Effect of Soil Behavior on Diaphragm Wall in Soils of Chennai City

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Abstract - *Diaphragm walls also known as Dwall are widely adopted and one of the most efficient Earth Retaining Structural System (ERSS) for Underground metro construction. Performance of Dwall is dependent on many factors including construction sequence, depth of excavation, type of soil, stiffness of Dwall, ground water table variation and most importantly the accuracy of execution during construction. This technical paper discusses the behavior of Dwall under soil conditions of different locations in Chennai city. Parametric study has also been performed by changing various parameters to understand the behavior of Dwall in a wider perspective. From various analyses, it has been observed that the impact on design of Dwall due to varying soil conditions is relatively high compared to any other parameters.*

Key Words: Diaphragm wall, temporary stage, undrained, drained soil, embedment, ground water table

1. INTRODUCTION

Dwall is one of the most accepted ERSS for the underground metro construction as this wall can be a part of permanent structure unlike other retaining structures. There are various codes of practices [1-7] available on the general guidelines for the various ERSS. Dwall is a cast in situ retaining wall with thickness varying from 0.6 to 1.2m, depending on strength and serviceability requirements. As the underground metro construction is generally adopted in congested urban areas, earth retaining system should always serve the purpose of restricting the horizontal movement of ground until the construction of underground station is completed. There are various literatures available on the various considerations associated with the construction of Dwall [8-10]. Few researchers also studied the effects of installation of Dwall to surrounding soil and adjacent buildings [11-12]. Some researchers have done extensive study on effect of D wall stiffness on its performance [13-14]. Literature is also available on effect of anchor rod on the behaviour of Diaphragm wall [18]. In an underground excavation, Soil Structure Interaction (SSI) plays crucial role on the stability of Dwall. Various case studies are available on the performance of Dwall at a particular location in various soil conditions. The objective of the present study is to understand the effect of soil type, ground water table, and embedment into rock mass on the Dwall performance in different soil conditions of Chennai city. Parametric study has also been performed by varying the stiffness of Dwall.

1.1. Geology at Chennai City

The major geological formations of Chennai city are Archean crystalline rocks, consolidated Gondwana & Tertiary sediments and recent alluviums. Alluvium covers a major part of the city and this has been defined as sand, silt and clays. This alluvium is underlain by Charnockite rock at some regions and by Sedimentary deposits at some regions. For current study two locations have been considered. One location where entire soil overburden is sandy soil and is underlain by Charnockite deposit and another location where majority of soil overburden is clayey soil and is underlain by sedimentary deposits like shale.

1.2. Construction Sequence

Construction of cut and cover structures is generally carried out using either bottom-up construction or top-down construction. Method of construction will be chosen based on the space available for construction and other economic aspects. Present study is being carried out using top-down construction sequence. In this sequence, RC slabs are constructed after the desired level is reached and temporary struts are placed at intermediate levels to control the excessive horizontal movements.

1.3. Design Methodology

Unlike other ERSS, the structural design of Dwall is complex because, it acts both temporary as well as permanent structural system in cut-and-cover structures. So, the structural analysis of Dwall in cut-and-cover structures requires two types of analysis: (1) temporary/construction stage analysis, and (2) permanent stage analysis. The design forces (such as bending moment and shear force) are obtained on both faces (i.e. soil face and excavation face) of Dwall from construction stage as well as permanent stage analysis at various levels for ULS and SLS conditions. The capacity charts are produced for bending moment and shear force for different reinforcement ratios for the given Dwall thickness and checked against requirements. This paper concentrates only on temporary stage analysis. Temporary stage analysis can be carried out using PLAXIS or WALLAP.

In the current study, construction stage analysis is carried out using WALLAP software which is a plane strain analysis tool. Typical Dwall analysis in WALLAP tool is shown in Fig 1.

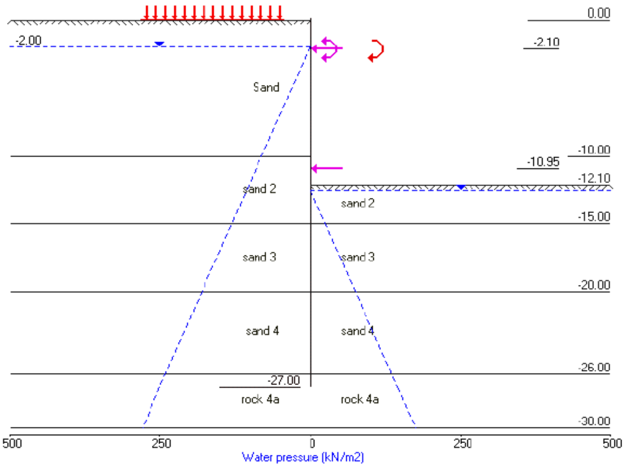

Fig -1: Typical Dwall analysis in WALLAP

2. PARAMETRIC STUDY

In this study, a typical two-level cut-and-cover structure is considered. Soil conditions at two different locations of Chennai city are considered for the parametric study with actual geotechnical parameters obtained from the bore hole tests.

Structural parameters:

The schematic representation of a typical two-level cut-and-cover structure with geometric dimensions is shown in Fig. 2. Concrete Grade of M40 is adopted for Dwall and slabs.

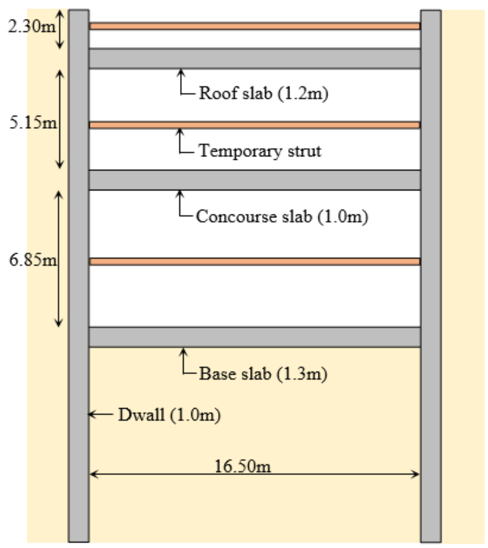

Fig -2: Geometry

The thickness of structural components considered for the present study is given below.

- Base slab thickness 1.3 m
- Roof slab thickness 1.2 m
- Concourse slab thickness 1.0 m
- D-wall thickness 1.0 m
- Clear width of station 16.5 m

Temporary struts are placed above roof slab, between roof slab and concourse slab and between concourse slab & base slab to avoid excessive movements of Dwall as show in Fig. 2. Vehicular surcharge of 20kPa has been applied behind the Dwall to simulate the loading due to construction equipment. Stage wise excavation has been carried out and temporary struts and RC slabs with openings are installed upon reaching the required excavation level. Ground water table has been lowered to 1m below the required excavation level to create a dry space for excavation.

Soil parameters:

Soil stratification and corresponding design parameters considered for the present study are mentioned in Table 1 and Table 2, respectively.

Table -1: Geotechnical parameters for sandy soil

Depth (m)	**From**	**0**	**1.5**	**10**	**15**	**20**	**25**	**27**
	to	**1.5**	**10**	**15**	**20**	**25**	**27**	**--**
Soil		Fill	Silty sand				CWR	SWR
γ_b (kN/m³)		18	18	18	18	20	22	26
γ_{sat} (kN/m³)		19	19.5	19.5	19.5	21	22	26
E (MPa)		8	12	15	25	75	200	5000
μ		0.35	0.38	0.38	0.38	0.38	0.26	0.22
C_u (kPa)		-	-	-	-	-	-	-
C' (kPa)		-	-	-	-	-	-	360
φ (deg)		28	31	31	31	39	45	65

Where,

γ_b and γ_{sat}	-	Bulk and saturated unit weights of soil/rock mass.
E	-	Drained young's modulus for sandy soil and undrained Young's modulus for clayey soil.
C_u and C'	-	Undrained and drained cohesion of soil
φ	-	Drained angle of internal friction.
CWR	-	Completely weathered rock
SWR	-	Slightly weathered rock/Fresh rock

Table -2: Geotechnical parameters for clayey soil

Depth (m)	From	0	1.5	10	27	31
	to	1.5	10	27	31	33
Soil		Fill	Clayey Soil		Silty sand	CWR
γ_b (kN/m³)		18	18.5	18.5	19	22
γ_{sat} (kN/m³)		19	19	19	20	22
E (MPa)		8	12	25	30	200
μ		0.35	0.4	0.4	0.35	0.26
C_u (kPa)		-	48	100	-	-
C' (kPa)		-	-	-	-	-
φ (deg)		28	-	-	30	45

All the analyses with clayey soil as overburden soil are carried out under undrained conditions and all the analyses with sandy soil as overburden soil are carried out under drained condition.

2.1. Effect of Soil behavior

Analyses have been carried out under different soil conditions as mentioned in Table 1 & Table 2. In addition to the soil strata mentioned in Table 1 & Table 2 another case has been analyzed to check the effect of embedment into strong rock. In addition Obtained results are presented in Fig 3 & Fig 4. D wall of 1m thickness is considered for all cases.

(1) Case 1: Clayey soil + 2m embedment into completely weathered rock (Soil strata in Table 2).

(2) Case 2: Sandy soil + 2m embedment into completely weathered rock (Soil strata in Table 1).

(3) Case 3: Sandy soil + 1m embedment into completely weathered rock + 1m embedment into slightly weathered rock (Soil strata in Table 1).

From Fig 3 & Fig 4 it is understood that the bending moment is around 40% high in the condition where clay is present to a larger extent than sand. Deformation tends to be lower at top with clay as overburden and it is tend to be higher at deeper depths. It is also observed that extending the embedment into fresh rock would only help in reducing the toe deformations and may not be helpful in reducing bending moment or deformation at top. Hence, construction aspect must be considered carefully to extend the embedment into fresh/strong rock.

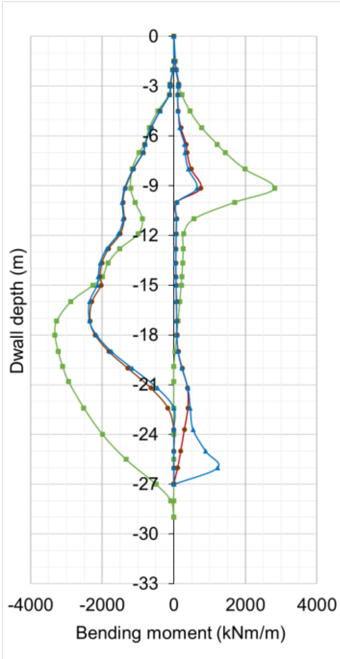

Fig -3: Bending moment profile

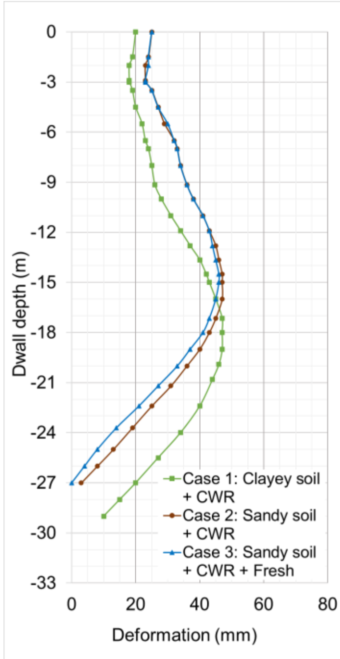

Fig -4: Horizontal deformation profile

2.2. Effect of different embedment depth

Analyses have been carried out with three different embedment depths 2m, 5m & 10m in completely weathered rock with the overburden soil being Sand and Clay. Results are presented in Fig 5 to Fig 8. D wall of 1m thickness is considered for all cases.

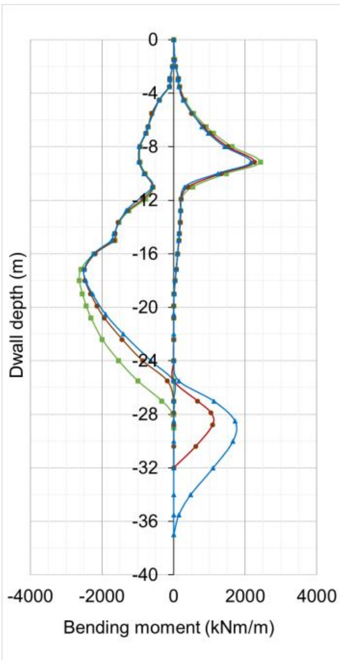

Fig -5: Bending moment

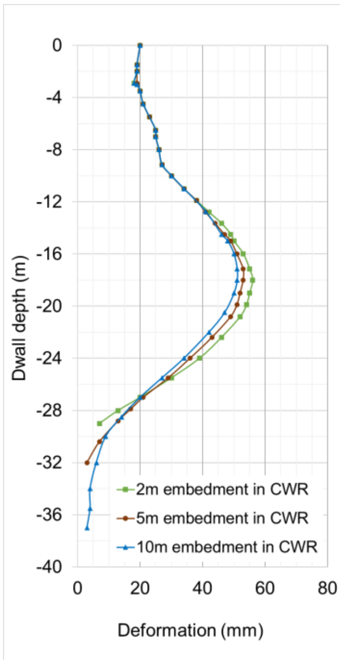

Fig -6: Deformation profile

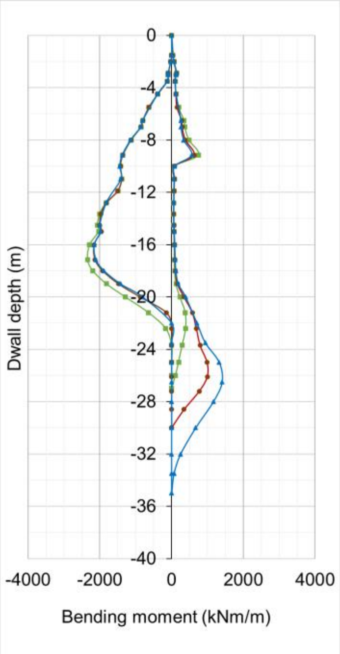

Fig -7: Bending moment profile (Soil overburden: Sandy soil)

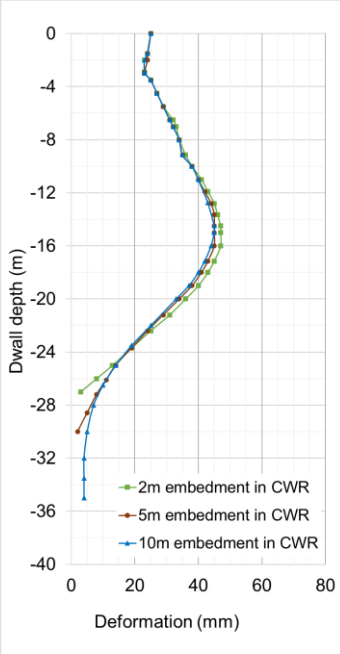

Fig -8: Deformation profile (Soil overburden: Sandy soil)

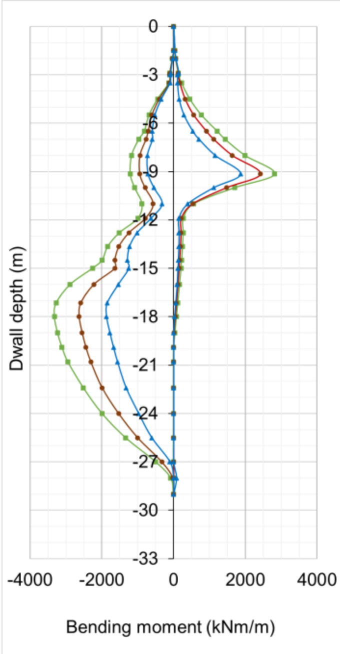

Fig -9: Bending moment profile (Soil overburden: Clayey soil)

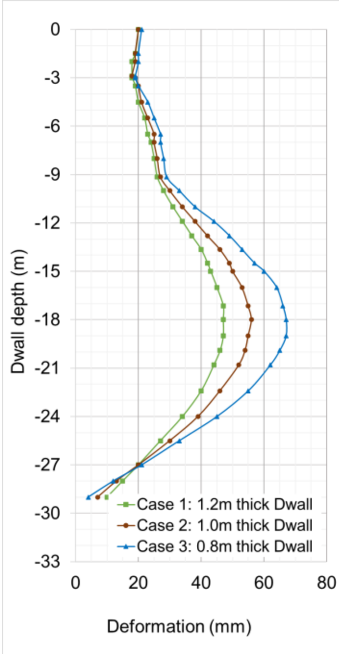

Fig -10: Deformation profile (Soil overburden: Clayey soil)

From Fig. 5 to Fig 8, it is understood that the benefit from decrease in bending moment and decrease in horizontal deformation is less irrespective of overburden soil compared to the effort to increase the embedment into weathered rock. Hence, the construction aspect must be considered carefully to extend the embedment into weathered rock. It is also worth to mention here that the toe stability checks to be carried out while fixing the embedment depth of Dwall.

2.3. Effect of Dwall thickness

Analyses have been carried out with three D wall thickness values 0.8m, 1m and 1.2m with overburden soil being sandy soil and clayey soil. Results are presented in Fig 9 to Fig 12.

As anticipated, Fig 9 to Fig 12 show that increase in Dwall thickness greatly reduce the horizontal deformations upto 30% with sandy soil as overburden and upto 40% with clayey soil as overburden. However, increase in flexural stiffness leads to higher bending moments which in turn increases the reinforcement quantity. Hence, an optimum thickness must be chosen based on allowable horizontal deformation criteria.

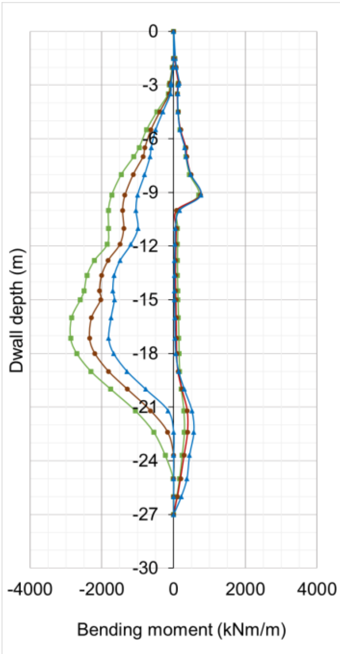

Fig -11: Bending moment profile (Soil overburden: Sandy soil)

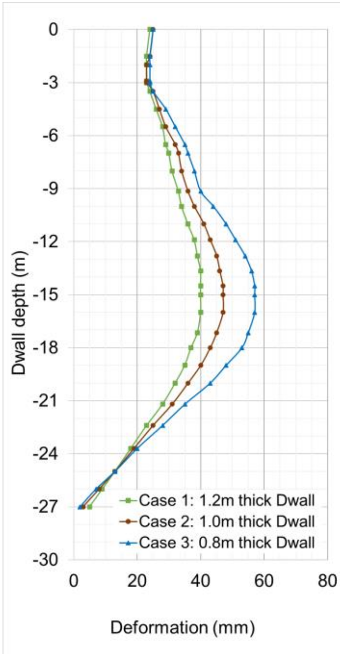

Fig -12: Deformation profile (Soil overburden: Sandy soil)

2.4. Effect of Ground water table variation

It is very well known that ground water table is one of the major parameter which greatly affects the design of Dwall. Majority of Dwall designs are governed by temporary stage analysis and always considering the ground water table may lead to uneconomical solution. Hence, analyses have been carried out considering ground water table at ground level, at 3m below ground level and at 10m below ground level. D wall of 1m thickness is considered for all cases. Results are presented in Fig 13 to Fig 16.

From Fig 13 to Fig 16, it has been observed that variation of Ground water table has greater impact of reducing horizontal deformations about 50% when GWT has been lowered from GL to 10m below GL. This reduction has only been observed in the condition where sandy soil is present as overburden soil. It has also been observed that there is very little or negligible impact on horizontal deformation when clayey soil is present as overburden. This may be attributed to consideration of undrained analysis during construction stage.

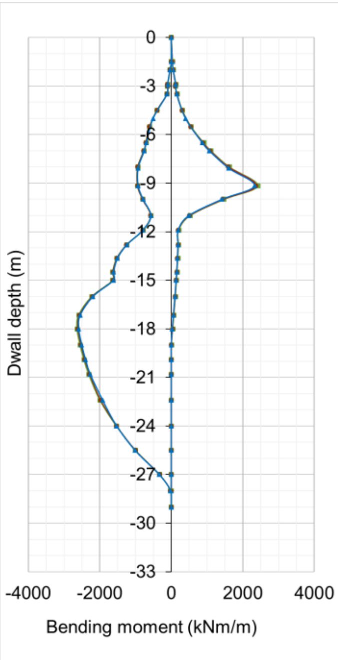

Fig -13: Bending moment profile (Soil overburden: Clayey soil)

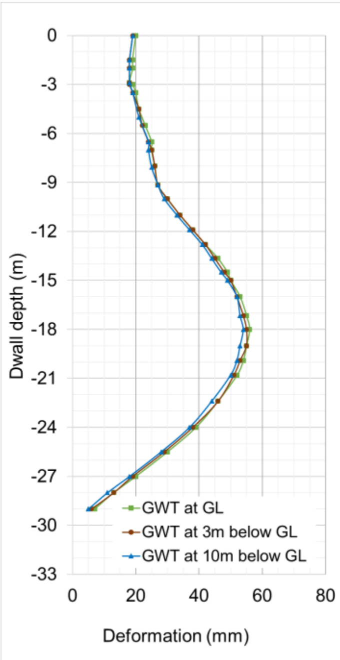

Fig -14: Deformation profile (Soil overburden: Clayey soil)

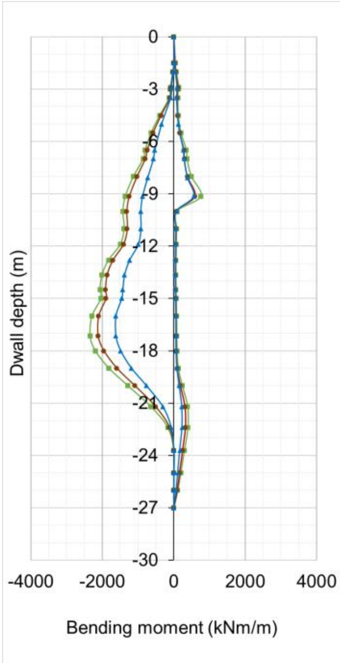

Fig -15: Bending moment profile (Soil overburden: Sandy soil)

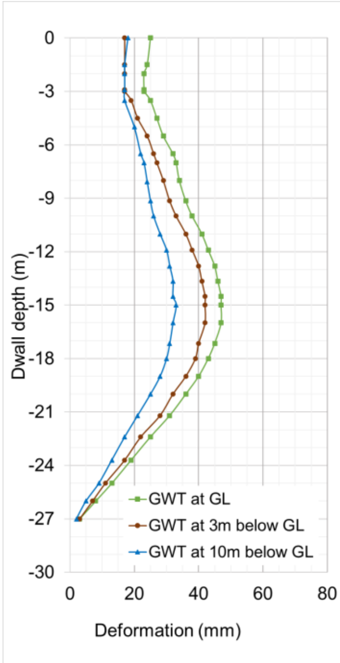

Fig -16: Deformation profile (Soil overburden: Sandy soil)

3. CONCLUSIONS

From the above parametric study following conclusions are being made.

(1) Design of Dwall and performance of Dwall depends on the type of soil the wall is embedded in. Consideration of clay under undrained condition leads to reduced effective stresses which in turn increases the horizontal deformation of wall and bending moments.

(2) Depending on the time span of construction and permeability of soil, careful consideration shall be made on the type of analysis as Drained or Undrained. Also, if clay is observed only along certain stretch of station, it may not be optimum to design entire station Dwall considering clay as overburden. Hence, additional cost can be incurred for detailed investigation to confirm the extent of clay rather than designing entire station considering in clay strata.

(3) It is very well known that stiffness of Dwall always plays a crucial role on the design of Dwall. Decrease in thickness of Dwall decreases the flexural stiffness of Dwall which in turn increase the horizontal deformations of wall. However, consideration of horizontal movement may not always be an economic approach. Hence, reinforcement quantity and horizontal deformations should be studied in parallel to arrive at an optimized thickness of Dwall.

(4) In case of higher horizontal deformations, increasing the embedment in completely weathered rock or strong rock is not always an efficient solution. Hence, time and cost of Dwall excavation in weathered rock and strong rock must always be considered and sensitive analysis shall be carried out by introducing additional support to reduce horizontal deformations.

(5) Ground water table depth also plays and important role on the design of Dwall. As the excavation is temporary, it may not always be required to consider the GWT at GL. If the geotechnical investigation reveals GWT at a very deep depth, careful consideration of depth of GWT should be made based on the fluctuations of GWT at a particular location. If the seasonal variation is observed to be high, it may always to safe to consider the shallowest GWT during analysis and design.

(6) In the current study, seepage analysis has not been considered. However carrying our seepage analysis along with analysis of excavation helps understanding the behavior of Dwall in a more realistic way.

(7) As it is always known, instrumentation and monitoring is inevitable and design should be constantly verified and modified as per the instrumentation and monitoring data before, during and after construction.

(8) It is inevitable that lateral deformation of Dwall shall be given prime importance in all the above scenarios. As per CIRIA 517 [19], allowable lateral deformation of Dwall depends on the allowable settlement behind the Dwall. So, for an allowable settlement of 25mm behind Dwall, allowable lateral deformations is around 40mm. Hence, care must be taken if sensitive structures are present in the close proximity of excavation.

ACKNOWLEDGEMENT

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