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Dynamic Stability Analysis of Shallow Triple Tunnel in Rock

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Abstract. Blast resistant designing of underground structures has become an integral part of safety measures. The designing of tunnels and subways for blast resistance requires an understanding of the behaviour of a structure and its material. The triple-tunnel and other complex tunnel systems are the future of the modern transportation industry. The response of the triple-tunnel system has been analyzed in this study when subjected to airblast. The CONWEP method of blast loading and analysis has been used in the finite element modelling. The tunnel considered in this study has an overburden depth of 10m, and it is a combination of a square box that has two circular boxes at the sides. The each circular section of the tunnel has 5.5m of inner diameter. Moreover, the distance from centre to centre between the two circular sections is 15.5m and the total longitudinal length of the triple tunnel is 27.5m. The triple tunnel passes through Medium Weathered Basalt rock. The Mohr-Coulomb constitutive material model has been adopted for basalt rock. The concrete behaviour has been incorporated by using concrete damage plasticity model. Air blast loading has been applied in the triple tunnel system at four different standoff distances. The source-point of the blast has significant effect on the tunnel stability and deformation has inversely proportional relation with the stand-off distance. The ground surface has experienced 112mm of deformation and crown of the tunnel has 32mm of deformation when the source of blast has 1m of standoff distance. The blasting effect has been completed in 2 milliseconds of time period; however, vibrations existed for the duration of analysis.

Keywords: Triple Tunnel; Basalt; Rock; CONWEP; Blast; Finite Element Analysis

1 Introduction

Tunnels have improved the conveyance between the locations by claiming the underground spaces. These are being used for different purposes such as water tunnel, transportation tunnels, and so on. The study of the performance behavior of the tunnels has become a prime requirement to validate their long term stability under different geographical conditions. With the advancement of technology, underground tunneling has become a preferred choice for the traffic flow so as to save the above ground land for afforestation and urbanization. The stability of the tunnels has been a function of the surrounding medium e.g. soil or rock. The tunnels passing through the soft grounds face the problems of liquefaction as the main concern for their stability [1-5]. The tunnels in the hilly regions require proper designing and few researchers have analysed the behavior of such tunnels by adopting different experimental [6, 7] analytical [8] and numerical [9, 19] approaches.

To further improve the connectivity between the locations, twin tunnels are being constructed. The interaction between the sections of complex tunnels has significant influence of the geometry, method of construction and the properties of ground material, which has been focus of research in the past few years [20-23].

Technological advancements has resulted in the construction of triple tunnels that require further research in this regard as it involve complex geometry. A triple tunnel consists of a three closely spaced tunnels which form a triplet complex for the underground traffic movement. The construction arrangement of the triple tunnel has been discussed by Naseem et al. [24], and a bare minimum amount of research over the dynamic behavior of such tunnels has been performed [25, 26]. However, the behavior of the triple tunnel under the blast loading had rarely been studied in the available literature. Therefore, the present study has been carried out to analyse the behavior of triple tunnel under blasting loadings. The CONWEP method of blast loading has been used in the Abaqus/Explicit to determine the behaviour of the tunnel and the damage developed due to blast loading. The TNT explosive has been assumed to act at four standoff locations in the tunnel to understand the damage caused in the concrete lining. This research would help in the better understanding of the behavior of the triple tunnels under blast loadings.

2 Finite Element modelling of Triple Tunnel

The finite element analysis has been performed by using Abaqus and the blast loading has been incorporated in the model using CONWEP method which is an empirical approach. The section of the triple tunnel has been adopted form a research paper by Naseem et al. [24] and is shown in Fig. 1. The two circular sections of the tunnels are having an internal diameter of 5.5m and are connected by a box of 11.78m arch length. The centre to centre distance between circular sections is 15.5m and the total width of the tunnel is 27.5m with tunnel liner thickness of 0.5m.The numerical model is shown in Fig. 2 which is having a total dimension as 82.5m by 82.5m and the total length of tunnel as 40m.

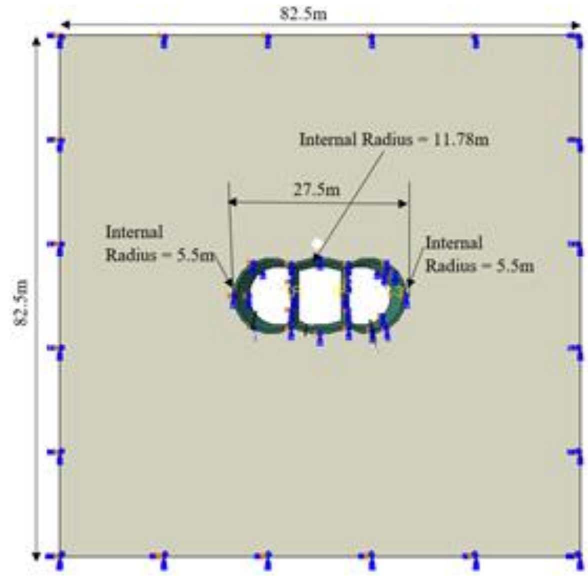
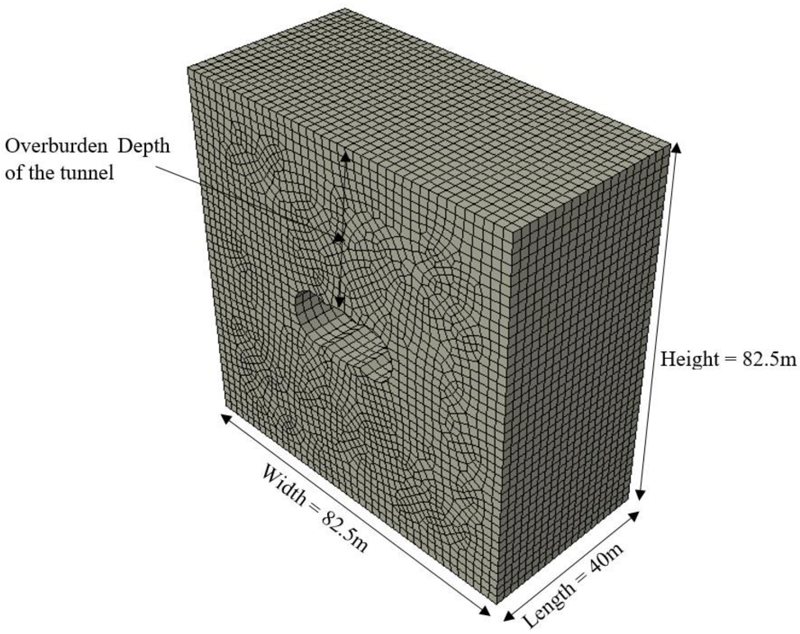
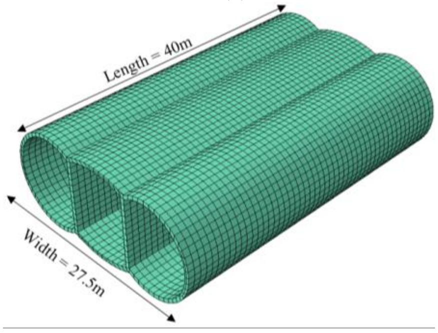


Fig. 1. The Geometry of a present tunnel



(a)



(b)

Fig. 2. Numerical model for blast study of triple tunnel (a) Meshed model and (b) Triple tunnel liner.

Mohr-coulomb constitutive model which introduces the elastoplastic behavior has been adopted to represent the rockmass. The rockmass of Basalt has been used in the analysis with the material properties as given in Table 1. Moreover, concrete of grade 30 (M30) has been used in the analysis to represent the tunnel liner which has been modeled as a concrete damage plasticity (CDP) model. The concrete liner properties have been adopted form the paper from Sadique et al. [27] and are given in Table 2. Both rockmass and the concrete liner have been meshed by C3D8R elements and the size of mesh element has been adopted as 0.7m throughout the study which has been finalised by performing the sensitivity analysis. Boundary condition of the model are fixed at the base and the sides have roller supports

Table 1. Input parameters of Mohr-Coulomb model.

	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio	Cohesion (MPa)	Friction Angle (degree)	UCS (MPa)
Medium Weathered Basalt	2560	2.770	0.272	8.080	43.870	17.800

The analysis has been run for the blast loading by using the CONWEP in Abaqus. The blast loading has been applied at four separate locations by assuming a 1000kg TNT explosive. The three four standoff distance considered in this study are 1m, 3m, 7m and 15m that have been varied in this study.

Table 2. Properties of Concrete-Damage-Plasticity model of M30 grade concrete [27]

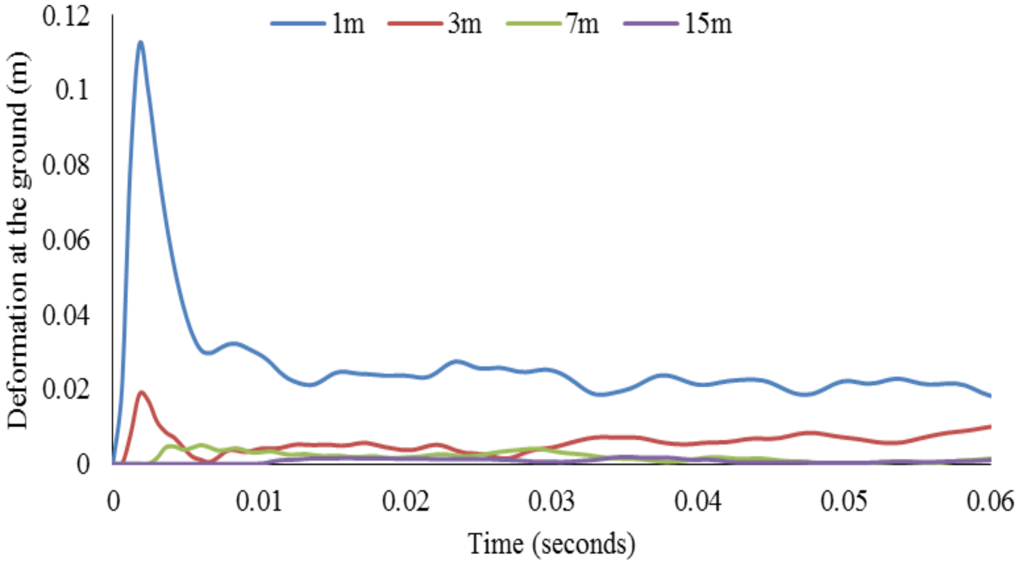
Parameters	Value
Density (kg/m^3)	2400
Modulus of Elasticity (GPa)	27.386

Poisson's Ratio	0.17
Dilation Angle (degrees)	30
Eccentricity (constant)	1
Initial equi-biaxial compressive yield stress to initial uniaxial compressive yield stress (constant)	1.16
Second stress invariant ratio, K	0.666
Fracture Energy released (N/m)	720
Uniaxial Failure Stress (Tension) (MPa)	10.8
Cracking Displacement (m)	0.0001332
Tensile Strength (MPa)	3.86
Compressive Strength (MPa)	30

3 Results and Discussion

This study has been carried out to understand the response of triple tunnel constructed in medium weathered basalt rock. Abaqus/Explicit code has been used for the blast loading. An empirical relation based method, CONWEP method, has been considered for the blast loading on the ground surface in the form of air blast. 1000kg of explosive weight has been assumed in the analysis.

Fig. 3 shows the variation of deformation with the time for the analysis of different cases of blast source point. The distance between the source of blast point and the ground surface has significant effect on the magnitude of deformation at the ground surface and the internal surface of the tunnel. It has been observed that distance of blast source is inversely proportional to the deformation in the tunnel and ground surface. Therefore, maximum deformation due to surface blast will occur for the lesser distance. Moreover, tunnels will be safer for the cases when source point lies far away from the tunnel. For the 1m distance between the source of blast of the surface, the maximum deformation has been observed and peak of maximum deformation has been observed before 2 milliseconds.



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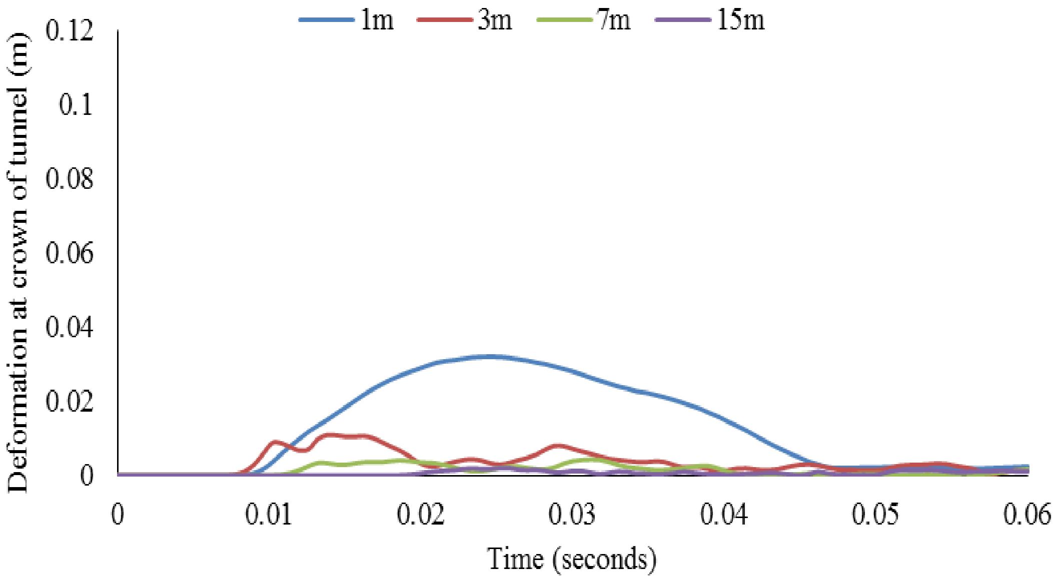
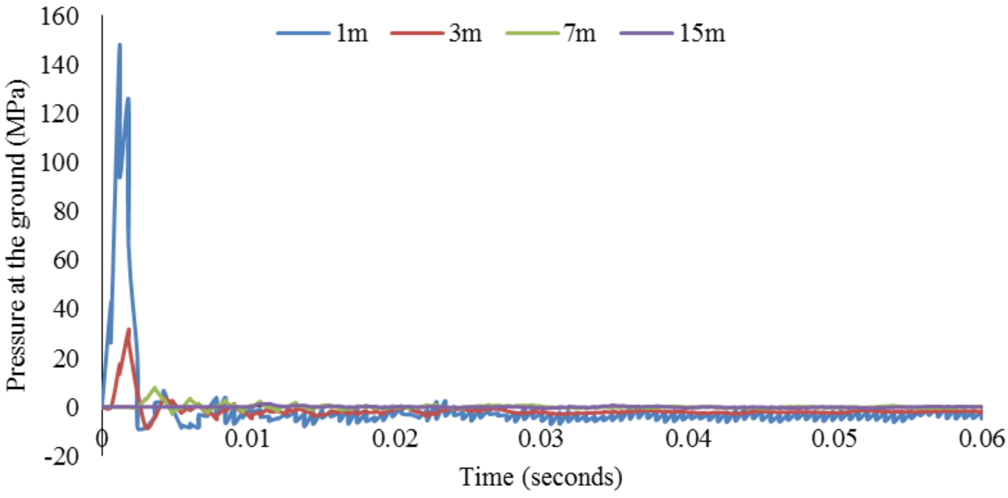


(b)

Fig. 3. Plot of deformation versus time at (a) ground point above the crown of the tunnel and (b) the crown of the mid-section of tunnel for the comparison of different distances between the source point and the ground surface



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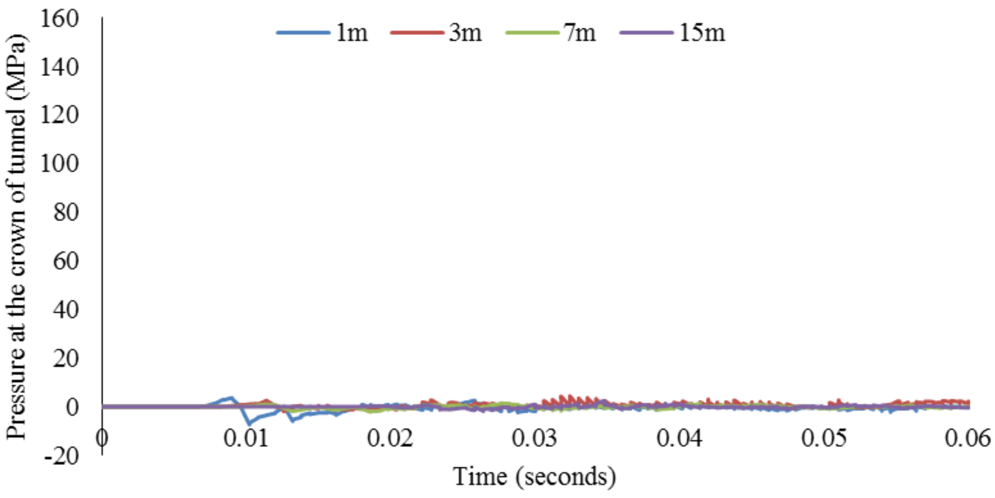
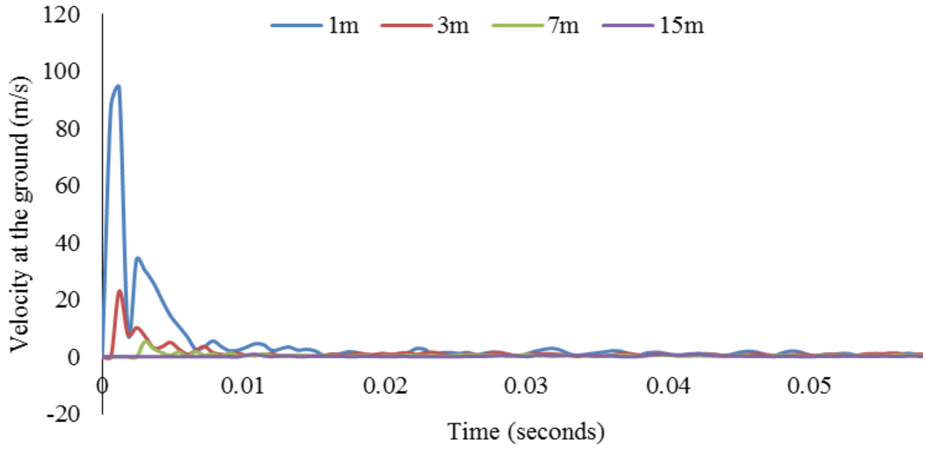


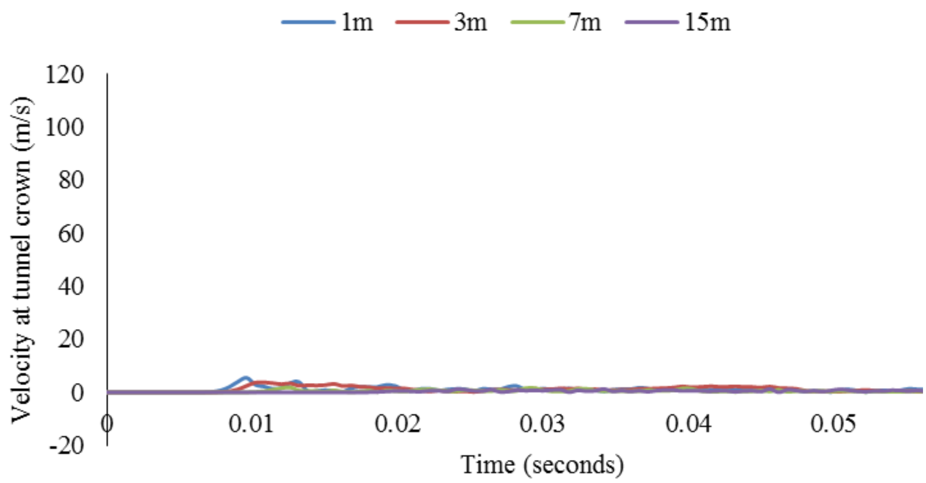
(b)

Fig. 4. Pressure-time response at (a) ground point above the crown of the tunnel and (b) the crown of the mid-section of tunnel for the comparison of different distances between the source point and the ground surface

Fig. 4 shows the response of triple tunnel when subjected to surface blast loading in terms of pressure variation with time at crown of the tunnel and ground surface. The peak pressure has been observed before 0.01 seconds in all the cases. The pressure magnitude at the crown of the tunnel is negligible in comparison to the magnitude of pressure at the ground surface. The maximum pressure has been observed at the 1m distance between the source and the surface of blast loading and minimum pressure has been observed for 15m distance.



(a)



(b)

Fig. 5. Variation of velocity with time for the comparison of different distances between the source point and the ground surface at (a) ground point above the crown of the tunnel and (b) the crown of the mid-section of tunnel

The variation of velocity with time gives an idea about the disturbances in the medium when blast waves interact with the surface, is shown in Fig. 5. It has been observed that when the source of blast in at short distance than there is maximum disturbance in the medium. Moreover, the disturbances decrease in the medium as the distance of blast source keeps on increasing. In addition, the disturbances in the case of 1m are 4.5 times greater than the 3m case.

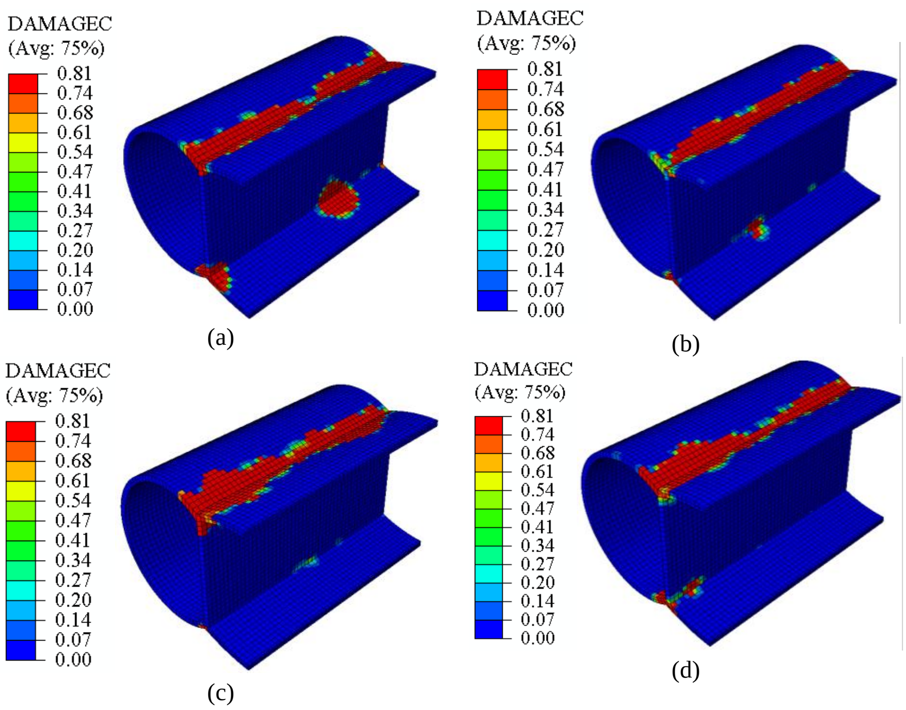


Fig. 6. Contours of compression damage in the concrete lining of the tunnel when source of blast is at (a) 1m, (b) 3m, (c) 7m and (d) 15m

The serviceability and health of the tunnel is greatly affected by the dynamic loads, especially blast load. The failure of the concrete lining of the tunnel is shown in the form of damage contours in Fig. 6 and Fig. 7 for compression damage and tension damage respectively. The triple tunnels are damaged highly when the blast source is at 1m distance while lesser damage has been observed for case of 15m distance. Therefore, the section of the long length triple tunnel is said to be more serviceable when the blast occurs at far distance.

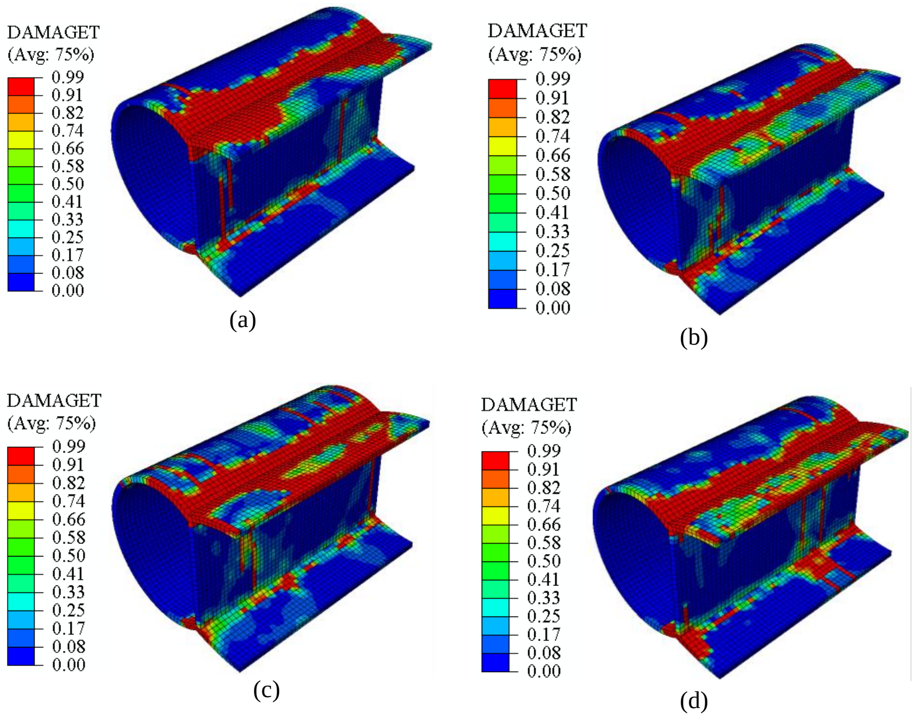


Fig. 7. Contours of tension damage in the concrete lining of the tunnel when source of blast at (a) 1m, (b) 3m, (c) 7m and (d) 15m

4 Conclusion

The blast resistant analysis of triple tunnel constructed in medium weathered Basalt has been analyzed in the present study using nonlinear finite element technique. Four different standoff distances have been considered to understand the extent of tunnel against airblast. It has been concluded that:

a) The maximum deformation at the ground surface has been observed before 3 milliseconds of time period and a crater has formed due to 112mm of deformation. Moreover, the depth of crater and magnitude of deformation reduced by approximately 6.5-times when standoff distance has been increased from 1m to 3m. Further, increase in the standoff reduces the magnitude of deformation in the rock.

b) The internal surface of the tunnel has experienced maximum deformation when blast source has 1m standoff distance that resulted in 32mmod deformation. However, in other cases the magnitude of deformation remains insignificant.

c) The vibration at the ground reduces in a short duration of time but it subsists for longer duration at internal surface of tunnel.

d) The damage of the concrete lining remains significant along the boundary of boxes in the triple tunnel, and therefore, crushing of concrete has been observed throughout the length of tunnel along the intersection boundary.

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