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Settlement Analysis and Building Damages Associated with Tunneling

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***Abstract*: High growth in population tends to increase in demand of the infrastructures. As the ground space becomes limited, it is essential to construct underground structures. Tunnel construction induces ground movements which includes urban areas, hilly areas etc. It causes damages to buildings and constructions above the ground. The tunnel designs which are used for construction are based on the site conditions and the experiences which get from geological investigations. Besides, the mechanisms which control the tunnel-soil-structure interaction problems are not well understood yet. These conditions varies according to the geological conditions. As such, new tunnel projects are being constructed beneath high density urban areas, the construction and operation of these systems can cause a restriction of services, and damage to surface or other subsurface structures. Therefore, the prediction of tunnel induced building deformation becomes issue in the planning process. As deep excavations initiate lateral and vertical ground deformations due to the stresses relaxation and bottom heave associated with the excavation process, the adjacent buildings and buried utilities become kinematically loaded by the induced ground deformations which depend in magnitude and direction on the building proximity to the excavations.**

***Keywords*: settlement analysis, building damages.**

1. Introduction

Ground movements are certain to happen when construction is done in soft grounds. When an underground construction takes place in an urban area it causes damages to existing structures or buildings above the ground. For grounds not having any presence of constructions i.e., under green field conditions semi- empirical method is a used. To calculate the interaction between ground soil and tunnel and subsurface structures, Finite Element Method is used.

Tunnelling in ground disturb the stresses in the ground and induced deformations. Therefore, to control these ground movements in allowable is an important task for civil engineers working at the site. Excessive settlement, differential settlement, tension, and angle twist in façade causes the damages to an existing structure on the ground. Some criteria are given by Burland et al., 1977; Bhattacharya & Singh, 1984; Yu et al., 1988; Rankin, 1988; Boscardin & Cording, 1989; Forth et al., 1995; Mair et al., 1996 to control the damages in the buildings but these criteria varies according to the ground conditions. It is given that the influence the serviceability of a building, but it does not harm or cause little or no damage to its structure. So, the factors which affects the ground conditions are differential settlement and angle twist in facade. The deformation of a building must be surveyed before the underground construction is going to start, and allowable incremental deformation should be determined by considering the existing deformation. During a construction process, both the total and incremental deformations should be controlled.

The objectives of this study are, to identify the behavior of the structures above ground. To identify surface settlements and building damages. To measure the quantity of settlements and degree of damage of buildings. How to avoid settlement and damages caused due to construction of tunnels deformation of the adjacent structures as a result of the ground displacements.

2. Deformation of Ground in Green Field Condition

A. Surface Movement

1) Transverse behaviour of ground

Peck (1969) stated that the transverse settlement trough can be given by a Gaussian error function or invert probability curve which is given below.

$$S_Y = S_{max}\exp(-y^2/2i^2) \quad (1)$$

Where,

- S(y) is the vertical settlement at point y
- S_{max} is the maximum settlement directly above the tunnel centreline
- y is the transverse horizontal distance from the tunnel centre line of the trough
- i is the trough width parameter

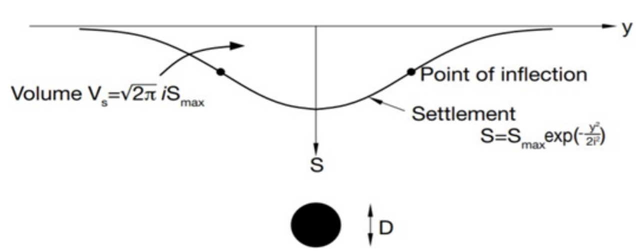

Fig. 1. Gaussian curve for representing the transverse settlements above a tunnel

Here, maximum slope at the point of inflection. Point of

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inflection is a point where the curve changes its concavity that is from cancave curve to convex and vice versa. The volume of the surface settlement trough (per meter length of tunnel), VS, can be approximated by integrating the equation 2.

$$V_s=\sqrt{2\pi} i \, S_{max} \quad (2)$$

Where,

- V_s is the volume of settlement trough per unit length

In materials with a low permeability such as stiff clay the initial response of the ground to the tunnel construction can be considered to be undrained. The volume of the surface settlement trough therefore is equal to the volume of soil which is excavated in excess of the theoretical volume of the tunnel. It is given as follows,

$$V_L = [V_s / \pi. (D^2/ 4)] \quad (3)$$

Where,
V_L= Volume loss
D = Outer diameter of tunnel

2) Longitudinal behaviour of ground

Attewell & Woodman (1982) stated that the longitudinal settlement profile can be given by considering a tunnel as a number of point sources in the longitudinal direction. Here, it has been found that the vertical displacements can be estimated by a 'cumulative probability curve' which is given in following figure.

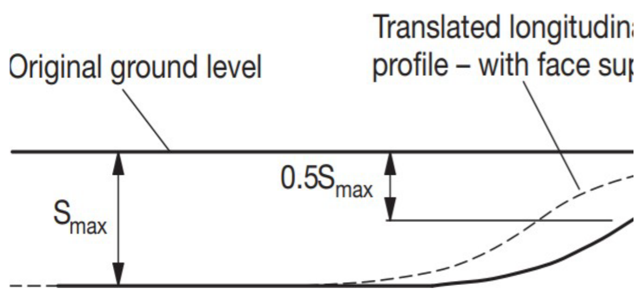

Fig. 2.

- For tunnels constructed in stiff clays without face support, the surface settlement directly above the tunnel face corresponds to 0.5 S_{max}.
- For tunnels in soft clays with face support, for example in EPB or slurry shield machines, the surface settlement directly above the tunnel face is much less than 0.5Smax.

Above figure shows a longitudinal settlement profile. Settlement increases in the negative y-direction and reaches Smax at y = -∞ while S_v = 0 develops at y =∞. The settlement at y = 0 is equal to $S_{v,max}/2$. Attewell & Woodman (1982) showed that in stiff clay 30% - 50% of $S_{v,max}$ occurs above the tunnel face with an average value at about 40%. For convenience it is often assumed that the tunnel face is at y = 0 where 50% of $S_{v,max}$ is predicted, adopting the coordinate system. Attewell & Woodman (1982) assumed that if the resultant displacement vectors point towards the centre point of the current tunnel face then the longitudinal soil displacement in horizontal direction is given by,

$$S_{hy}(y)_{x=0} = [V_L D^2 / 8z]*e^{-y2/2i2} \quad (4)$$

To calculate horizontal strain in longitudinal direction above the tunnel centre line, differentiate Shy with respect to y.

$$€hy(y)x=0 = -y*[VLD^2/8i^2Z0] *e^{-y2/i2} \quad (5)$$

Here it describes the tension i.e., the positive value ahead of the tunnel face (negative y-coordinate) and compression behind.

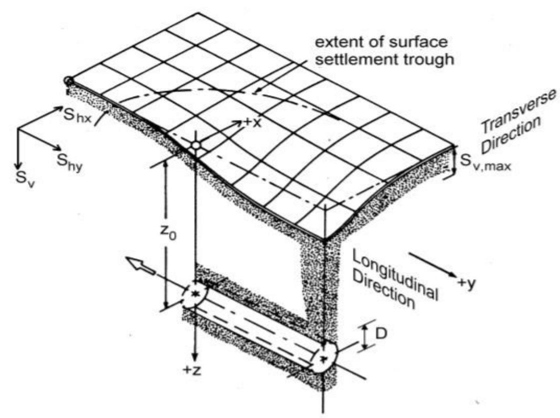

Fig. 3.

3) Volume Loss

While constructing a tunnel, it leads to excavate more amount of soil than the volume tunnel to be replaced. This amount of over excavation is calculated by the Volume Loss which is the ratio of the difference between volume of excavated soil and tunnel volume. For shield tunnelling Attewell (1978) divides the sources of volume loss into 3 categories: -

- *Face loss V1:* Soil movement towards the tunnel face as a result of full (open face) or partial (closed face) stress relief at the tunnel face.
- *Shield loss V2:* The radial ground loss around the tunnel shield due to the presence of the annulus around the shield and the soil (over-cutting and ploughing of the tunnel shield).
- *Ground losses behind the shield V3:*
  a) Ground loss during and subsequent to lining erection: There is a gap of unsupported soil over which soil can squeeze into the tunnel. Once the lining is constructed soil movement might occur around the lining.
  b) This ground loss can be minimize ich soil can using tail grouting. Ground loss after grouting: Radial losses continue after grouting as the lining is de-formed due to the transfer of overburden

pressure to the new boundary.

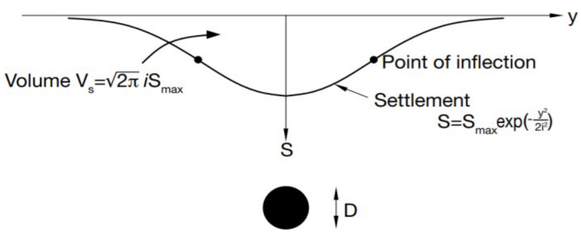

Fig. 4.

4) Trough width parameter

Trough width parameter is the parameter which describes the width of the settlement trough. It is the distance of point of inflection from centre line of the tunnel.

5) Trough width parameter

Trough width parameter is the parameter which describes the width of the settlement trough. It is the distance of point of inflection from centre line of the tunnel. O'Reilly & New (1982), from linear regression, obtained the relation by plotting the trough width parameter i against the corresponding tunnel depth z_0:

$$i = 0.43z_0 + 1.1$$

When linear regression passes closer to centerline of tunnel then the equation becomes:

$i = K_{z0}$ (the value of K varies between 0.4-0.7 for stiff and soft clay)

B. Subsurface Movement

Mair & Taylor (1993) gives a linear relation to describe ground movements as S_v/R or S_{hx}/R against R/D where R is radius of the tunnel and D is the vertical/horizontal distance from the centre of the tunnel. In their work Mair & Taylor (1993) only focused on vertical soil movement above the tunnel centre line and on horizontal movement at tunnel axis level. When describing the shape of transverse subsurface settlement troughs, a Gaussian curve is commonly adopted.

Mair et al. (1993) showed that this assumption is in reasonable agreement with field data. To predict the settlement trough parameters I of subsurface settlements they substitute (z0-z) for the depth of the tunnel z0. Which is given by:

$$i = 0.5(z_0 - z)$$

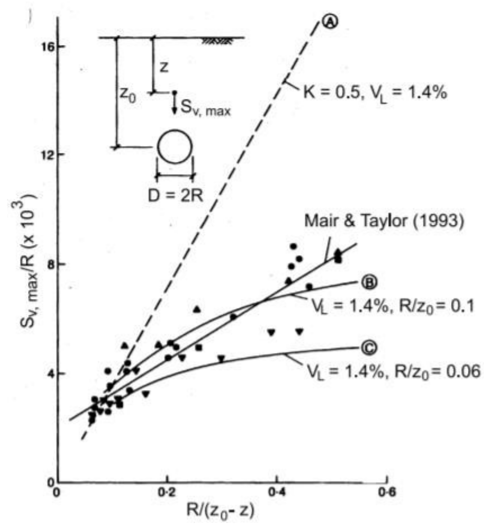

Fig. 5. Subsurface settlement above tunnel centre line (After Mair et al., 1993)

3. Conclusion

It is clearly accepted that the greenfield data which is calculated for the transverse surface and subsurface settlements are calculated by Gaussian Error curve. The Cumulative error curve is used to calculate longitudinal surface settlements. A comparison of calculated and measured displacements is often not possible because tunnelling conditions are too variable to be modelled adequately in the calculations. It must not be forgotten that the measured displacements are the true displacements, and not the calculated values. If the measured displacements cannot be checked against calculated triggers, the monitoring cross sections have to be checked against each other.

References

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