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Deformation response of Twin Tunnels under the effect of static loading conditions.

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Abstract. Underground structures can be used in various application such as transportation, sewage, gas pipelines, military purposes etc. Design parameters of underground structures play an important role in the stability of structures. Underground structures are subjected to various type of loads such as static, dynamic etc. So, the stability of underground structures is a major topic in order to keep structure safe in various loading conditions.This paper presents the deformation behavior of Twin Tunnels under the effect of static loading conditions. The objective of this work is to simulate the in-situ conditions through physical modeling. The spacing between the Twin Tunnels models is varied as 1.5D, 2D and 2.5D where "D" is the diameter of the tunnel. Both lined and unlined samples of Twin tunnel are prepared in laboratory. Plaster of Paris is used for making tunnel models. From the results it may be concluded that deformation of twin tunnels largely depends upon the spacing between the two tunnels. The results which are obtained from tests are studied for computation of stress and deformation in tunnels.

Keywords: Underground Structures, Deformation, Static Loading, Geomaterial.

1. Introduction

Tunnels are horizontal, man-made underground passages that can be constructed without affecting the surrounding surface. Materials are typically transported through tunnels. Tunnels can be built through rocky terrain, including hills, rivers, etc. Tunnels are utilised for many different things today. There are many different uses for tunnels, including for highways, railroads, sewage and water supply tunnels, underground power plants, storage facilities, etc. Given the wide range of underground applications, it is crucial to take into account the many facets of underground openings as well as their stress and deformation characteristics. Any opening initially stresses rock, which creates early stress.The construction of the underground tube is quite old. In general, a tunnel structure is needed when a railway or highway route encounters an obstruction. In ancient times, tunnels were created to deliver pure water to key cities. Such tunnels are still used for the same purpose in Jammu and Kashmir, Egypt, Greece, Rome, and other places. Historically, manual mining techniques were used to create a number of tunnels in hard rock. Timber was employed as a temporary support to ensure the security of the tunnel workers. Brunel created the tunnelling shield in the 19th century, which prevented numerous fatalities due to timber collapses. The tunnelling technique, which is still in use today, was somewhat modified in the 20th century and given the term "open-faced" approach. Later in the 20th century, circular tunnel linings were employed to transport the weight of the rock and soil. The first tunnel was built some 4000 years ago. That tunnel was built in Babylon to connect two structures. Both the Egyptians and the Babylonians built it. That tunnel measured 3.6 metres in width, 4.5 metres in height, and 910 metres in length. Claudius, the Roman emperor, constructed the first tunnel in Europe later on to transport spring water through the Appennine Mountains.Chehade and Shahrour (2008) conducted a study on the interaction behaviour of twin tunnels with the help of numerical software. From the results, it can be concluded that higher settlement will occur if the upper tunnel is constructed first. Elshamy et al. (2013) conducted a study to determine the effect of different shapes of the tunnel on its deformation behavior. From the result obtained from the study, it is noticed that the circular tunnel is the best shape of twin tunnels. Yingjie et al. (2014) investigated the failure process of weak rock surrounding the tunnel using physical and computational methods. According to the findings, the weak rocks surrounding the tunnel fail predominantly due to shear wedge failure in the minimal principle stress direction, causing the tunnel arch to collapse. Oliaei and Manafi (2015) noticed that vertically aligned tunnels experienced the maximum settlement. Bayoumi et al. (2016) determine the effect of the construction of a twin tunnel on the structure with the help of PLAXIS 2D software. From the results, it has been concluded that the construction procedure affects the settlement of vertical twin tunnels.Kumar and Shrivastava (2017) and Kumar and Shrivastava (2019) reviewed the various factors which affect the stability of underground structures. A study conducted by Shrivastava and Rao (2011), Shrivastava and Rao (2015) and Shrivastava and Rao (2018) concluded that the shear behaviour of infilled rock joints depends upon the thickness of the infill material. Singh et al. (2018) conducted a numerical investigation to analyze the spacing and diameter effect on the stability of twin tunnels and concluded that the minimum spacing for twin tunnels should be 0.8 times the diameter of the circular opening. Kumar and Shrivastava (2021) conducted a study on the deformation behaviour of a single tunnel under static loading conditions and concluded that in the case of tunnels at shallow depths the extent of the damage along the tunnel axis depends upon the strength characteristics of the rock. Mishra et al. (2018) discuss the effect on the shallow tunnel under static and dynamic loading. The result shows that the strength of the rock plays an important factor in stability behaviour.Mishra et al. (2021) conducted a study to investigate the stability behaviour of a single tunnel in soft rock and found that depth of tunnel, intensity of drop load and strength of rock decide the extent of deformation in tunnel. Kumar and Shrivastava (2022) conducted a comparative study on the deformation behaviour of single and twin tunnels and concluded UCS value of the model material plays an important role in the deformation of tunnel.

1.1 Selection of the Model Material.

Finding a model material that can be utilised to imitate actual rock conditions is the main obstacle encountered during the testing phase because it is very difficult to incorporate all the challenges that must be confronted in the field circumstances in the laboratory. As a result, a material that can be utilised to prepare rock tunnel samples and imitate real-world field conditions is discovered in order to address this issue. Plaster of Paris is chosen as the model material because it is commonly available and has the ability to mould into any shape when mixed with water. Kumar and Shrivastava (2021) used plaster of paris as a model material in creating rock tunnels models. The compressive strength plaster of paris is around 8MPa which is greater than 1MPa therefore it represents the rock behavior. According to Deere Miller classification (1968) the classification of plaster of paris is done as EM (Medium Elastic). The following Table 1 gives a summary of properties of model material.

Table 1.Properties of Model Material

Properties	Value	Testing Method
Dry Density (kN/m^3)	12.19	ISRM (1972)
UCS (MPa)	10.6	ISRM(1979)
Modulus E_{t50} (MPa)	2510	ISRM(1979)
Tensile Strength (MPa)	0.79	ISRM(1979)
Deere–Miller Classification (1968)	*EM*	Deere Miller classification (1968)

1.2 Fixing dimension of tunnel models

The twin tunnel sample measures 425x375x230mm in size (LxWxH). The boundary conditions, i.e., r=4a, where "a" is the tunnel's radius, indicate the twin tunnel's width. Three distinct spacings, 1.5D, 2D, and 2.5D (where "D" is the tunnel's diameter), are evaluated for twin tunnel samples. The tunnel's cover depth is kept between 3 cm and 5 cm below the surface of the model. The tunnel's diameter is held constant at 5 cm. When it comes to twin tunnel models, PVC pipe is once again used as a liner material for lined tunnels.

1.3 Casting of Twin Tunnel Models

The plaster of paris used to create the twin tunnel samples. As indicated in Fig. 1, 18 of the approximately 36 tunnel samples cast for twin tunnel samples are unlined tunnel samples whereas 18 lined twin tunnel models are casted. After the casting of tunnel sample, they are left undisturbed for 28 days under air curing conditions before being evaluated under static loading circumstances. Fig.1.shows the Twin Tunnel Samples having different c/c spacing and cover depth.

Fig.1. Twin Tunnel Samples having different c/c spacing and cover depth.

1.4 Physical modelling of Twin tunnel

Physical modelling technique is very useful to imitate field circumstances in the lab because it is impossible to conduct all the experiments in the field. Because there are many unfavourable circumstances in the field that prevent the ideal testing from being done successfully. Field experiments are challenging to carry out for practical reasons, so physical model testing must be utilised instead.

The sample used in the Twin Tunnel case is made of 100% plaster of paris with 60% water content. The twin tunnel sample remains 42.5x37.5x23 cm in size (LxWxH). Three distinct spacings, 1.5D, 2D, and 2.5D (where "D" is the tunnel's diameter), are investigated for twin tunnel samples. The tunnel's cover depth is kept between 3 cm and 5 cm below the surface of the model. Twin tunnels are prepared as lined and unlined samples in the laboratory. Six LVDTs are positioned in various positions to collect the tunnel sample's deformation. According to the degree of deformation that occurs in the tunnel sample, the placement of LVDTs is chosen.Each tunnel has three different locations for the three LVDTs. L is the length of the tunnel, and the distances between LVDTs are L/3, L/2, and 9L/15. The identical approach used in one tunnel is used to insert the LVDTs. Six 10mm-diameter holes are drilled from the surface's bottom for installation. The LVDT is then secured with the use of a three-pin clamp to keep it tight and prevent movement.

1.5 Result and Discussions

Plaster of Paris material is employed as the model material for Twin tunnel samples. The static loading condition is applied to the 1.5D c/c spaced twin tunnel sample. The maximum crown deformation value for 3 cm unlined tunnels is 0.25 mm, measured at L/2 distance. While at L/3 and 9L/15, the deformation measured was 0.03mm and 0.16mm, respectively. The crown deformation in 5 cm unlined tunnels is 0.20 mm at L/2 distance, 0.02 mm at L/3, and 0.12 mm at 9L/15, respectively. In the case of lined tunnels having 1.5D centre to centre spacing and 3cm cover depth, the crown deformation at L/2 distance is 0.12mm, whereas the deformation noticed at points L/3 and 9L/15 is 0.01mm and 0.07mm.The crown deformation at L/2 distance in lined tunnels with 1.5D center-to-centre spacing and 3cm cover depth is 0.12mm, but the distortion seen at points L/3 and 9L/15 is 0.01mm and 0.07mm. The deformation encountered at L/3, L/2, and 9L/15 in the case of 5cm lined samples is 0.01 mm, 0.10 mm, and 0.05 mm, respectively as shown in Fig 2.

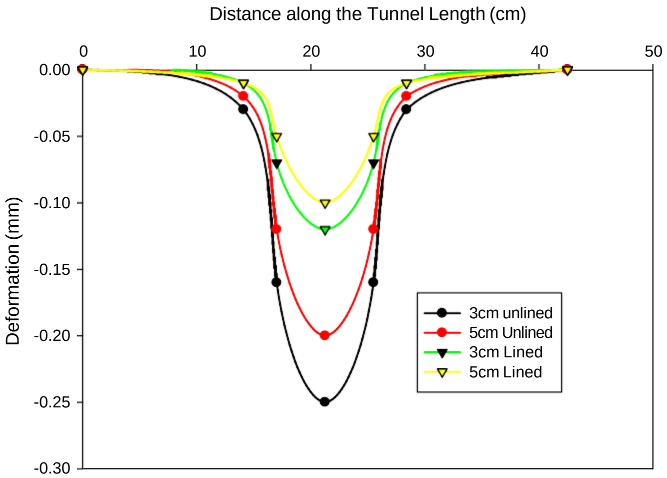

Fig.2. Deformation profiles of 1.5D c/c spacing twin tunnels models obtained from experimental results.

The highest crown deformation value for 2D c/c spacing twin tunnels of 3 cm unlined tunnels is 0.22 mm, obtained at L/2 distance. While at L/3 and 9L/15, the deformation measured was 0.02mm and 0.14mm, respectively. The crown deformation in 5 cm unlined tunnels is 0.18 mm at L/2 distance, 0.02 mm at L/3, and 0.11 mm at 9L/15, respectively. The crown deformation at L/2 distance in lined tunnels with 2Dcentre to centre spacing and 3cm cover depth is 0.10mm, while the distortion seen at L/3 and 9L/15 is 0.01mm and 0.06mm, respectively. The deformation encountered at L/3, L/2, and 9L/15 for 5 cm lined samples is 0.01 mm, 0.07 mm, and 0.04 mm, respectively as shown in Fig 3.

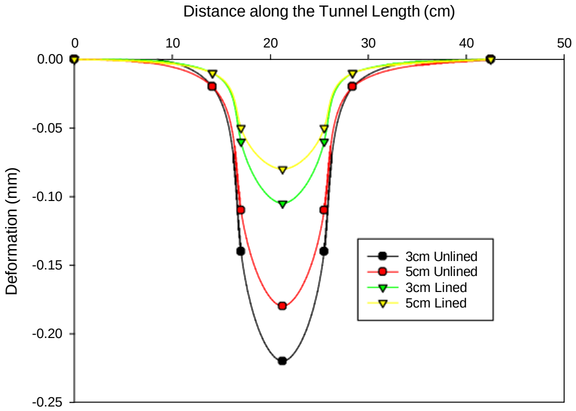

Fig.3. Deformation profiles of 2D c/c spacing twin tunnels models obtained from experimental results.The highest crown deformation value for 2.5D c/c spacing twin tunnels of 3cm unlined tunnels is 0.19mm, obtained at L/2 distance. While at L/3 and

9L/15, the deformations are 0.02mm and 0.10mm, respectively. In 5 cm unlined tunnels, the crown deformation at L/2 is 0.16 mm, whereas the deformation at L/3 and 9L/15 is 0.02 mm and 0.09 mm, respectively. The crown deformation in lined tunnels with 2.5D center-to-centre spacing and 3cm cover depth is 0.09mm at L/2 distance, whereas it is 0.01mm and 0.04mm at L/3 and 9L/15, respectively. The deformation encountered at L/3, L/2, and 9L/15 in the case of 5cm lined samples is 0.01mm, 0.08mm, and 0.03mm, respectively as shown in Fig 4.

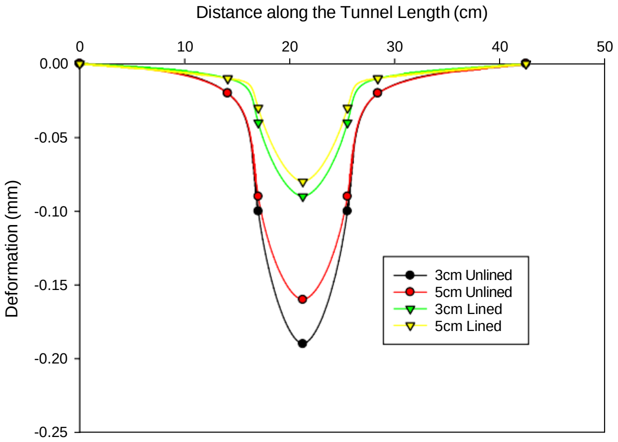

Fig.4. Deformation profiles of 2.5D c/c spacing twin tunnels models obtained from experimental results.

1.6 Conclusions

A comparative study is carried out in this study on the deformation behaviour of twin tunnels with the help of experimental investigation. Various unlined and lined twin tunnel models are prepared in the laboratory with varying strength properties, cover depth and spacing between the tunnel. The following conclusion can be made for the present study.

- The maximum deformation is recorded at center of the tunnel i.e at L/2 distance in all the cases and minimum at L/3.
- The extent of deformation in tunnels mainly depends upon the presence of liner material. Less deformation is observed in lined tunnels as compared to unlined tunnels.
- With increase in the spacing between the twin tunnel,the value of deformation decreases.

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