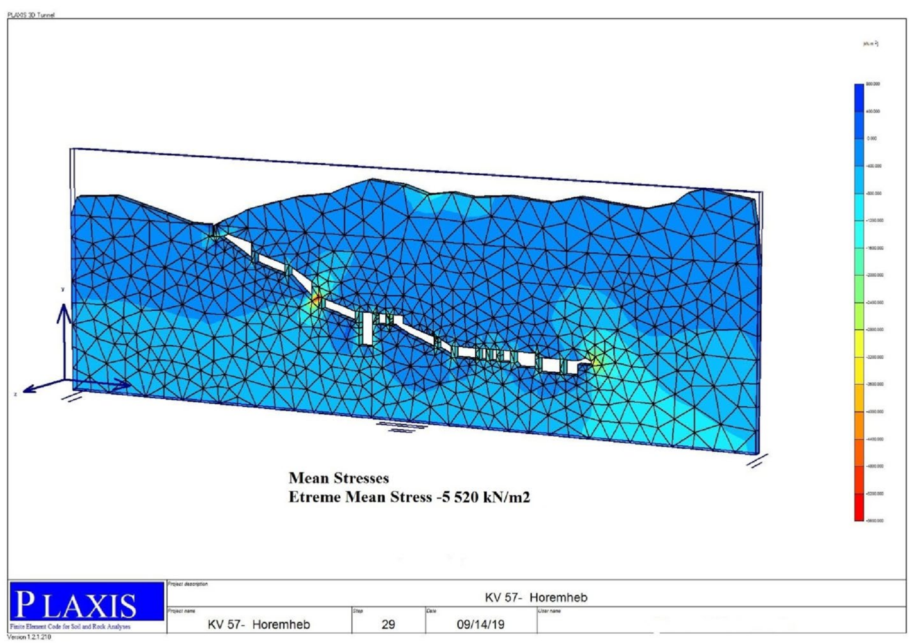

Fig. 4. Mean stresses for the supported rock pillars and sidewalls in KV57, the extreme value is 5.52 × 10^3 kN/m^2

Figure 3 represents the deformed mesh with extreme displacement is 3.92 × 10^{-3} m. The mean stresses for the supported rock pillars and sidewalls in KV57 calculated and the extreme value is 5.52 × 10^3 kN/m^2, as shown in Fig. 4. For the horizontal stresses σ zz, the extreme value is 3.83 × 10^3 kN/m^2 as shown in Fig. 5. Figure 6 represents the horizontal displacement Uz, the extreme value is 10.87 × 10^{-6} m. The calculated vertical incremental displacement showed that the extreme value is 1.03 × 10^{-3} m, as shown in Fig. 7. For the incremental volumetric strains, the calculated extreme value is 74.75 × 10^{-3}% as shown in Fig. 8. For the vertical strain increments, the calculated

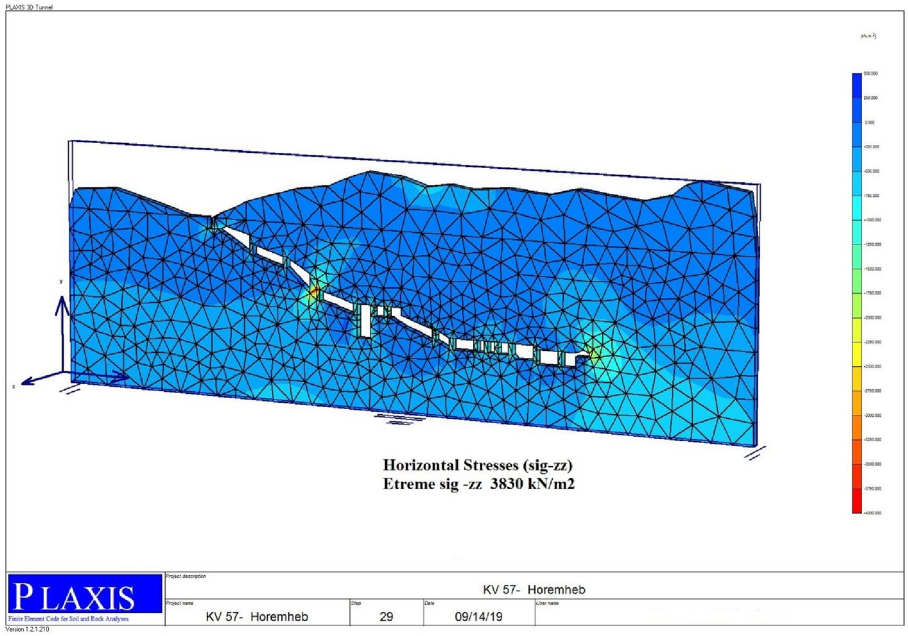

Fig. 5. Horizontal stresses sig –zz, the extreme value is 3.83×10^3 kN/m^2

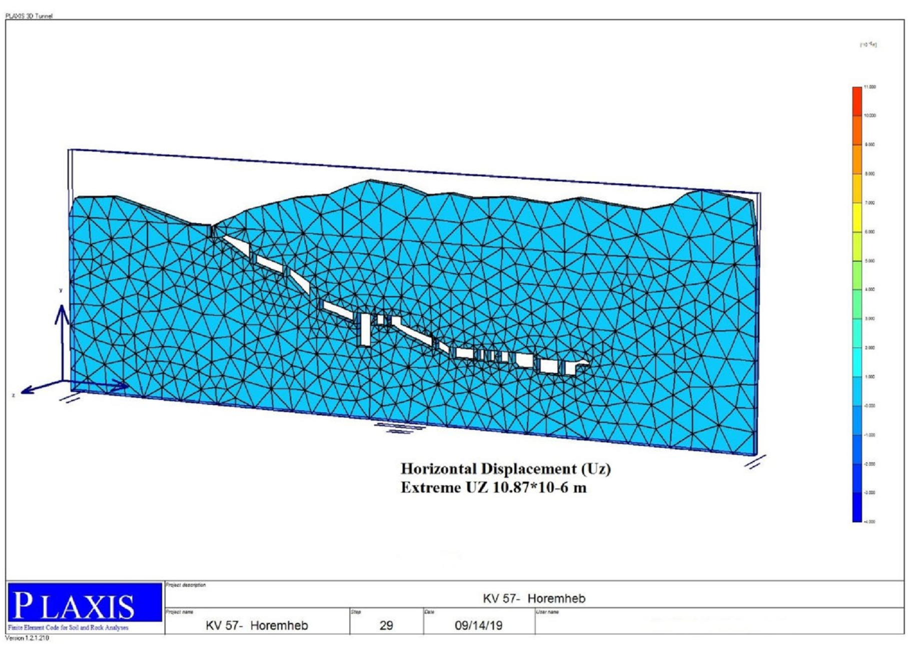

Fig. 6. Horizontal displacement Uz, the extreme value is 10.87×10^{-6} m

extreme value is $-\ 60.08 \times 10^{-3}$% as shown in Fig. 9. FEA revealed that total incremental displacement is 1.07 mm and the volumetric strain is 1.45%.

The FE numerical analysis reveals that the roof of the tomb which has suffered from exfoliation is those in compression. Given that the exfoliation is the result from a

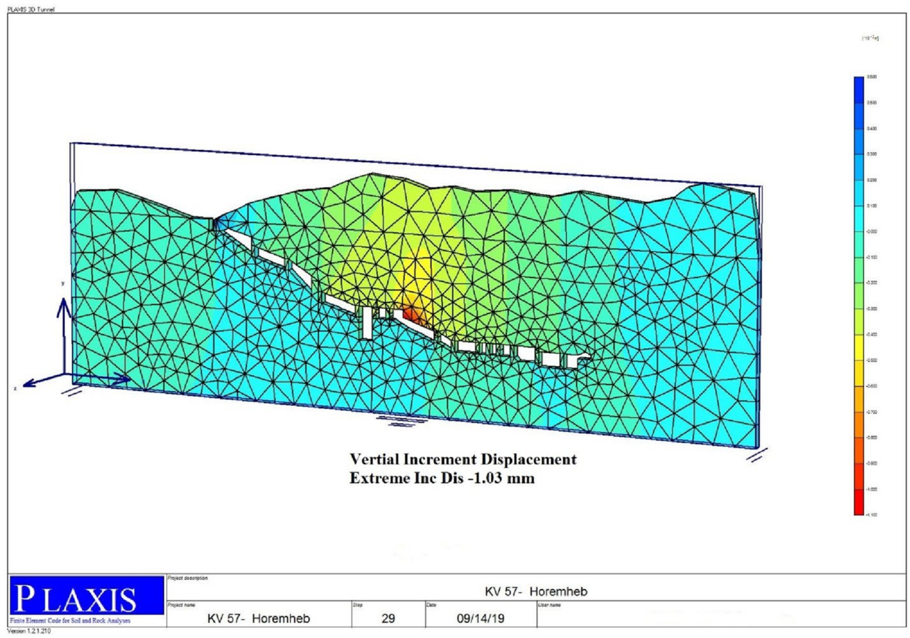

Fig. 7. Vertical Incremental displacement, the extreme value is 1.03 × 10^{-3} m

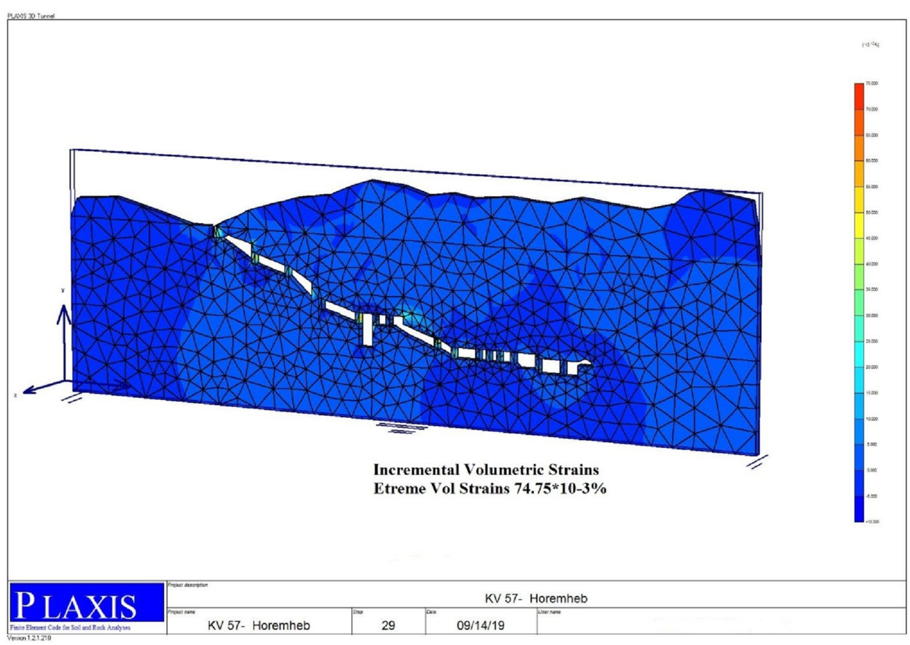

Fig. 8. Incremental Volumetric Strains, the extreme value is 74.75 × 10^{-3}%

combination of the fluctuation of humidity and compressive stresses, the study concludes that the fluctuation of humidity needs to be minimizes by preventing the active circulation of air through the tomb.

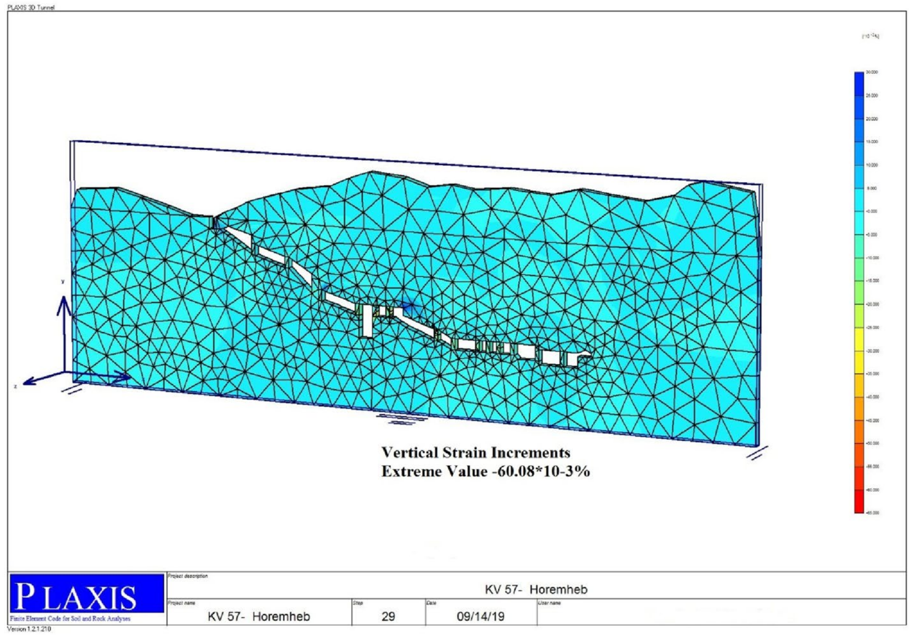

Fig. 9. Vertical Strain Increments, the extreme value is -60.08 × 10^{-3}%

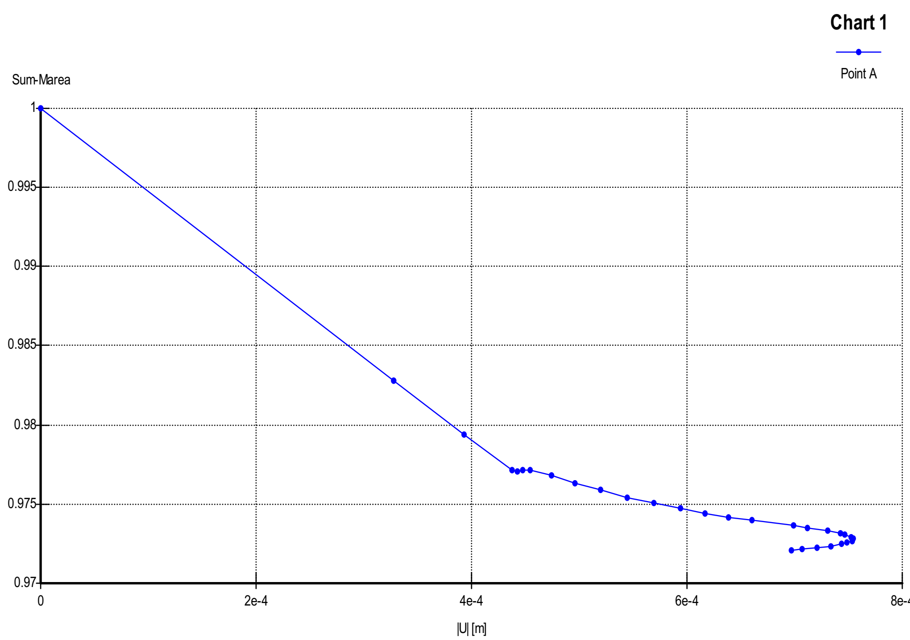

Fig. 10. Load- Displacement Curve for Hormheb tomb (KV57), the Sum-M area-U [m] Curve for point A

Pillars axial stress versus displacement curves provide insightful information on pillar failure mechanism associated with increasing axial loads. It can be seen that for pillars with $W/H = 1/3 \leq 0.5$ the pillars generally exhibit a linear elastic behaviour up to peak strength then a brittle failure followed by an approximate perfectly plastic post-peak behaviour[25,26].

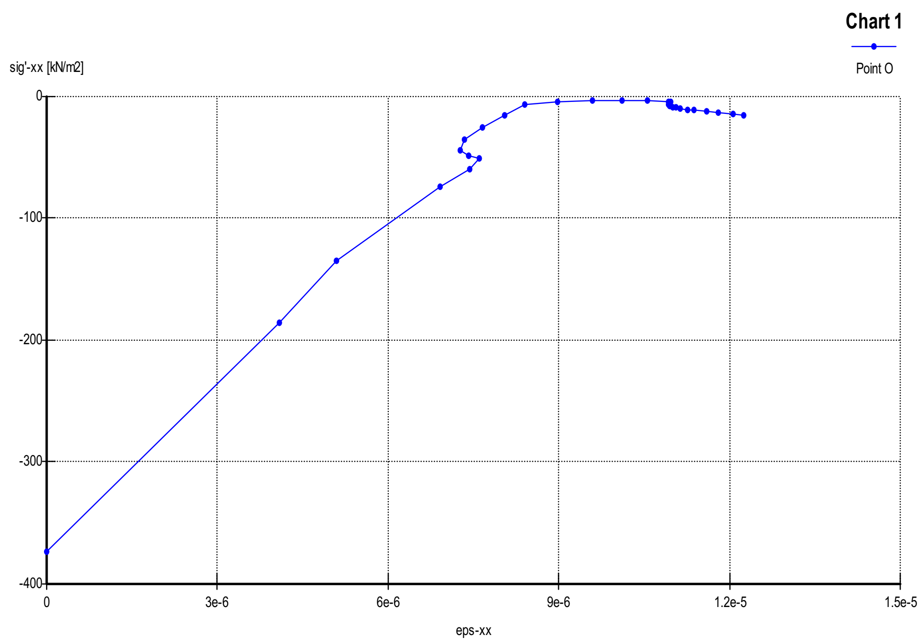

Fig. 11. Vertical Stress- Displacement Curve for Hormheb tomb (KV57), Sig-xx [kN/m^2]-eps-xx curve for point O

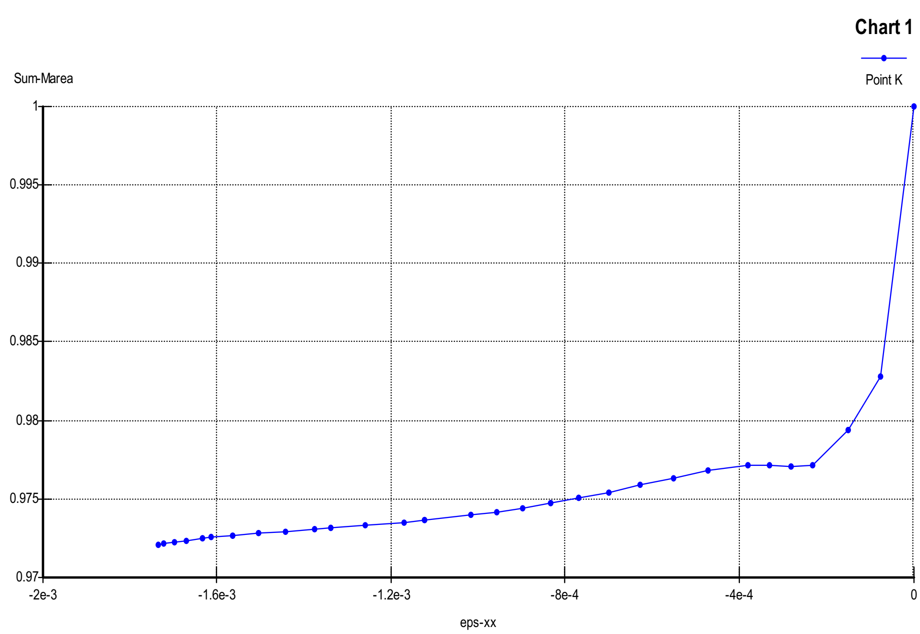

Fig. 12. Load-Displacement Curve for Hormheb tomb (KV57), Sum-M area-eps-xx curve for point K

Generating load–displacement curves

The results indicate general agreement with the empirical relationship for pillar width to height ratios. On the other hand, there is a significant reduction in pillar strength for ratios $W/H < 0.5$. In these cases and where the pillar stability is controlled by unfavorable defects.

In addition to the results of the final calculation step, it is often useful to view a load–displacement curve for purpose of comparison. Therefore, the PLAXIS package is used. In order to generate the load displacement curve as a given in Fig. 10. For the X-axis is represented the displacement and the Y-axis is represented Sum-Mstage. Hence, the quantity to be plotted on the y-axis is the amount of the specified changes that has been applied.

Figure 10 represents the Sum-Marea-U[m] Curve. Figure 11 represents the Sig-x [kN/m^2]-eps-xx curve. Figure 12 represents the Sum-Marea-eps-xx curve. Figures 10, 11 and 12 indicated that the values of stress and displacement distribution on the roofs and structural rock pillars did not increase due to the excavation process extending behind the main hall and this may be due to the lower level of the ceiling for these small burial chambers. Numerical results suggested that failure could be more influenced by the orientation of vertical joint sets rather than bedding planes. Figure 10. Represents the Load- Displacement Curve for Hormheb tomb (KV57), the Sum-M area-U [m] Curve for point (A) on the top of the structure. Figure 11. Represents the Vertical Stress-Displacement Curve for Hormheb tomb (KV57), Sig-xx [kN/m^2]-eps-xx curve for point (O) in the middle of the structure. Figure 12. Represents the Load- Displacement Curve for Hormheb tomb (KV57), Sum-M area-eps-xx curve for point (K) on the bottom of the structure.

Hence the curve will range from 0 to 1, which means that 100% of the prescribed load has been applied and the prescribed ultimate state has been fully reached.

Conclusions

In conclusion, the rock mass properties and environmental conditions of the area were gathered to conduct a preliminary stability assessment Hormheb tomb (KV57) in the valley of kings in the west bank of Luxor. A 3D numerical model was developed in PLAXIS 3D using the hardening soil modelling method, which indicates the importance of the swelling pressure and vertical joints on the underground structure stability of KV57.

Detailed remote sensing geo-environmental monitoring accompanied with detailed Geotechnical analysis of the Horemheb tomb KV57 in Luxor, Egypt, demonstrated that these unique underground structures offer low static safety factors for roof and structurally damaged rock pillars under current conditions of geostatic stresses. The state of the overpressure of the surrounding rocks exceeds the flexible system (field boundaries), and all structural supports of the ceiling, side walls and rock columns are subject to high vertical pressure pressures due to high in-situ stresses and poor geotechnical properties of the marl limestone and marl Shale. Several instability problems of static and dynamic loading have been recorded and analyzed. As a result, a well-focused enhancement and adjustment program is essential and demand urgently since the KV57 is closed due to the instability and unsafe conditions.

Abbreviations

At	Is the area supported by the pillar
Ap	Is the area of the pillar
σv	Is the vertical stress at the level of the roof of the excavation (KV5)
σp	Is the strength of the pillar,
W and H	Are the width and height of the pillar respectively

qu	Is the UCS strength of the pillar material on cylinders with height (h) equal to twice the diameter
hcrit	Is the minimum height of the cubical specimen of pillar material such that an increase in the specimen dimension will produce no further reduction in strength.
β	Angle between the normal to the fracture plane and the horizontal plane
φ	Friction angle of the fracture
x τ	Shear stress in resin annulus
σ b	Applied stress
α	Decay coefficient 1/in which depends on the stiffness of the system
β	Reduction coefficient of dilation angle
σ c	Uniaxial compressive strength of rock
Aj	Joint area
φ b	Basic joint friction angle
Ds	Rib spacing
U	The shear displacement at each step of loading
c	Cohesion between block joints
σ n	Normal force
b u	Shear displacement
N p	Normal force at failure
Qp	Shear force at failure
M D	Bending moment at yield limit
M p	Bending moment at plastic limit
Ei	Modulus of elasticity of intact rock
Qcf	Shear force
Lcp	Reaction length
ν	Poison ration of rock mass
Po	In situ stress
JRC	Joint roughness coefficient
JCS	Joint compressive strength
RMR	Rock mass rating
RQD	Rock mass Designation
Q	Rock mass quality
Jn	Joint set number
Jr	Joint roughness number
Ja	Joint alteration number
Jw	Joint water reduction factor
SRF	Stress reduction factor

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Authors contributions
The whole database construction and analysis are presented in the manuscript had been achieved by the author. The author read and approved the final manuscript.

Availability of data and materials
Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Competing interests
The author declare that he has no competing interests

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