BEHAVIOUR OF IMMERSED TUNNELS UNDER THE DEFORMATION OF OVERBURDEN SOIL INDUCED BY LONGITUDINAL THRUST FAULTING

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Abstract

Design of immersed tunnels are sensitive to soil deformations such as those imposed by a fault rupturing underneath. For the two-dimensional analysis the stress applied to the lining might not cause it to fail; however, in a three-dimensional sense, it can be foreseen that this large displacement may cause longitudinal deformation and cause the tunnel to move and to fail along the longitudinal direction. This longitudinal faulting often causes damage to underground tunnels located in the shear zone. The paper investigates the response of an immersed tunnel to the consecutive action of a major fault rupturing in an earthquake occurring in the basement rock underneath the tunnel based on the 3D numerical analysis using PLAXIS 3D Tunnel software.

Based on the numerical comparisons, it is found that current results are in agreement with some previous results of sandbox model tests. It was also identified that stiffness of the soil and the fault dip angles are among the major factors controlling the configuration of shear zones, the stresses within the soil, and the loads on tunnel linings.

Keywords : Faults; Tunnel wall ;Urban tunnel stands at alluvium , PLAXIS 3D Tunnel.

Introduction

Construction of urban tunnels at the area of alluviums should be typically increased due to public transportation and diverting part of transportation to subway in seismic zones in order to abate traffic jam and pollution. The role convenient design of tunnels is crucial under plausible challenges like settlement of buildings , land surface collapse and destruction of urban infrastructures specifically with proximity of tunnel along the faults , it is evident whenever it is impossible to deviate the course of tunnel from proximity of fault there are resolution to find a way to construct the tunnel in the vicinity of fault under special mechanism of design and construction , optimized construction and safety factor requirements for underground structures at the time of construction and influence of quake in tunnels in metropolitans closing to faults are counted as elements which should be manipulated during dedicated studies and researches by subsurface structure designers.

Transformation arisen by faults as forces pushed the tunnel walls is neglected by typical methods in urban metro tunnel design . many studies carried out in connection with forces applied to tunnel generated by quakes and faults, while those studies focused on tunnels outbound of town located at rocky areas ,therefore they paid attention less to urban tunnels at the alluvium areas , thus few researches carried out by 2D on fault consequences for tunnels situated in alluvium , it is evident that those analyses utilized 2D in alluvium lands because the fault influence is hardly studied along the tunnels , hence the current research performs the

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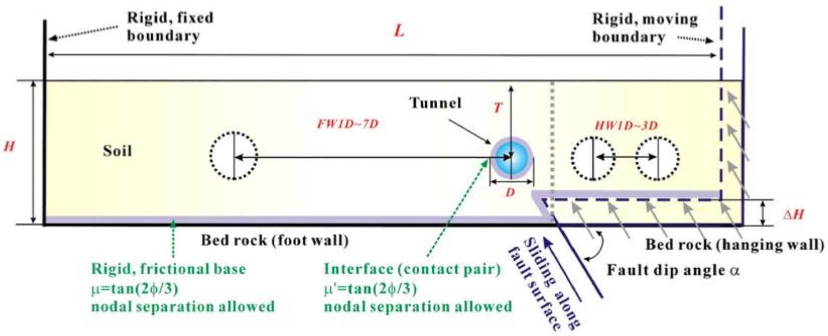
analysis of information concerning influence of fault on tunnel located in proximity with it by PLAXIS 3D Tunnel software application , since geometrical 3D analysis provides optimal engineering perspective in spite of more concise inquiries versus 2D mode in the course of design process. Surveying urban tunnel behaviors stand at fault with contribution of precise numerical model is reliable method , the current paper uses PLAXIS 3D Tunnel software application as a potent schedule in geotechnics, the different parameters like forces applied to tunnel wall arisen by transformation followed by fault received more attention by the said software , influences of nature and soil profile ascribe to tunnels excavated including the fault characteristics and position of tunnel against it affect the design of tunnels along the faults.

Influence of Fault on Tunnel Design

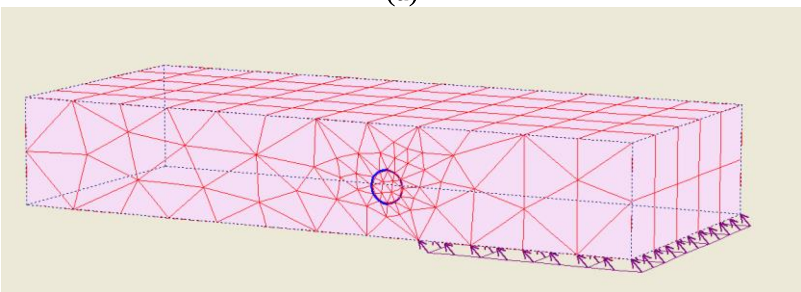
Underground structures and installations applicable in different aspects like urban subway railway and intercity tracks ,expressways and huge fuel resources , types of silos , armament warehouses ,nuclear wastes , water and wastewater supply installations .Some of underground installations constructed in the contingent seismic areas , therefore those structure should endure the quake and static loads , empirically underground structures are more resistant than surface structures ,although underground structures exposed to significant damages during quakes like Japan Kuwie in 1995, Taiwan Chi Chi in 1995 and Turkish Cocacoli in 1999 (1) , initial studies on underground seismic & tectonic behaviors ascribed to underground nuclear shelters in decade 60 with contribution of dynamic analysis (2).

Faults are formed by earth ‘crust with extensive transformations , sometimes small faults are evident in vicinity of road trenches because sedimentary layers displaced . Faults with those scales are merged in form of single rupture or disconnection , large faults on the contrary are seen in several fault planes (Plates) involved ,while that fault zone extended for a few kilometers which usually are discriminable by photogrammetry , virtually the presence of fault in an area proofs that region exposed to relocation in the last time either gentle with no tremor or sudden displacement followed by disrupted relocation parallel to faults which generate tremors.

Shear displacement along a narrowed zone produces sever demolitions in sub-ground structures ,strains created by faults in vicinity of tunnel profile or other underground structures exceed significantly the strains generated by tremor and creep , tunnel design for aim of resisting few centimeters or meters against faults are doomed to fail in view point of cost effective, consequently study of fault risk along tunnel or other underground structures are very crucial and effective (3-4) , it is possible to review the influence of fault on tunnel in two ways : lateral and longitudinal faults , designs in terms of lateral faults or 2D is plausible by fault formation and displacement so as to study the implications of space between tunnel and faults, but in longitudinal or 3D mode other than 2D mode it is plausible to represent lining thrusts and real modeling the fault site against tunnel with more outputs.



(a)



(b)

Figure 1. a)Fault along longitudinal line of tunnel (2D) b) versus perpendicular line (3D)

Numerical modeling

The current paper studies the influence of fault on underground structures and behaviors by application of PLAXIS 3D Tunnel software ,initially vector authenticity of PLAXIS 3D Tunnel software ,outcomes collected by numerical analysis and laboratory carried out by Ming and et al and compared with outcomes collected by numerical analysis attributed to PLAXIS 3D Tunnel software, there is schematic form attained by lab model , dimensions and localization of tunnel and reviewed by Ming and et al , characteristics of soil and underground structures depicted in real scale and laboratory in fig. 1.

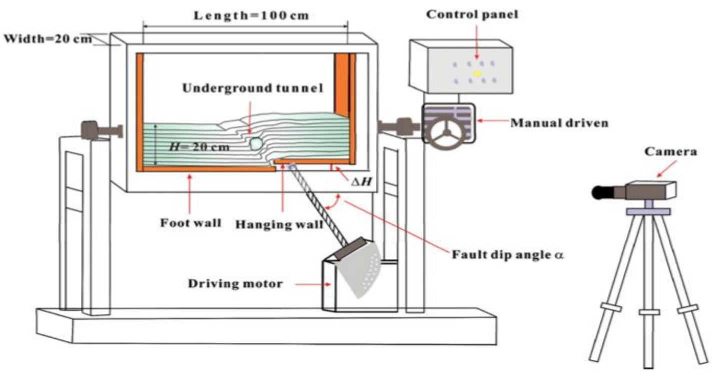


Figure 2. Fault physical modeling and study of its influences on tunnel by Ming and et al.

Table 1. Materials used by Ming & et al according to the physical and numerical modeling

Parameter	Lab sample	Real scale	Unit
Tunnel elasticity module	400	31800	Mpa
Tunnel poison coefficient	0.3	0.2	-
Soil specific weight	15.7	20.0	KN/m3
Soil module	1.29	19	Mpa
Soil poison coefficient	0.3	0.3	-
Soil cohesion	5	5	Kpa
Soil friction angle	30	30	o

Outcomes collected by PLAXIS 3D Tunnel software demonstrated with convenient overlap according to the outcomes arisen by ABAQUS Lab and numerical plan , it is evident that the concerning software furnished with fitted reliability for underground structural modeling and study of fault influences on underground structures , therefore the fundaments of those outcomes , the current paper surveys the numerical models and reviewing the fault parametric effects on underground structures and their influences on structural parameters like momentum , axial thrust and shear thrust on the tunnel linings .

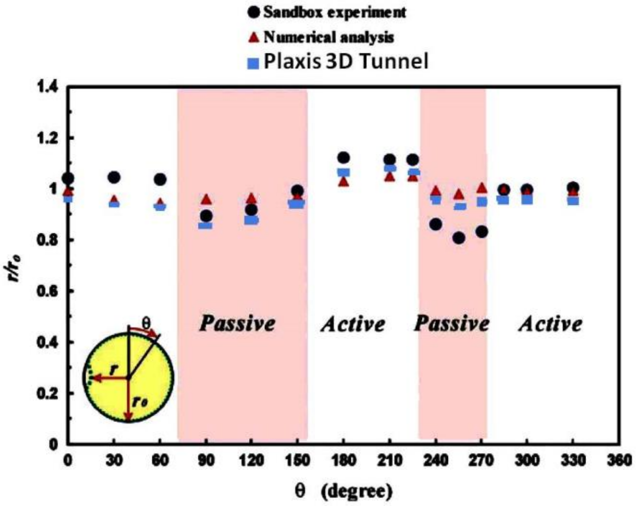


Figure 3. Comparison of tunnel distortion by ABAQUS - PLAXIS 3D Tunnel software with lab model.

Modeling direction is scrutinized sample of rectangular with dimensions of 50 x 40 m .while direction of tunnel modeling composes of semicircles with diameters of 8 m . and width of 0.4 m . thus at the center three ratios of T/H = 3,2/3 reviewed , hence H = 40 m , therefore T changes in two spaces of 14 & 26 against fault.

Fault angle exposed to more study in terms of displacement along perpendicular direction (Y) against displacement along planes depth (Z) as another variable , the rate of fault displacement (ΔH) parallel to perpendicular direction equals to 2,4 & 6 m . ,thus Moher – Columb elasto plastic behavior model applied for modeling process , characteristics of the general materials depicted in table 2. dilation angle demonstrated in degrees , clay soils display little dilation other than pre-consolidated layers. (ψ =0) ,sand dilation depends on density and friction , hence equation $\psi = \varphi - 30$ ̊ holds for friction angle. Dilation angle is zero in friction angle less than 30 degrees, angle ψ with negative range applied for sever loose sands (6).

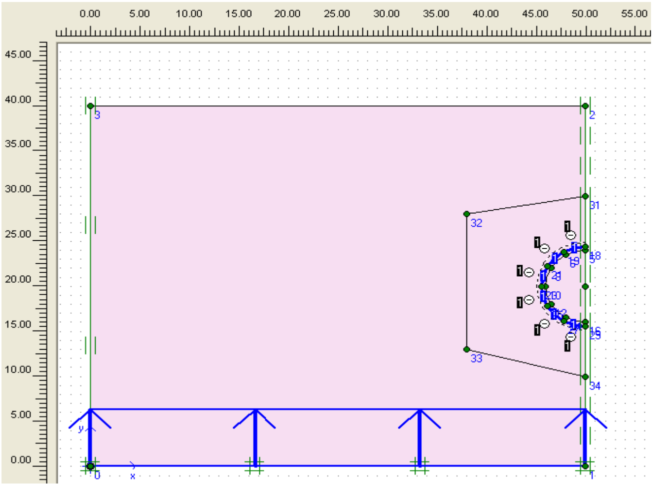


Figure 4. Model provided with simple lining elements

Table 2. Material characteristics in modeling by PLAXIS 3D Tunnel software

Elastic Modulus(Mpa)	Dilation angle ψ	φ (degree)	C(Kpa)	μ	γ (KN/m3)	Loose sand
60-20	15-0	30	0.1	0.3	20	

Tunnel lining with plate element affords buckling rigidity in spite of axial rigidity, while elastic lining element is significant that elements depicted in table 3.

Table 3. Parameters in Plate elements

EA [kN/m]	EI [kN/m2/m]	thin(cm)	υ	Tunnel Cover
2’000’000	26700	40	0.2	

Discussion

The current paper applies different parameters like fault angle , underground structures space against fault, soil vicinity profiles like soil module, moreover their influences on axial thrust maximum (N) , generated stress and displacement , shear thrust maximum (Q) and applied momentum maximum (M) , the control consists of a rectangular dimensioned 50 x 40 m. thus semicircles with dimensions of8 and 0.4 m in diameter and depth used , thus its center was studied with two ratios of T/H= 1.3 , 2.3, H = 40 m . satisfies T with two spaces of14 & 26 m changed against fault.

Fault angle α = 45 ψ = 0 , assumed that fault angle is 45 degrees and ψ = 0 , the parameters of soil elastic module , fault displacement and structural depth and its influence on axial thrust maximum and momentum maximum are analyzed.

Displacement increment from 2 to 6 m bring about momentum maximum mark up in three depths including different rigidities ,while that increment holds 60 mpa (mega Pascal) in every three depth it signifies the significance of soil elastic module for generated momentum increment within underground structural lining ,thus the scale of momentum maximum rate increased 123 % pursuant displacement from 2 to 6 m . , the rate of depth increment from 14 to 26 m .against 60 mpa(mega Pascal) and approaching to fault plate the rate of momentum increased 53 %, meanwhile by approaching the structure to fault plate the rate of axial thrust increased 34 % in module with 60 mpa (mega Pascal) in connection with axial thrusts ., hence the rate of increment with module of60 mpa in depth of 26 m .with displacement scale from 2 to 6 m . exposed to 60 % increment , meanwhile shear thrust increased like momentum and axial thrust pursuant to soil module mark up a rate of 60% increment in elastic module with 20 mpa within 6 m . displacement is emerged .

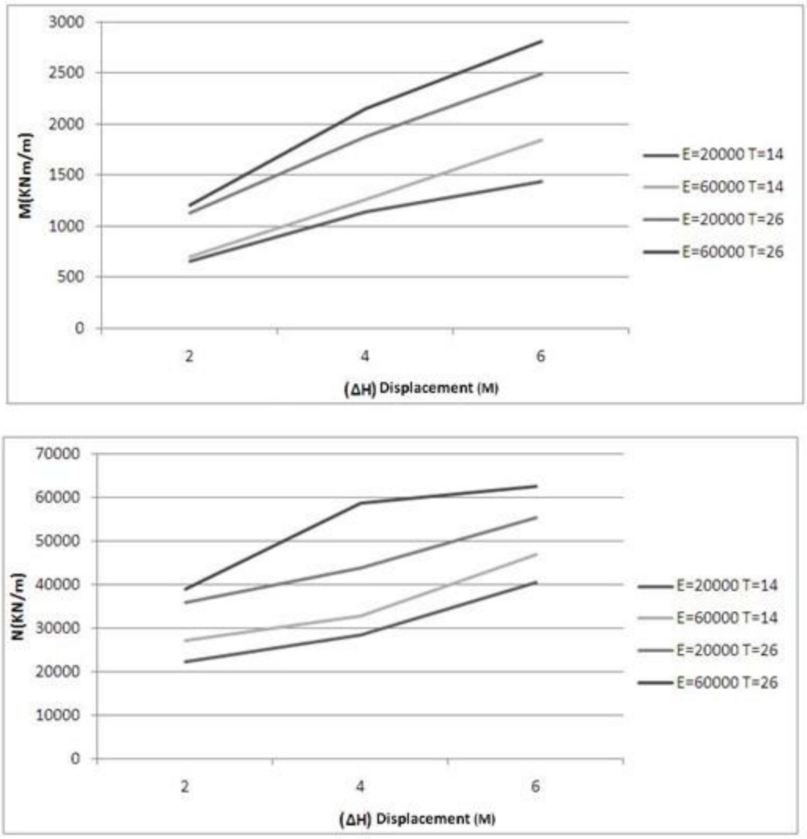
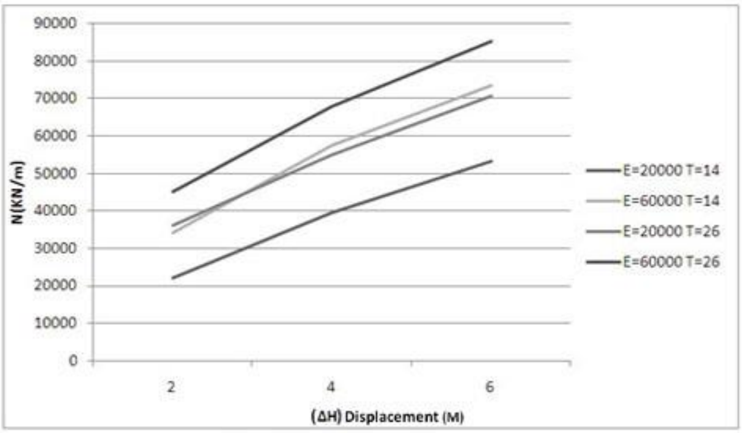


Figure 5. Momentum maximum, axial & shear thrust in tunnel lining with different soil rigidity and variable structural depth (fault angle , $\alpha = 45$ $\psi = 0$)

Fault angle $\alpha = 45$ $\psi = 0$: Different soil rigidity with rate of momentum maximum in every three depth and with displacement from 2 to 6 m .Shall increase , the soil rigidity in rate of 60 mpa (mega Pascal)stands more in every three depths by approaching of underground structures to fault plate ,therefore the rate of momentum maximum increased 165 % in underground structural lining which it increased in the range of 30 % against $\psi = 0$, increment of depth from 14 to 26 m . and approaching to fault plate the rate of momentum increased 95 % for module of 60 mpa (mega Pascal), axial changes depicted in fig. 6 ,thus those changes against module with 60 mpa at depth of 26 and displacement from 2 to 6 m .Demonstrate 80 % ,shear thrust increased similar to momentum and axial thrust and stays in 64 % increment with displacement of 6 and depth increment ,while elastic module is 20 mpa.



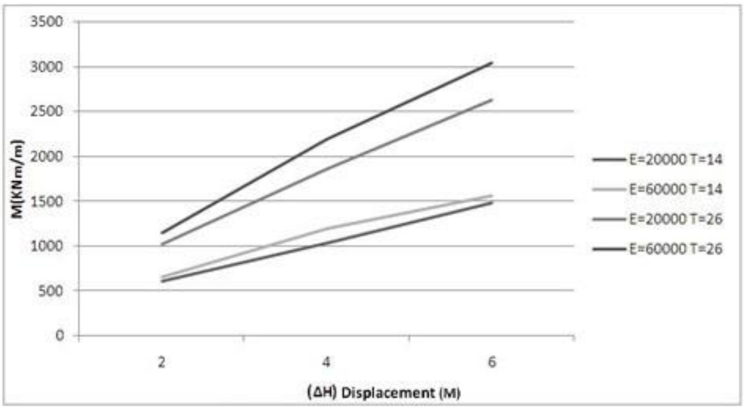
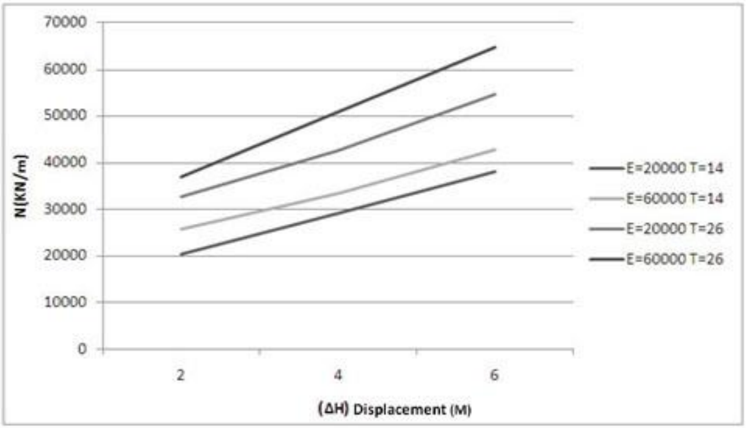


Figure 6. Momentum maximum, axial and shear thrust of tunnel lining with different rigidity and soil depth in variable structures (fault angle α = 45 ψ = 15)

Fault angle α = 64 ψ = 0 :Momentum increased 155 % for module of 60 mpa for soil rigidity and approaching to fault plate (T =26 m) and displacement from 2 to 6 ,thus the rate of momentum maximum in underground structures lining depicted in fig. 7, moreover increment of depth from 14 to 26 m .Approaching to fault plate the increment rate of momentum stays at 74 % ,hence axial changes with module of 60 mpa at the depth of 26 and displacement change from 2 to 6 increment rate is 75 % ,shear thrust at underground structures lining the soil module increased with displacement of 6 m . and depth too ,holds elastic module within 20 mpa increased 86 %.

Fault angle α = 64 ψ = 15 :Momentum increased 170 % for module of 60 mpa for soil rigidity and approaching to fault plate (T =26 m) and displacement from 2 to 6 ,thus the rate of momentum maximum in underground structures lining depicted in fig. 8 ,moreover increment of depth from 14 to 26 m .Approaching to fault plate the increment rate of momentum stays at 81 % ,hence axial changes with module of 60 mpa at the depth of 26 and displacement change from 2 to 6 increment rate is 84 % , shear thrust at underground structures lining the soil module increased with displacement of 6 m . and depth too ,holds elastic module within 20 mpa increased 97 %.



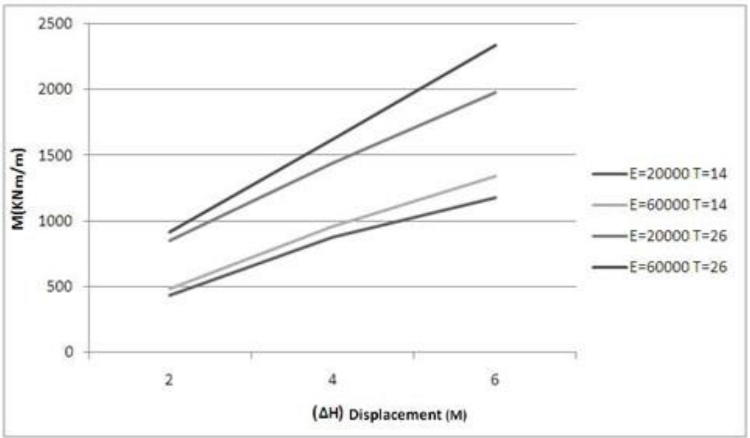
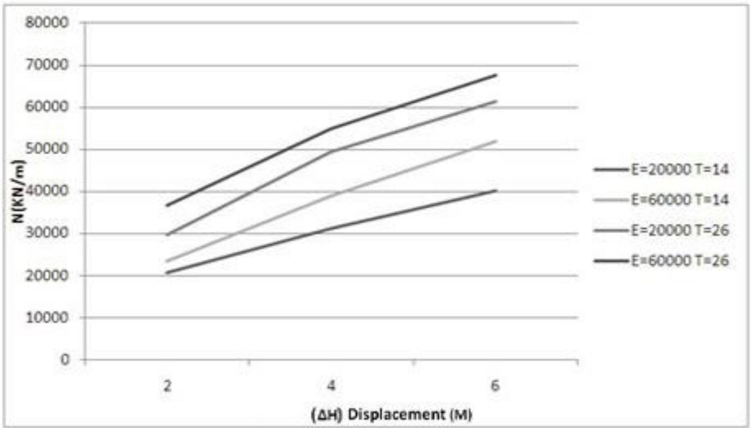


Figure 7. Momentum maximum , axial and shear thrusts in tunnel lining with different soil rigidity & depth with structural variable (fault angle $\alpha = 64$ $\psi = 0$)

Conclusion

The maximum thrusts availed at time of closed space of tunnel face to the fault area pursuant to extensive reviewing axial thrust applied to tunnel lining constructed in the vicinity of fault with elasticity module maximum ,changes of numbers prove the issue that elasticity module provides most effect to axial thrust due to shear and momentum thrust factors generated against tunnel lining face ,thus the rate of momentum ,axial & shear thrust changed significantly pursuant to displacement increment due to presence of fault it seems similar to fault angle, consequently the range of axial and momentum increased because of ψ increment.



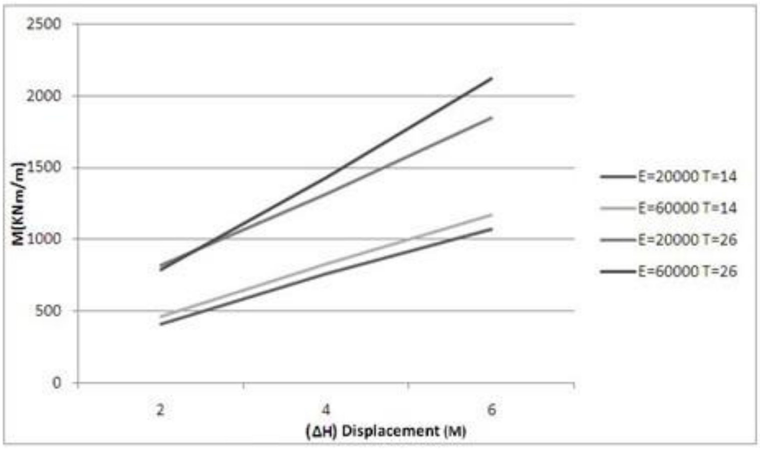


Figure 8. Momentum maximum , axial and shear thrusts in tunnel lining with different soil rigidity & depth with structural variable (fault angle $\alpha = 64$ $\psi = 15$)

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