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Behavior of Steel Lining of a Vertical Sidewall Tunnel in Rock Media under Explosion Loading.

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Abstract

Due to the progressive development of military destructive weapons such as conventional weapons, a consequence development of the fortified structures is essential. One of the most important types of the fortified structures is tunnel in rock media.

The basic premise of this work is studying the response of tunnels in rock-media exposed to high explosion loads, which help tunnel designers and military engineers in estimating displacements, stresses and over all damage in the tunnels due to wave propagation generated by that explosion loads. In this study, the tunnel steel lining for a vertical sidewall cross-section tunnel is studied for different rock types. 2500 kg TNT was used as an explosive load. This charge was located at 3.25m-bellow ground surface. The distance between charge and tunnel crown was fixed to 10m for all models.

With regard to finite element solution, an appropriate mesh is employed to represent the geometry of the problem. The rock and lining are simulated by solid elements (one quarter of the domain) in a three-dimensional finite formulation.

Joint to joint are used to simulate rock-lining interaction. The steel lining thickness to arc radius (ts/R) ratio was considered 1/300, 1/150, 1/100, 1/75 and 1/30 for ts_1, ts_2, ts_3, ts_4, ts_5, and ts_6 respectively. Von-Mises material model is used to simulate the behavior of steel lining. Grade 50 of steel is used where yield stress is 360MPa and the strength is 468.4MPa, modulus of elasticity equal to 210000MPa, elongation equal to 12%.

The response of displacements and stresses, for all rock types and tunnel spans are determined at different lining points.

Key Words: Finite Element, Under Ground Structures, Explosion Wave, Rocks.

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Parameters Affecting the Behavior of Tunnels:

A parametric study is performed for tunnel in rock media under explosion load. The following main parameters are taken into consideration:

1. Rock type.
2. Tunnel radius.
3. Lining thickness.

These parameters have a great influence on the stresses and deformation in rock, and also internal forces in tunnels. Non-linear analysis was conducted for a three-dimensional finite element models by using AUTODYN 3-D version 4.3 package.

Model Description:

Due to the symmetric conditions of this problem and to reduce the running time of the model, only a quarter of the domain is taken as a computation model. Figure (1) shows the F.E. mesh for which the model dimensions in the X and Y-directions are 5R and 7.5m, respectively. The non-reflection boundary is given by transmitting the boundary conditions at ambient rock masses, the plane X=0 and Y=0 are treated as symmetric boundary.

Steel is studied in as a lining material by different thickness ts, (1/300)R, (1/150)R, (1/100)R and (1/75)R and (1/30)R as shown in figure (2). Joint to joint are used to simulate rock-lining interaction. Transmitting boundary is applied at the model boundaries to represent the infinite steel lining.

Material Properties:

Material properties for poor rock, adopted in these models are shown in table (1).

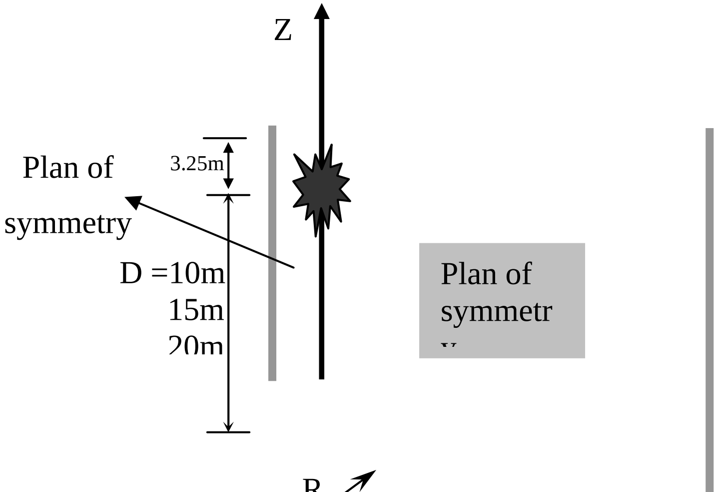
Table (1) Rock properties

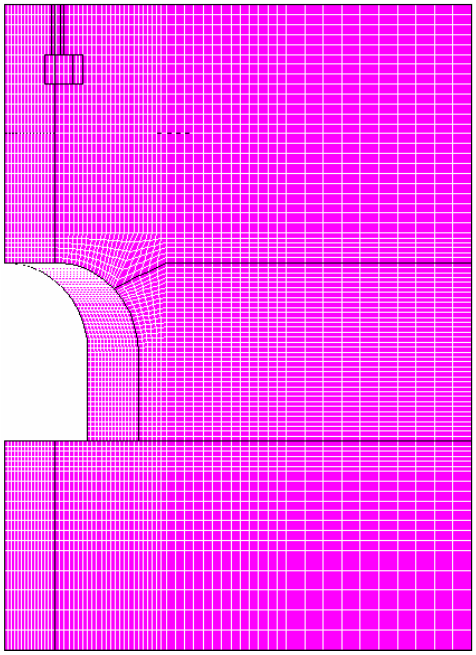
Rock Type	**Rock Quality Design (RQD) %**	**Rock Mass Ratting (RMR) %**	**Density γ t/m^3**	**Modulus of elasticity E GPa**	**Poisson ratio ν**	**Bulk Modulus K GPa**	**Shear Modulus G GPa**	**Unc. Com. Strength MPa**	**Failure Strain**
Hard	90	85	2.75	70	0.23	43.21	28.45	100	0.0025
Mod.	50-75	65	2.4	30	0.25	20	12	25	0.005
Poor	25-50	44	2.21	8.5	0.3	7.083	3.27	10	0.0075

The values of strength and moduli were based on numerous references [1], [2] and [3].

The rock is assumed to be continuous, isotropic and homogeneous medium. RHT brittle material model [4], [5] and [6] is used for characterizing the nonlinear behavior of the rock.

Non-linear Von-Mises material model is used to simulate the behavior of steel lining. Grade 50 of steel is used where yield stress is 360MPa and the strength is 468.4MPa, modulus of elasticity equal to 210000Mpa, elongation equal to 12% [7].





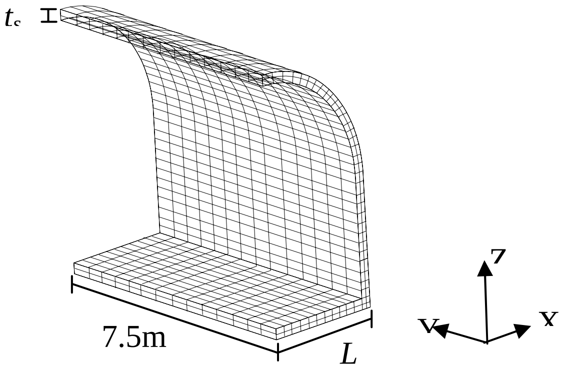


Fig. (2) 3-D FE model of steel lining tunnel

Result and Discussion

Displacements

The displacements time history responses of steel lining tunnel at tunnel crown is shown in figures (3) to (5) for different rock conditions with various thickness of steel lining. The relation between peak displacements responses and lining thickness-radius ratio for different rock types and tunnel spans is presented in figure (6)

From the obtained results and dada shown in these figures, the following points can be noted:

1. Vertical displacements is maximum at crown point of tunnel
2. The increase in tunnel thickness (ts) causes a decline in vertical displacement, this decline is much more noticed up to (1/100)R specially in large tunnel spans case , After (1/50)R, the displacements become constant for hard and moderate rock.
3. The peak displacements at tunnel crown was nearly the same for all tunnel spans, when the lining thickness reach up to (1/30)R

In general, the thickness-radius ratio equal to 1/100 is the economic ratio for reducing the peak displacement at tunnel crown.

Stresses

Since the effect of static loading is very small comparing with the effect of explosion loading, then it can be neglected in this study. The stresses time history response of steel lining tunnel at tunnel crown are shown in figures (7) to (9). Figures (10) to (12) present the relation between peak stresses responses and lining thickness-radius ratio for different rock types and tunnel spans.

From these figures, the following points can be noted:

1. In case of hard rock, the stresses at critical point of lining (around $\theta=22.5^o$) exceed the yield stress only, when the lining thickness is less than (1/300)R for 6m tunnel span.
2. In case of moderate rock, the stresses at critical point of lining (around $\theta=45^o$) exceed the yield stress when, the lining thickness is less than (1/75)R, (1/300)R for 6m, 9m tunnel span respectively, but are not in 12m tunnel span case for any thickness.
3. In case of poor rock, the stresses at critical rang of lining ($0^o < \theta < 67.5^o$) exceed the yield stress (360 MPa) when, the lining thickness is less than (1/30)R for 9m and 12m tunnel span, while the stresses exceed the yield stress in 6m tunnel span for any thickness.
4. For all cases studied the lining stresses do not exceed the steel strength (468.4MPa).

   In general, the required thickness-radius ratio decreases when the tunnel radius increases, also good rock properties

Conclusions

The lining thickness-half span ratio t_s/R equal to 1/100 is considered the economic ratio that can be used to reduce the peak displacement at tunnel crown particularly for weak rocks. The thickness-half span ratio required to resist the explosion decreases due to increasing the tunnel span and improving rock properties. The effect of static loading can be neglected comparing with the effect of explosion loading.

The critical point of lining which is subjected to maximum stresses was around angel θ=22.5° for hard rock, and around angel θ=45° for moderate rock. For poor rock θ was in range from 0° to 67.5°. In hard rock case, the stress at critical point of lining exceed the yield stress for 6 m span when the lining thickness is less than (1/300)R however, this stress does not exceed the yield stress in 9m and 12m span cases. In case of moderate rock, the stress at critical point of lining exceeds the yield stress for 6m and 9m spans when the lining thickness is less than (1/75)R and (1/300)R respectively, but this stress does not exceed the yield stress in 12m span case for any lining thickness. In case of poor rock, the stresses at critical range of lining exceed the yield stress for 9m and 12m span cases when the lining thickness is less than (1/30)R, while this stress exceeds the yield stress in 6m span case for any thickness.

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