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A REVIEW ON TRENCH STABILITY OF DIAPHRAGM WALL

Maninder Singh[1], Balaji Thamatam [2]

[1]Project Manager-Bauer international FZE,
[2]Design Engineer- Bauer international FZE,

Abstract— A paper presents the factors affecting the stability of the diaphragm wall trenches. The stability of the trenches varies in different kind of soils. The stability of the trench can be calculated by numerical calculations of equilibrium forces acting on the rigid wedge or it can be calculated by using different tools like 3D plaxis foundations or GGU trench. A case study of project Corniche towers situated in Abu Dhabi, UAE is explained where trench stability was carried out by using GGU trench tool.

Keywords— trench stability, diaphragm walls,

I. INTRODUCTION

Trench excavation is carried out as a first part of the methodology for various special geotechnical works like diaphragm walling, slurry or cut off walls or barrettes. All these geotechnical works include the trenching of vertical cuts in the ground either without usage of supporting slurries or with supporting slurries like bentonite suspension or poly gels.

A trench dug into the ground in rectangular section, using special cutting equipment and stabilizing agent such as bentonite slurry and polymers. First tie Diaphragm Walls were tried and tested in 1948 by Icos, Italy to construct a cut-off-wall on a dam site. Structural wall were then followed during 1950’s to construct Milan Metro using cut and cover method mainly known the Milan Method. The Diaphragm Wall is generally efficient in cost and execution time, where it can be used for both permanent and temporary sub soil retention for walls of great depth. The Diaphragm Wall being underground walls constructed of reinforced concrete, plain concrete or other predominantly cement based materials. Having structural and/or water retaining and/or protective function. Diaphragm walls are suitable for both temporary and permanent applications.

The very first stage in construction of the diaphragm wall is trenching of the panel which is very critical in various soil conditions whereas second stage of construction which is concreting is the predominantly more critical as pressure in the trench increases due to continuous replacement of the drilling slurry with the concrete. It exerts pressure on the walls as well as sides of the walls. In order to keep the trench stable on the top part usually slurry level is kept minimum 1m above the water levels and quality of the slurry to be achieved as per standards such as API and BS EN1587.

Since trench stability is very important aspect of diaphragm wall construction so proper calculations considering actual conditions of the site should be done prior to execution of the project. Trench stability can be calculated using the Limit equilibrium method and various programs based on this method such as GGU trench are available for calculating the trench stability.

Slurry-supported trenches are used in the construction of subsurface structural diaphragm walls and ground water cut-off walls. Coulomb type force equilibrium concepts are considered to analyze three dimensional stability of slurry supported trench. As per cl. 9.1.4.1 of DIN 4126, factor of safety defined as ratio of shear parameter tan calφ to shear parameter tan erfφ necessary for equilibrium.

$$\eta_{\varphi} = \frac{\tan cal\varphi}{\tan erf\varphi}$$

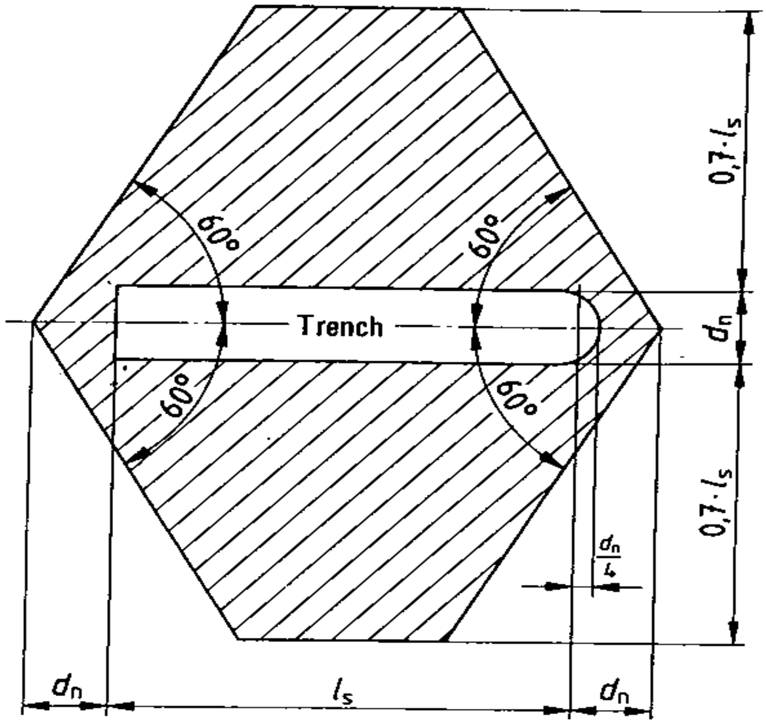

Fig-1: Critical zone of a trench, shown in plan view and determination of the trench length, ls

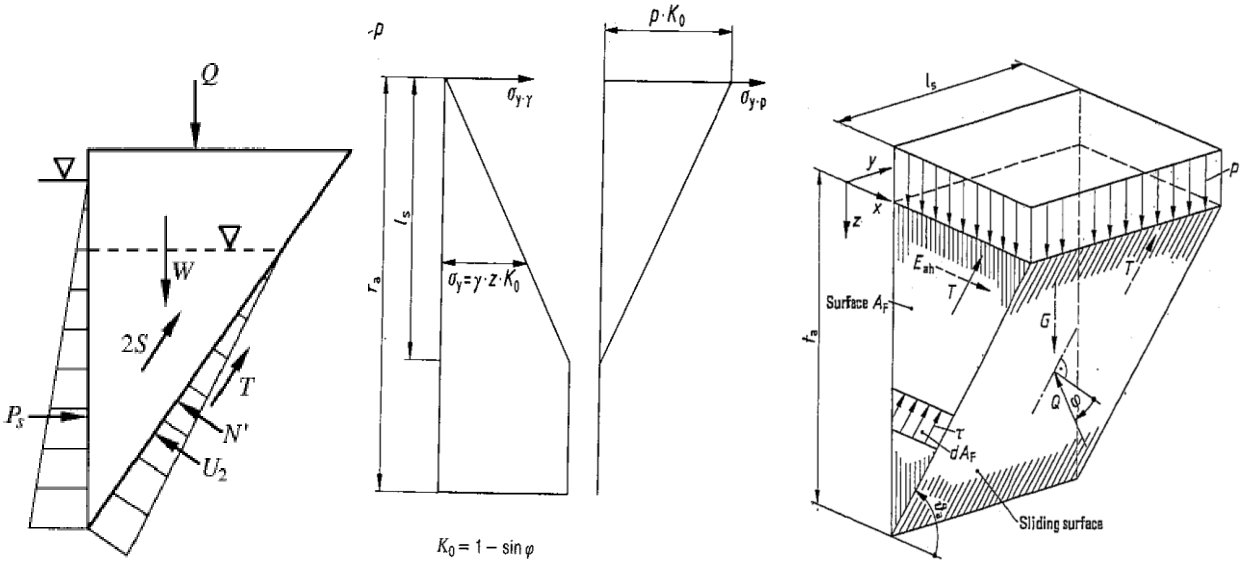

Fig-2: Estimate of supporting shear stresses in the triangular side surfaces of the rupture body (DIN 4126)

Summing force components for the failure wedge in directions normal and tangential to the bottom failure plane.

$$\sum F_N = N' + U_2 - (W + Q)\cos\theta - P_s \sin\theta = 0 \quad \text{.... (1)}$$

$$\sum F_T = 2S + T - (W + Q)\sin\theta + P_s \cos\theta = 0 \quad \text{..... (2)}$$

Where,

N'=Effective normal force on bottom failure plane

U2 = Pore pressure force on bottom failure plane below groundwater table

W = Weight of failure wedge

Q = Surcharge force on failure wedge

Ps = Slurry force on failure wedge

S = Shear resistance force on each side panel of failure wedge

= Ultimate shear resistance (S1)/FOS
T =Shear force on bottom failure plane
= Ultimate shear resistance (T1)/FOS
θ = Angle of bottom failure plane from horizontal (deg.)
From Fig-1 & Fig-2, we get

Shear stress, $\tau = c + \sigma_y \tan\varphi$........... (3)

Ultimate shear resistance, $S_1 = \int_0^H \tau \, dA_F$ .... (4)

Weight of failure wedge, $W = \int_0^H \gamma L \, dA_F$ .... (5)

Surcharge force on failure wedge, $Q = qLH/\tan\theta$ .....(6)

Slurry force, $P_S = {}^1/_2 \, \gamma_S H_S{}^2$ ...... (7)

Pore water pressure force, $U_2 = {}^1/_2 \, \gamma_w (H - Z_w)^2$.....(8)

Shear force, $T_1 = \sum cL \, H/\tan\theta + N' \tan\varphi_{avg}$ .... (9)

The following symbols are used for the above equations (eq.no. 3 to eq.no. 9)

c = cohesion of soil
φ = Angle of internal friction of soil
q = vertical surcharge pressure
H = Depth of Trench
L = Length of the trench
Hs = Depth of slurry from the bottom of trench
γs = Unit weight of slurry
Zs = Depth of groundwater table below EGL
γw = Unit weight of water
φavg. = weighted average of angle of internal friction over trench depth
Factor of safety against sliding of the wedge is determined by solving the equation no. 1 & 2.

II. CASE STUDY OF TRENCH STABILITY

An example of trench stability for the diaphragm wall which executed by Bauer International FZE in heart of Abu Dhabi at corniche road is explained below. The trench stability was calculated using GGU trench.

A. Project Introduction

The project is located on plot C37, Sector W8, Corniche Road, Abu Dhabi, UAE.

This plot is surrounded by Corniche Road on longer side, an old gymnasium building which is quite close to the excavation on inner longer side, Al Khaleej Al Arabi Street on the shorter side, and ADNOC office building further away on the other short side.
Diaphragm wall is envisioned for all road side and parking side next to ADNOC building and at the existing gymnasium building side, secant pile wall of 1200mm diameter with 228mm over cutting is envisioned. The selection of secant pile wall was dictated by the fact that footing of gymnasium have been found 40cm inside the plot during the investigation pits excavated during the initial mobilization phase of the project. Such close proximity of footing together with already poor structural condition of the gymnasium building with existing cracks posed a great risk for the safe trenching of diaphragm wall with slurry. This risk has been mitigated by using a cased drilling system, thereby switching from diaphragm wall to a secant pile wall at this location.

Another similar risk for slurry trenching was the high advertisement hoarding on the Corniche Side, which has been decided to be temporarily shifted 5m away from the diaphragm wall. The relevant analysis in which this safe distance is determines is given in section 6. The advertisement hoarding on Al Khaleej Al Arabi Street was removed initially, only to be placed back after execution of diaphragm wall and before or after excavation. The timing of this placement (after diaphragm wall trenching) is due to the fact that 5m distancing was not possible at this side. So the surcharge load of the hoarding at the shorter side has only been considered for the lateral support design, but not for the trench stability calculation.

B. ***Soil Conditions***

The soil investigation for the proposed development was carried out M/s. ACES, Abu Dhabi. The investigation consisted of 13 boreholes drilled at different locations within the plot limits down to a depth of 40m to 60m.Ground water table was encountered at 1.5m to 2m from EGL.

The design soil parameters required for the analysis of deep excavation system are Mohr Coulomb the shear strength parameters, i.e. Angle of internal friction (°), Cohesion (c) and Young Modulus (E) for sand and rock, which have been provided by M/s. ACES as listed below in Table 1.

Layers	Average Ground Level (NADD)		Avg. SPT / UCS	RQD	Unit weight of soil/Rock	Angle of friction	Cohesion	Young's Modulus E
	From (m)	To (m)	Blows /MPa	(%)	Ɣ/Ɣ'	°	kPa	MPa
Compacted fill	2.05	1	Nil		19/9	10	0	20
Sand	1	-5	21		17.5/7.5	33	0	22
Calcarenite -1	-5	-13	2.5	56	19.5/9.5	32	142	277
Sandstone -1	-13	-14	1.2	24	20/10	25	39	190
Calcarenite -2	-14	-16	1	27	19.5/9.5	25	31	146
Sandstone -2	-16	-19	1	42	20/10	30	46	152
Gypsum-1	-19	-21	7	52	22/12	30	336	1521
Mudstone-1	-21	-24	3.6	61	20.5/10.5	27	144	332
Gypsum-2	-24	-26	11	55	22/12	31	548	2449
Mudstone-2	-26	-32	2.8	56	20.5/10.5	24	113	332

Table 1- Soil parameters

C. *Trench dimensions*

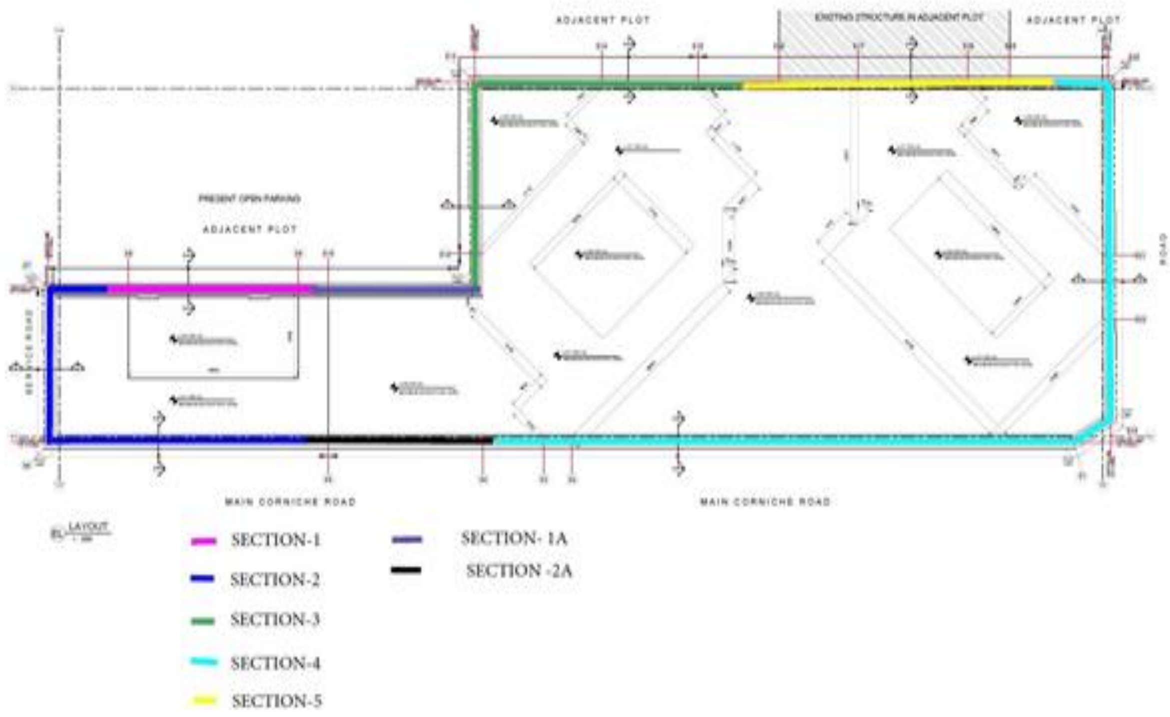

Fig3- Sections showing trench dimensions

The trench stability calculations have been performed according to DIN 4126 for all sections with different panel widths and surcharge loads. Guide wall shall rise for extra 20cm above the ground level to maintain stability in trench for diaphragm wall. In section 2, the hoarding pressure of 200kPa, this was unusual load, on ground acts 5m away from the external face of the trench.

Section 1: -
In this section, dimensions of the diaphragm wall are 1m thick, 7.07m width and a 26.25 depth where surcharge of maximum 20kPa is considered in the analysis.

Section 2 and 4: -
In this section, dimensions of diaphragm wall are 1m thick, 6.5m width and 26.25m depth is considered. The advertisement hoarding load of 200kPa is considered on the cornice roadside whereas on Khaleej Al Arabi, existing hoarding shall be removed during the execution of the diaphragm wall. General surcharge loads of 10kPa inside the hoarding during trenching of the diaphragm wall and 20kPa outside of the hoarding are considered in the analysis.

Section 3: -
In this section, dimensions of the diaphragm wall are 1m thick, 7.07m width and 26.25m depth where surcharge of maximum 20kPa is considered in the analysis.

Section 5: -
In this section, the very close proximity of the existing old gymnasium building dictated the use of secant pile wall instead of diaphragm wall as a shoring system, so no trench analysis is done.

D. *Results*

A detailed calculation of GGU program have been shown in this report.: -

Section 1

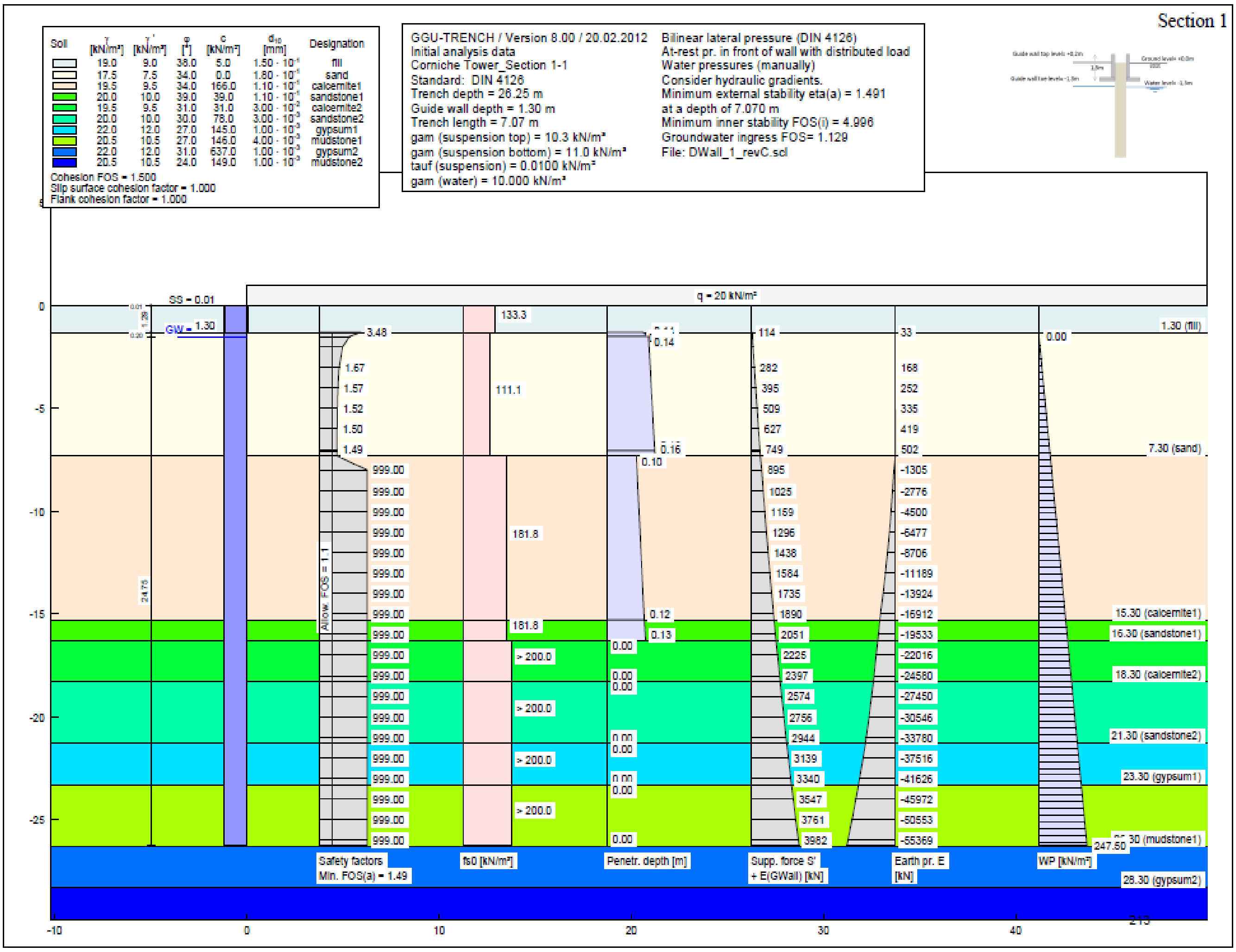

Fig 4-GGU analysis for Section 1-1

Section 2 and Section 4

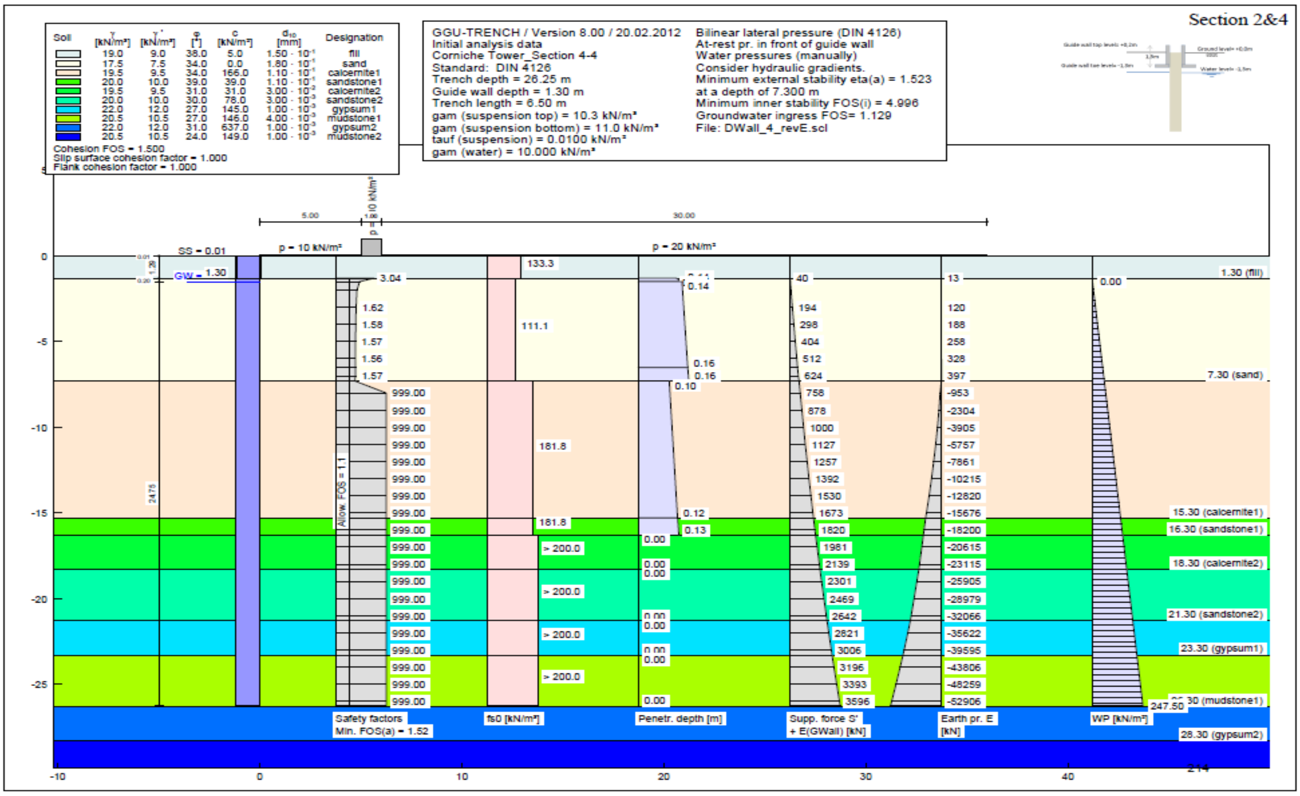

Fig 5-GGU analysis for Section 2-2, 4

Section 3

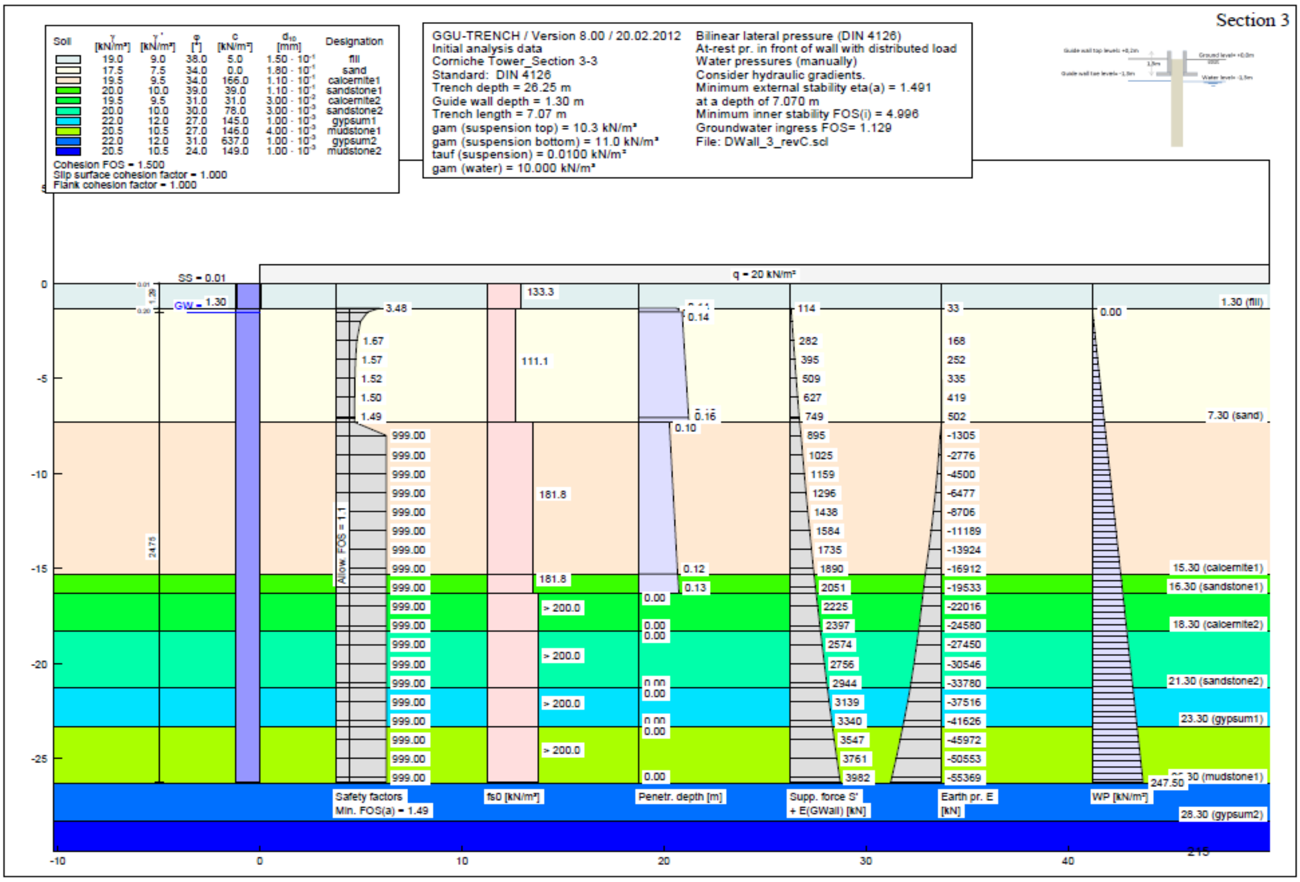

Fig 6-GGU analysis for section 3-3

III. CONCLUSIONS

Trench stability plays an important role in the design of the diaphragm walls, hence proper study of trench stability must be carried out before the execution of the actual design. Based on the case study given above, various conclusions can be drawn from the study as:

1. Surcharge loads at various places of the site must be taken in consideration since it plays a major role in the instability of the trench.
2. Impact of heavy loads such as high hoardings covering the site periphery should not be neglected.
3. Since trenches in cohesive soils are under the effect of large cohesive forces and arching effect, hence trench stability analysis must be carries out for all cases.

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