Analysis of Ground Distress Along a Busy Highway – A Case Study from Mumbai, India

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Abstract

Ground heaving is one of the major causes of damages to highways and other roads, leading to loss of human life and economic losses. Chembur-Sewri highway is one of the busiest roads in Mumbai, adjoining the Wadala Truck Terminal, and constructed on a reclaimed land. Part of the Phase I of Mumbai's elevated Monorail, first of its kind in independent India, runs along this highway. Construction of monorail project was started in 2009, and is made open to public in 2014. Substantial ground heaving/settlement has been observed over a distance of 6 km along this highway, noticeably adjacent to the supporting pillars of the monorail, after its construction. This highway is made of concrete pavement, and ground distress is observed to increase with time, posing serious threat to the public safety. The ground water table is very close to the ground surface, and soil profiles in the close vicinity exhibit very low SPT 'N' values. A strip of 1 m width on either side of the pillar along the highway is highly disturbed and poses serious threat to the users. The aim of the present study is understanding the causes of ground distress, through systematic study of the ground profiles, and geotechnical properties of the subsoil. Based on the present analysis, it can be concluded that the consolidation of thick soft to medium stiff clay layer is mainly responsible for the differential settlement of the pavement. Keeping in mind the subsoil and traffic conditions on this stretch of the highway, a hybrid ground improvement strategy, involving installation of stone columns penetrating through the clay layers, overlying a well-designed in-filled geocell reinforced soil layer, can be adopted at the site, which can prevent further settlement of the pavement.

Introduction

Substantial volume change resulting in ground heaving or ground subsidence is one of the major causes of damages to highways and other roads, leading to poor ride quality, frequent disruptions to traffic, traffic diversions, economic losses, and loss of life (Chen et al. 2009, Chen et al. 2012,. Chembur-Sewri 6-lane highway is one of the busiest roads in Mumbai, adjoining the Wadala Truck Terminal, and constructed on a reclaimed land. Part of the Phase I of Mumbai's elevated Monorail, first of its kind in independent India, runs along this highway. Construction of monorail project was started in 2009, and is made open to public in 2014. This highway is made of concrete pavement. Substantial ground distress, in the form of differential settlement of the pavement, has been observed over a distance of 6 km along this highway, noticeably around each pillar of the monorail, after its construction, as shown in Figure 1. It is reported that this distress was smaller in magnitude initially and has been increasing with time, posing serious threat to the public safety, as several accidents have been reported in the last couple of years. Figure 1 also shows severe cracking of the pavement in addition to large differential settlement at several locations of the highway. To date, the monorail system is not affected by this uncontrolled volume changes, and a hazard may not be ruled out in near future, if the reasons for this distress is not understood properly and controlled forever. Such failure can be averted if through and systematic study of the ground profiles, geotechnical properties of the subsoil is done before planning and construction of any major structures. From the observed ground features, one of the following two causes for the ground distress can be thought of. They are (i) continuous settlement of the pavement due to consolidation of clay deposit, except in the zone surrounding each monorail pillar, which is supported by a strong piled raft foundation; and (ii) pavement distress due to ground heaving around each monorail pillar, probably due to buoyancy effect. If the second possibility is true, it should also be reflected in the upheaval (uplift) of the monorail pillar.

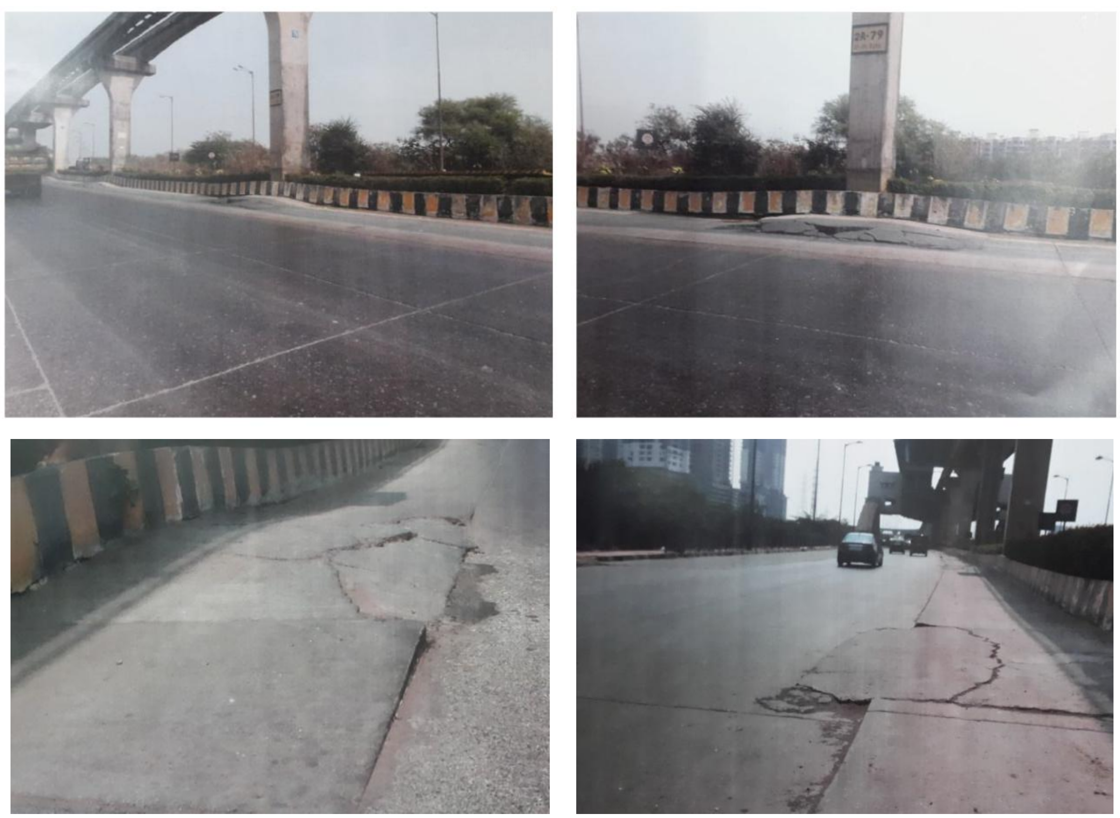

Figure 1: Pavement distress along Wadala-Sewri highway

History of the study area and details of subsoil

The typical soil profile along the highway stretch consists of 0-3 m of fill material underlain by soft marine clay deposits of soft to medium stiff consistency extended up to 11 m below the existing ground surface, followed by basalt rock of varying degrees of weathering. The typical borehole profile at the site is shown in Figure 2. There is a high degree of variability in the soil profiles and estimated geotechnical properties all-over the study area. The SPT-N values of the marine clay deposit vary in the range of 1-5 m, whereas for the top 3 m layer, SPT-N values vary in the range of 6-15 m. The particle size distribution analysis reveals that 86-97% clay content in the clay layer, whereas 66-90% of the fill material is coarse grained soil, predominantly of sand. The liquid and plastic limits of the clay layer typically vary in the range of 63-88% and 30-35%, with plasticity index in the range of 30-53%. The data on organic content and swelling characteristics of the marine clay deposit is not available. Part of this area is covered with salt pans and frequently inundated with sea water during the high-tides. The ground water table is very high and at times reaches very close to ground surface, especially during the monsoon. Based on the data collected from reliable sources, there is no history of ground improvement adopted at this site.

Co-ordinate: 19.029072°N 72.877532°E
R.L.: 100
Location: Chembur-Sewri Road
Dia of Borehole: 100/Nx
Depth of GWT: 1.0m

Bore Hole No: BH 1
Depth of Bore Hole: 24.0 m
Depth of Casing: 15.50
Date of Commencement: 20/08/2010
Date of Completion: 26/08/2010

Scale m	Depth m	R.L. m	Log	Description	Sample No.	Type	Depth (m)		SPT 'N' Value					CR %	RQD %	P.R. m/hr	Remarks/ Other Tests
							From	To	15	15	15	15	N				
1				Fill up Soil (GM-GC)													GWT
2																	
3					1	SPT-1	2.0	2.30	9	20			R				
					2	SPT-2	3.0	3.38	10	13	8/ 27		R				
4	4.0	96.0		[4 m]													
5				Grey Soil Marine Clay (CH)	4	SPT-3	4.0	4.60	2	2	3	3	5				
6					5	SPT-4	5.0	5.60	2	2	3	4	5				
					9	UDS	6.0	6.60									
7	7.0	93.0		[3 m]													
8				Grey Medium Stiff to Stiff Marine Clay (CH)	6	SPT-5	7.0	7.60	2	3	3	4	6				
					7	SPT-6	8.0	8.60	3	3	3	7	6				
9					8	SPT-7	9.0	9.60	4	3	4	6	7				
10.5	10.6	89.4		[3.6 m]	9	SPT-8	10.0	10.6	4	4	4	6	8				
11				Completely Weathered Rock		DR1	11.0	11.5						14	Nil		Small Pieces
						DR2	11.5	12.0						Nil	Nil		Small Pieces
12						DR3	12.0	12.5						Nil	Nil		Small Pieces
						DR4	12.5	13.0						Nil	Nil		Small Pieces
13						DR5	13.0	13.5						Nil	Nil		Small Pieces
						DR6	13.5	14.0						Nil	Nil		Small Pieces
14						DR7	14.0	14.5						Nil	Nil		Small Pieces
						DR8	14.5	15.0						Nil	Nil		Small Pieces
						DR9	15.0	15.5						Nil	Nil		Small Pieces
15	15.0	85.0		[4.4 m]													

DS: Disturbed sample
USD: Undisturbed sample
SPT: Standard Penetration Test
WS: Wash Sample
CR: Core Recovery
RQD: Rock Quality Designation
PR: Rate of Penetration in Rock
VST: Vane Shear Test
K: Permeability of Soil/Rock
PT: Packer Permeability tests
DR: Drill Run
GWT: Ground Water Table

Figure 2. Typical borelog profile at the affected site (MCGM, 2015)

Forensic investigation of pavement distress

From the limited information available, the pillars of monorail are supported by piled raft foundations, wherein each pile was extended below 16 m and terminated in weathered rock strata. In view of the possible normally consolidated state of the clay, and no visible signs of upheaval of the monorail pillars, it can be safely concluded that the distress in the pavement is, in fact, due to the consolidation of the clay and subsequent settlement of the pavement, except around the monorail pillars, which is firmly supported.

Remedial measures

In order to prevent further settlements of the subgrade due to consolidation of the soft marine clay deposit, the ground should be substantially improved. Pre-consolidation of the clay deposit is a simple and effective method, and can be achieved by using prefabricated vertical drains with surcharge preloading. However, after installation of the PVD and placing the required surcharge, the ground should be left unattended for a minimum period of 3-6 months to achieve majority of the consolidation. However, owing to heavy and continuous vehicular traffic on the highway, being only access to some of the important establishments, such as Wadala truck terminal, Wadala RTO, and remote possibility of closing the highway even for a small duration, the conventional ground improvement techniques, such as surcharge preloading, sand columns, PVD assisted consolidation, vacuum consolidation, to accelerate the consolidation of the clay layer, may not be suitable at this site. Instead, one of the following alternative ground improvement strategies can be adopted at the site: (i) installation of stone columns extending into the poor subsoil, which can improve the load carrying capacity of the soft soil layer, and subsequently reduce the settlement due to working loads; (ii) placing in-filled geocell layer in base course or above the subgrade of the pavement, which can distribute the traffic loading on a wider area, and significantly reduce the intensity of vertical stresses transferred to the clay layer; (iii) compaction grouting extending into the poor subsoil; or (iv) a combination of stone columns underlying a reinforced in-filled geocell layer. In case of stone columns, a substantial loading needs to be applied on the stone columns and the surrounding area, in the form of embankment loading, in order to allow the stone columns to bulge and mobilize maximum passive resistance from the surrounding soft soil. Placing an additional fill of minimum 1-2 m over the stone columns to enhance the load carrying capacity of the reinforced ground, and substantially reduce the settlements under working loads, may not be possible in this project, and on the other hand increasing the replacement ratio of the stone columns, the control the settlements of the soft soil, proves very costly. In view of the above limitation, the more amenable alternative to improve the ground is to place a well-designed geocell reinforced soil layer overlying the stone columns. The geocell reinforced soil layer acts as a reinforcement layer, and dissipates the traffic loads on a wider area, and prevent overstressing of the soft clay layer. This hybrid reinforcing technique, involving both stone columns and geocell reinforced soil bed, can be effective in controlling the settlement of the pavement, and may prove economical. However, further studies are warranted to critically examine the geotechnical properties of the clay layer, and optimize the ground improvement strategy, in terms of choosing the spacing and depth of the stone columns, and type and thickness of the geocell reinforced soil bed overlying the stone columns.

Conclusions

Pavement distress due to substantial volume changes of the subsoil is one of the major causes of damages to highways and other roads. In the present study a forensic study has been carried out to identify the likely causes of distress to a 6 km highway stretch in Mumbai, India, and understand the most viable ground improvement strategy to prevent further settlement of the pavement. The following are some of the major conclusions from the study.

Consolidation of thick soft to medium stiff clay layer is mainly responsible for the differential settlement of the pavement.

Conventional ground improvement techniques, such as surcharge induced preloading, sand columns or PVD assisted preloading is not feasible to preconsolidate the soft clay layer in the present study, mainly due to heavy and continuous traffic at the affected area.

A hybrid ground improvement strategy, involving installation of stone columns penetrating through the clay layers, overlying a well-designed in-filled geocell reinforced soil layer, can be a viable option for the site, which can prevent further settlement of the pavement.

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