PERFORMANCE OF MICROPILES TO MITIGATE TUNNELLING EFFECT ON ADJACENT STRUCTURES

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Abstract—Tunnels have become an inevitable part of the urban transport systems, having greater demands now-a-days. Along with advantages of tunnel, it comes with deleterious effects on the structures adjacent to its alignment, which may be due to vibrations / volume loss of the soil material. Tunnelling may pose serious problems to the buildings which are historically important, vulnerable, old etc. There are various measures to mitigate the effect of tunnelling on the adjoining structure. Providing series of micropiles along the tunnel alignment is one such measures. In this study, analyses of micropiles are carried out using MIDAS GTS 3D software. The various parameters considered for analyses are length, number & spacing of micropiles, type of soil and foundation. Reduction in settlement of raft & pile foundations due to provision of micropiles were evaluated and optimum number, length & spacing of micropiles were decided from the analysis.

Keywords—Tunnelling, micropiles, mitigation, settlement, raft, pile foundation.

I. INTRODUCTION

Tunnelling is a process to excavate the soil so as to prepare an underground passageway known as tunnel. Tunnels are used for many purposes such as transportation, water lines, sewer lines etc. Various machines are used for the excavation of tunnel viz. Earth Pressure Balance, Slurry Shield, Open Face Tunnel Boring Machines etc.. Due to increased demand for the transit systems & services, unavailability of open lands to be provided; tunnels became most suitable option to serve the purpose, especially in the crowded cities and urban areas. Tunnels avoid interference of services with the utilities above the ground, thus avoiding congestion of utilities.

Tunnel is useful in many aspects, but it is harmful to the adjacent structures as well. Tunnelling may prove very harmful to the buildings which are founded on weak soil and are on the verge of vulnerability. To safeguard such structures it is necessary to mitigate deleterious effect of tunnelling on the adjacent structures by providing a barrier between tunnel and adjacent structures.

Various types of barriers can be provided between tunnel and adjacent structures viz. row of piles, micropiles, jet-grouted columns and diaphragm wall etc. Diaphragm wall is more efficient in mitigating tunnelling effect by virtue of its continuity in length. Row of piles / micropiles has less efficiency for the mitigation of tunnelling effect due to loss of continuity i.e. spacing. However, to undertake mitigation of tunnelling effect in crowded/ urban areas, micropiles prove more suitable due to the ability of its easy installation in constricted areas. Compared to other types, micropile is more suitable as mitigation technique in constricted areas. Tunnelling causes settlement & horizontal displacement of the foundation, mitigation of which is studied by using MIDAS GTS 3D software.

Paper is organized in sections viz., Section II briefly explains the studies on various techniques for the mitigation of tunnelling effect; the detail of analytical study is presented in Section III; Section IV presents the results of analysis and Section V presents conclusion of analyses.

II. LITERATURE REVIEW

Few studies had been carried out on the mitigation of settlement of adjacent structures due to tunnelling. Some experimental and analytical studies performed by various authors are briefly explained as follows.

Houman Sohaei et al. (2017)¹ performed an experimental study on the performance of micropile to mitigate tunnelling effect on the adjacent pile. It was found that micropile length of 145 mm, placed at 0.5D from the tunnel centre is more effective than other lengths & positions respectively. This method reduced the pile settlement and the pile lateral movement by more than 75 and 86%, respectively, compared with the situation without micropiles.

Emilio & Russo (2011)² performed numerical analyses on the effectiveness of row of piles, by means of the FE code Plaxis 3D Tunnel, to prevent damages induced by tunnel and compared the results of piles with the results of diaphragm wall. Use of rows of isolated piles caused a quick reduction in efficiency as compared to continuous-diaphragm walls. In the range s/b = 12 to s/b = 6, no significant benefits were expected by the reduction of the spacing and the computed efficiency was rather low (about 0.3).

Jinyang Fu et al. (2016)³ performed 3D FE analytical study on the use of jet-grouted partition wall as a mitigation technique for the ground movements. Authors concluded that, the efficiency of a partition wall could be improved by
increasing the modulus and thickness of the wall, the partition range angle, and the insert depth below the tunnel invert. Partition wall also cut off groundwater variation during the tunnel construction stage.

E. Bilotta (2008) conducted a series of centrifuge tests & numerical analyses to study the use of diaphragm wall to reduce ground movements due to tunnelling. It was concluded that, the effectiveness of the diaphragm wall mainly depended on its length and fundamental difference of behaviour was observed between rough and smooth walls. To perform well, a rough wall should not be too heavy. The efficiency of a light, rough wall increased with the length of the wall, and light, rough walls should be founded at least half a diameter below the tunnel invert. As the unit weight of the wall increase relatively to the unit weight of the surrounding soil, its efficiency decreased.

III. METHODOLOGY

The main objective of the research was to analyse the performance of micropiles to mitigate deleterious effects on the adjacent buildings due to tunnelling by using MIDAS 3D GTS software. The various parameters those were considered for the analysis are: a) Type of existing foundation, b) Length of micropiles, c) Number of micropiles and d) Spacing of Micropiles etc.. Fig.1. shows the existing condition for the analysis with the provision of micropiles between tunnel & foundation.

Fig.1. Existing conditions considered for the Analysis showing Elevation & Plan of: a) Raft & b) Pile Foundation

Fig.1 also shows the dimensions of the model in detail. The various parameters considered for the analysis were length, spacing & numbers of micropile, type of soil & foundation.

Where,
L = Length of Micropile (m),
S = Spacing of Micropile (m),
X = Distance of Micropile from Tunnel Centre (m),
H = Horizontal distance between Tunnel Centre & Foundation (m),
D = Diameter of Tunnel (m),
N = Number of Micropiles (m).
The properties of the materials used for various components in the model is shown in Table 1.

### TABLE 1

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Medium Dense Sand</th>
<th>Medium Clay</th>
<th>Raft</th>
<th>Pile</th>
<th>Micropile</th>
<th>Concrete Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Model</td>
<td></td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
<td>Elastic</td>
<td>Elastic</td>
<td>Elastic</td>
<td>Elastic</td>
</tr>
<tr>
<td>Stiffness (E)</td>
<td>kN/m²</td>
<td>40x10³</td>
<td>30x10³</td>
<td>3x10⁷</td>
<td>3x10⁷</td>
<td>3x10⁷</td>
<td>25x10⁶</td>
</tr>
<tr>
<td>Angle of Internal Friction (φ)</td>
<td>Deg</td>
<td>33</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dilatancy Angle (Ψ)</td>
<td>Deg</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cohesion (c)</td>
<td>kN/m²</td>
<td>5</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poisson’s Ratio (μ)</td>
<td></td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Unit Weight (γ)</td>
<td>kN/m³</td>
<td>17</td>
<td>17</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

Dimensions of soil model for raft & pile foundation were 92 m x 116 m x 54 m and 94.5 m x 82.5 m x 51 m respectively. Tunnel of diameter 6 m was selected for the present study. Cover of tunnel and the horizontal distance of tunnel from the tunnel centre were decided from the graphs presented in section IV. Uniformly distributed load of 400 kN/m² was applied on raft & pile foundation.

Medium dense sand & medium clay soils were considered for the analysis. Length of the micropiles varied from 13.5 m to 27 m. Number of micropiles considered for the analysis ranged from 6 to 60, whereas spacing varied from 0.6 m to 3 m. Fig. 2 shows 3D view of model in MIDAS 3D GTS highlighting foundation, row of micropiles & tunnel. Dimensions of raft & pile foundation were 13 m x 16 m and 17 m x 23 m respectively.

![Fig. 2. 3D view of Model in MIDAS 3D GTS: (a) Raft & (b) Pile Foundation](image)

### IV. ANALYTICAL RESULTS

The main objective of the study was to analyse the performance of micropile as a mitigation technique for tunnelling effect. Details of the parametric study is shown in Table 2. Analyses were done on both raft & pile foundation in medium dense sand & medium clay, where, number, spacing and length of micropiles were varied and percentage reduction in settlement of raft & pile foundation were observed. The results obtained from analyses are briefly discussed below.
TABLE 2
DETAILS OF PARAMETRIC STUDY

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of Foundation</td>
<td>Raft &amp; Pile Foundation</td>
</tr>
<tr>
<td>2</td>
<td>Type of Soil</td>
<td>Medium Dense Sand &amp; Medium Clay</td>
</tr>
<tr>
<td>3</td>
<td>Length of Micropile (L)</td>
<td>C – 0.25 D = 13.5 m, C + 0.5 D = 18 m, C + D = 21 m, C + 1.5 D = 24 m, C + 2 D = 27 m</td>
</tr>
<tr>
<td>4</td>
<td>Number of Micropiles (N)</td>
<td>6, 12, 18, 24, 30, 36, 42, 48, 54, 60</td>
</tr>
<tr>
<td>5</td>
<td>Spacing (S)</td>
<td>0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, 3</td>
</tr>
</tbody>
</table>

A. Effect of C/D ratios of Tunnel on the Settlement of Foundation

Fig.3. shows that settlement of raft in sand increases rapidly with C/D ratio upto 2.5 and thereafter increase in settlement is marginal for further increase in C/D ratio, whereas settlement of raft in medium clay increases with increasing values of C/D ratio. Also it is seen that, the settlement of pile foundation in sand is constant for all the values of C/D ratio, whereas it increases in medium clay with the increase of C/D ratio. Further study on raft & pile foundation was carried out for C/D = 2.5 for sand and the same was considered for medium clay also. However, C/D ratio generally lies between 1-3.

Fig.3. Variation of Settlement of Foundation with C/D ratio of Tunnel

B. Effect of H/D ratios of Tunnel on the Settlement of Foundation

Fig.4. shows that the settlement of raft & pile foundation in sand & medium clay decreases as the H/D ratio increases. Settlement of raft in sand & clay became zero at H/D = 3, this implies that H/D ratio had no effect on the settlement of raft beyond H/D = 3. The settlement of raft & pile foundation in sand & medium clay was maximum when placed at H/D = 1, therefore further analyses were carried out by placing raft & pile foundation at H/D = 1 from the tunnel axis.

Fig.4. Variation of Settlement of Pile Foundation with H/D Ratio of Tunnel
C. Effect of Number of Micropiles on the Settlement of Foundation

Effect of number of micropiles of various lengths on the settlement of raft & pile foundation for parameters $X = 0.75 \ D$ & $S = 0.6 \ m$ are presented below.

Fig.5. shows that settlement reduction of raft in sand increases with the increasing numbers of micropiles upto 36. With further increase in number of micropiles, there is marginal effect on settlement reduction of the raft. Thus, the optimum number of micropiles of raft for above parameters is 36. Micropile of length 27 m & 24 m showed nearly same percentage reduction in settlement of raft.

![Fig.5. Variation of % reduction in Settlement of Raft with number of Micropiles (Sand)](image)

Fig.6. shows that settlement reduction of raft in clay increases with the increasing numbers of micropiles upto 36. With further increase in number of micropiles, there is marginal effect on settlement reduction of the raft. Thus, the optimum number of micropiles of raft for above parameters is 36. Micropile of length 13.5 m has no effect on the percentage reduction in settlement of raft in clay. Micropile of length 27 m & 24 m showed nearly same percentage reduction in settlement of raft.

![Fig.6. Variation of % reduction in Settlement of Raft with number of Micropiles (Clay)](image)

Fig.7. shows that settlement reduction of pile foundation in sand increases with the increasing numbers of micropiles upto 42. With further increase in number of micropiles, there is marginal effect on settlement reduction of the pile foundation. Thus, the optimum number of micropiles of pile foundation for above parameters is 42. Micropile of length 27 m & 24 m showed nearly same percentage reduction in settlement of pile foundation.

![Fig.7. Variation of % reduction in Settlement of Pile Foundation with number of Micropiles (Sand)](image)
Fig. 8. shows that settlement reduction of pile foundation in clay increases with the increasing numbers of micropiles up to 42 respectively. With further increase in number of micropiles, there is marginal effect on settlement reduction of the pile foundation. Thus, the optimum number of micropiles of pile foundation for above parameters is 42. Micropile of length 27m & 24m showed nearly same percentage reduction in settlement of pile foundation.

**D. Effect of Length of Micropiles on the Settlement of Foundation**

Effect of length of micropiles of various lengths on the settlement of raft & pile foundation for parameters X = 0.75 D & S = 0.6 m are presented below.

From Fig.9 it is seen that % reduction in settlement of raft increases with increase in length of micropiles up to 24 m and thereafter, remains constant for both sand & medium clay. Micropile of length 13.5 m had no effect on the percentage reduction in settlement of raft in medium clay. Micropiles of larger lengths showed good performance in percentage reduction in settlement of raft in clay as compared shorter lengths.

Fig. 8. Variation of % reduction in Settlement of Pile Foundation with number of Micropiles (Clay)

Fig.9. Variation of % reduction in Settlement of Raft with Length of Micropiles

From Fig.10 it is seen that % reduction in settlement of pile foundation increases with increase in length of micropiles up to 24 m for sand & 27 m for medium clay and remains constant. Thus, optimum length of micropile for the percentage reduction in settlement of pile foundation in sand & medium clay is 24 m & 27 m respectively.

Fig. 10. Variation of % reduction in Settlement Pile Foundation with Length of Micropiles
E. Effect of Spacing of Micropiles on the Settlement of Foundation

Effect of spacing of micropiles on reduction in settlement of raft for parameters X = 0.75 D & L = 24 m is presented in Fig.11. From Fig.11 it is seen that % reduction in settlement of raft decreases with increase in spacing of micropiles. Optimum spacing of micropiles for mitigating settlement of raft in sand & medium clay is 1.8 m.

Fig.11. Variation of % reduction in Settlement of Raft with Spacing of Micropiles (L = 24 m)

Effect of spacing of micropiles on reduction in settlement of pile foundation for parameters X = 0.75 D & L = 27 m is presented in Fig.12. From Fig.12 it is seen that % reduction in settlement of pile foundation decreases with increase in spacing of micropiles. Optimum spacing of micropiles for mitigating settlement of pile foundation in sand & medium clay is 1.8 m.

Fig.12. Variation of % reduction in Settlement of Pile Foundation with Spacing of Micropiles (L = 27 m)

V. CONCLUSIONS

Based on the results of present study, following broad conclusions are drawn:
1. Settlement of raft foundation in sand increases till the cover of tunnel is 2.5 times the diameter of tunnel and then remains constant, whereas in medium clay it increases with the increase of tunnel cover.
2. Settlement of raft foundation in sand & medium clay is maximum when the tunnel is located at a horizontal distance equal to the tunnel diameter (H/D = 1) and is zero when located at a distance equal to 3 times the tunnel diameter (H/D = 3).
3. Optimum number & length of micropiles for mitigating raft settlement in sand is 30 to 36 & 24 m respectively.
4. Optimum number & length of micropiles for mitigating raft settlement in medium clay is 30 to 36 & 24 m respectively.
5. The tunnel cover has no significant effect on the settlement of pile foundation in sand, whereas settlement of pile foundation in medium clay increases as tunnel cover increase.
6. Settlement of pile foundation in sand & medium clay is maximum when the tunnel is located at a distance equal to tunnel diameter (1D) which gradually decreases thereafter.
7. Optimum number & length of micropile for mitigating pile foundation settlement in sand is 42 & 24 m respectively.
8. Optimum number & length of micropile for mitigating pile foundation settlement in medium clay is 42 & 27 m respectively.
9. The settlement of raft & pile foundation increases with the increase in spacing of micropiles. Optimum spacing of micropiles for mitigation of settlement of raft & pile foundation in sand & medium clay is 1.8 m respectively.

REFERENCES


