Retaining Wall Deflection Control in Relation to Augering Area

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ABSTRACT

When retaining walls are designed, design parameters of undisturbed soil are normally used. In reality, if the retaining wall is comprised of piles, they are often installed assisted by ancillary equipment, such as water jetting or augering, to reduce installation resistance. To what extent the impact of these ancillary methods has on the soil, and the effect of the retaining wall design is not known.
This report features impacts of driving assistance of pile installation on retaining wall design. A project in Le Mans, France was used as a case study to observe if the design of a retaining wall is still satisfied, despite a local ground disturbance by augering.

Key words: *Press-in Method, Retaining Wall, Chalk*

1. Outline of the project

1.1. Place

Le Mans is located on the River Sarthe, in the north west of France. Traditionally the capital of the province of Maine, it is also now the capital of the Sarthe Department and the seat of the Roman Catholic diocese of Le Mans. Le Mans is a part of the Pays de la Loire region.

The city has been famous for the Le Mons 24 Hour sports car endurance race since 1923.

The Gare du Mans is the main railway station of Le Mans. It takes 1 hour to reach Paris from Le Mans by TGV high speed train. There are also TGV connections to Lille, Marseille, Nantes, Rennes and Brest. Gare du Mans is also a hub for regional trains. Le Mans inaugurated a new light rail system on 17 November 2007.

1.2. Background and objectives of the project

The site is in the square in front of Le Mans train station and was previously used as a street level car park. As a part of the station renovation project, the car park was rebuilt as a single level underground car park.

2. Structural type and piling method

2.1. Site condition

The site is located close to the SNCF (the French national rail operator) tracks in Le Mans as shown in **Fig. 1**. The tracks include the TGV (France's intercity high-speed rail service) and therefore, there was a stringent vibration transmission restriction during the construction. Also, there were residential and commercial properties adjacent to the site, so construction noise was restricted.

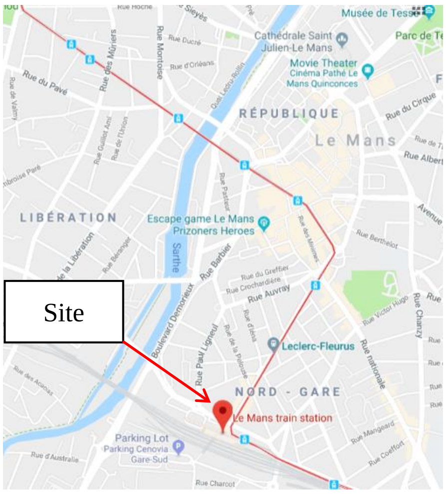

Fig. 1 Site Location Map

2.2. Ground condition

The basic soil makeup is alluvial deposits from the River Sarthe, which flows through the city of Le Mans. The alluvial deposits are comprised of mainly coarse soils as shown in **Fig. 2**.

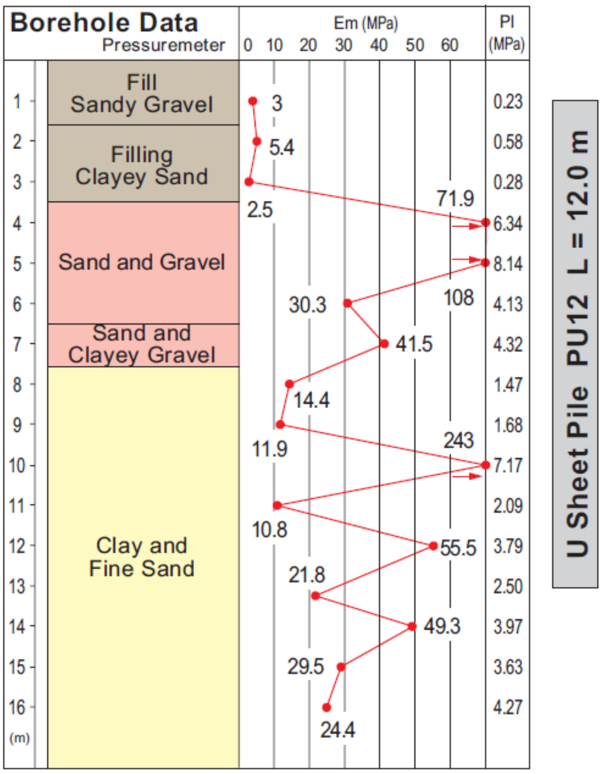

Fig. 2 Typical Borehole Log

"Pressuremeter tests" most commonly used in France, were carried out to investigate soil characteristics. **Fig. 2** shows the test results Pl (Pressure Limit) and Em (Pressuremeter Modulus) that were obtained. The outline of the Pressuremeter Test is described in **Fig. 3** below.

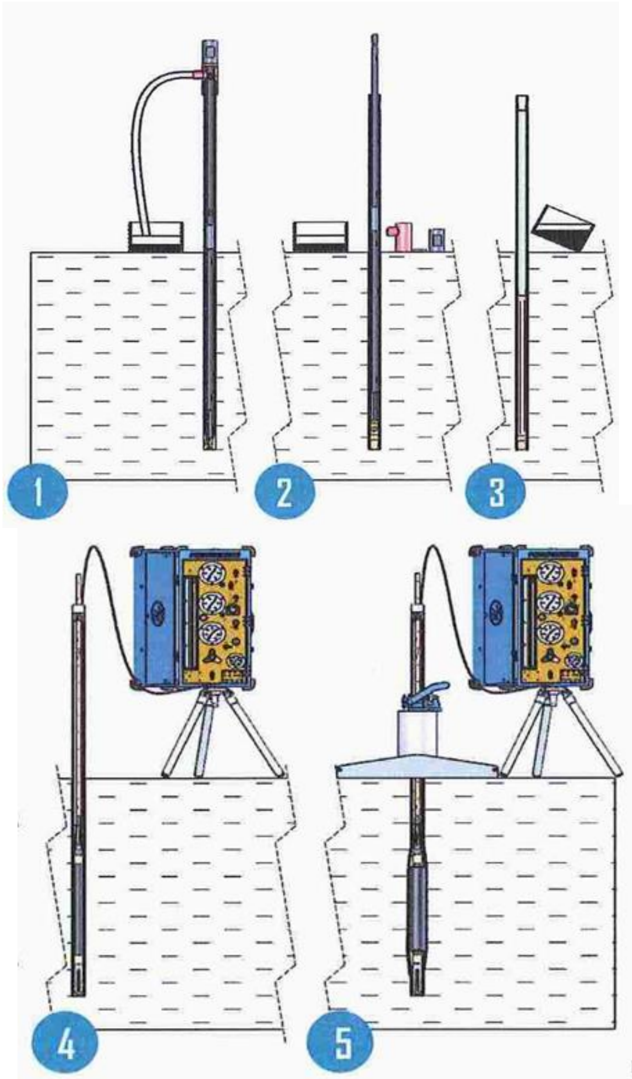

Fig. 3 Sequence of Pressuremeter Test

1) Rotary percussion drilling using a STAF System, which includes a STAF tool and a slotted tube, confirming to the STDTM specifications (Slotted Tube technique with inside Disintegrating Tool and Mud circulation) for Menard Pressuremeter testing. Slurry spills out into a sediment tank in which the borehole logging can be performed.
2) Extracting the STAF tool and its string of rods without remoulding the borehole walls.
3) The borehole remained lined. The slotted tube is ready to accept the Pressuremeter probe and clean slurry is ready to be circulated.
4) Using the locking device for the probe, the driller places the Pressuremeter probe into the slotted tube which is already in position. The probe is located exactly at the centre level of the steel

strips which form the slotted tube. Pressuremeter testing can then start. The coaxial or twin lines are protected from any squeezing or pinching by the string of STAF tubes.

5) The Pressuremeter tests are carried out, starting from the deepest location. The STAF string of pipes is pulled up to the level of the next test position using a specially designed pulling device. Pressuremeter readings can be recorded using the GEOSPAD data logger which is fitted to the Pressuremeter Control Unit, according to EN ISO 22476-4 Standard.

6)

Interpretations of Test Results

The typical test results of the Pressuremeter are shown in **Fig. 4**.

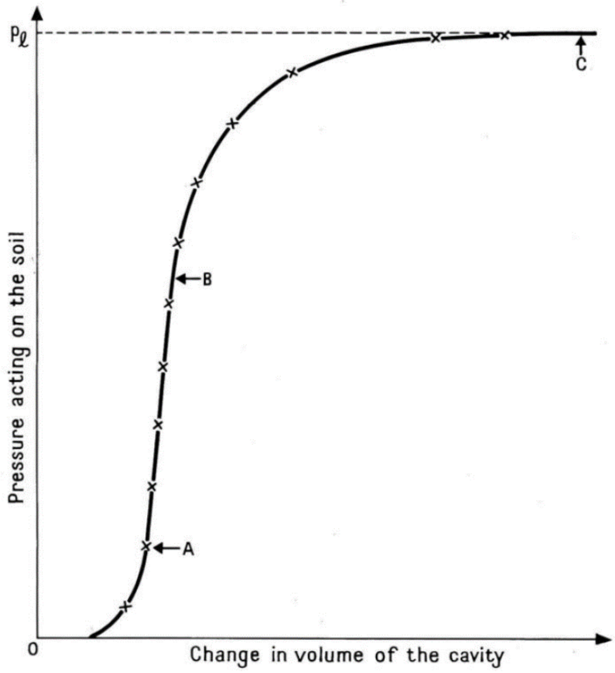

Fig. 4 Example Pressuremeter Test Results (from Baguelin, 1978)

There are three phases of the deformation curve: (1) the re-establishing phase, from the origin to point A; (2) the pseudo-elastic phase, from point A to point B; and (3) the plastic phase, from point B to point C.

After the borehole is drilled and the augers are withdrawn, the borehole walls relax, thus reducing the cavity volume. As the pressuremeter probe is initially inflated, the walls of the borehole are pushed back to their original position. Point A marks the point at which the volume of the borehole cavity has fully returned to its original position, and is given the coordinates, v_0, p_0. The pseudo-elastic phase, the straight-line portion of the curve between points A and B, is named so because of its resemblance to the elastic behavior of steel or concrete. Point B is the point at which creep pressure has been reached, and is given the coordinates, v_f, p_f. The plastic phase begins at point B and extends to point C, which is asymptotic to the limit pressure. Point C, which is given the coordinates v_L, Pl, is defined as the point where the pressure remains constant, despite increasing volume.

The limit pressure is defined as the pressure required to expand the measuring cell by an amount v_o beyond the volume required to inflate the pressuremeter (Vc) and to push the borehole wall back to its original position (v_o). This definition of limit pressure is analogous to defining failure in a triaxial test at a given value of axial strain, for example 10% to 15%. The Value of Vc depends on the size of the borehole, as shown in **Table 1**. The injected volume at the limit pressure (v_L) is thus:

$$v_L = v_o + Vc + v_o = 2v_o + Vc \qquad (1)$$

where:

v_o = volume required to inflate pressuremeter and push soil to its original position; and

Vc = initial volume of measuring cell (see **Table 1**).

Table 1. Values of Vc according to pressuremeter probe type (from Gambin and Rousseau, 1988)

Probe	Diameter of Borehole (mm)	Vc (cm^3)
EX	34	535
AX	44	535
BX	60	535
NX	76	790

If the volumetric increase at the end of the test is less than twice the cavity volume, extrapolation must be used to determine Pl. **Fig. 5** demonstrates this extrapolation procedure.

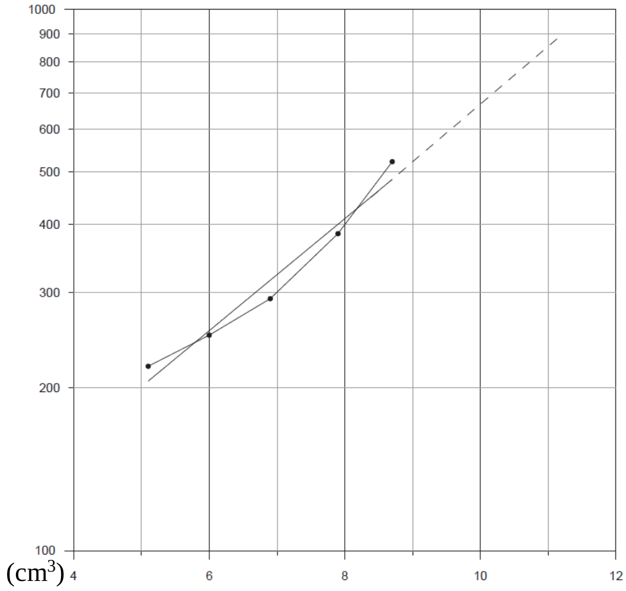

Fig. 5 Pressure vs. Log Volume Plot for Extrapolation of Limit Pressure at NCSU Research Site (from Wilson, 1988)

The "net limit pressure," Pl*, is used in foundation design, and is calculated using equation (2).

$$Pl^* = Pl - P_{ho} \qquad (2)$$

Where: Pl = limit pressure; and

P_{ho} = initial total horizontal pressure in the ground

$= [(\gamma - u)z]\, K_0 + u$

Although P_{ho} should equal the pressure corresponding to v_o (i.e. value corresponding to p_o), it is difficult to accurately determine p_o from the test data due to disturbance of the borehole walls and a lack of points at the beginning of the test.

The pressuremeter can be used in foundation designs for all types of soils, including residual soils. The settlement of foundations can be estimated using a deformation modulus, E_{PMT}, which can be derived from the pseudo-elastic phase (or straight-line portion) of the load deformation diagram. E_{PMT} is a function of Poisson's ratio, the slope of the straight line, and the cavity volume in the pseudo-elastic range, so it is conventional to use the mean volume, v_m, of the cavity during this phase. The deformation modulus, E_{PMT}, can be found using equation (3), and typical ranges of values for soil types are shown in **Table 2**.

$$E_{PMT} = 2(1 + \nu_s)\, V \frac{\Delta p}{\Delta v} \qquad (3)$$

Where: ν_s = Poisson's ratio

V= cavity volume during the pseudo-elastic phase

$= V_c + v_m$;

V_o= initial or at-rest volume of the measuring cell (see Table 1 for typical values);

v_m= the mean volume of the pseudo-elastic phase

$= (v_f + v_o)/2$; and

$\Delta p/\Delta v$= slope of the seudo-elastic phase

Table 2. Range of E_{PMT} and Pl for several soil types (from Gambin and Rousseau, 1988)

Soil Type	E_{PMT} (bars)	p_L (bars)
Mud, Peat	2 – 15	0.2 – 1.5
Soft clay	5 – 30	0.5 - 3
Medium clay	30 – 80	3 – 8
Stiff clay	80 – 400	6 - 20
Marl	50 – 600	6 - 40
Loose silty sand	5 – 20	1 – 5
Silt	20 – 100	2 - 15
Sand and gravel	80 – 400	12 - 50
Sedimentary sands	75 – 400	10 - 50
Limestone	800 - 200,000	30 – over 100
Recent fill	5 – 50	0.5 – 3
Old fill	40 – 150	4 - 10

The correlations between the pressure meter test and CPT were evaluated by Baguelin et al. in 1978. In the evaluations, the pressure limit Pl and cone resistance qc of CPT were correlated in different soil types, as described in **Table 3** below.

Table 3. qc/Pl for different soil types according to Baguelin, 1978

Soil Description	qc/Pl
Very soft to soft clays	close to 1 or 2.5 to 3.5
Firm to very stiff clay	2.5 to 3.5
Very stiff to hard clay	3 to 4
Very loose to loose sand and compressive silt	1 to 1.5 and 3 to 4
Compact silt	3 to 5
Sand and gravel	5 to 12

The sandy gravel and fine sand layers underlying the fill are generally dense to very dense. The Pl of the sand and gravel layers ranges from 4.13MPa up to 8.14MPa generally. In the clay and fine sand layer, the Pl exceeds 7.0MPa locally (as shown in **Fig. 2**). These values are correlated to cone resistance qc of 20MPa to 98MPa with the correlation factors from 5 to 12 described in Table 1, and the soil is categorized as "dense" to "very dense" (as shown in **Table 4** and **Table 5** below).

Table 4. Density of Fine Sand (qc/SPTN= 0.4-0.5)

Cone Resistance qc (MPa)	SPT N	Density
＜2	4-5	very loose
2-4	4-10	loose
4-12	8-30	medium dense
12-20	24-50	dense
＞20	40-50	very dense

Table 5. Density of Sandy Gravel (qc/SPTN= 1.1-1.8)

Cone Resistance qc (MPa)	SPT N	Density
＜5	＜5	very loose
5-10	3-9	loose
10-30	6-28	medium dense
30-50	17-45	dense
＞50	＞45	very dense

2.3. Structural type

The steel sheet piling was used as temporary retaining walls to construct a single level basement car park. The basement walls were constructed of reinforced concrete alongside of the temporary sheet pile walls. To allow rapid installation of these basement walls, a bulk excavation was carried out. In order to achieve the bulk excavation, the steel sheet piling was used as cantilever walls and anchored walls. The retained height of the cantilever sheet pile walls ranged from 3.6m to 5.0m, and the retained height of the anchored sheet pile walls ranged from 3.3m to 4.9m. Typical cross sections of the basement are shown in **Fig. 6**, **Fig. 7** and **Fig. 8** below.

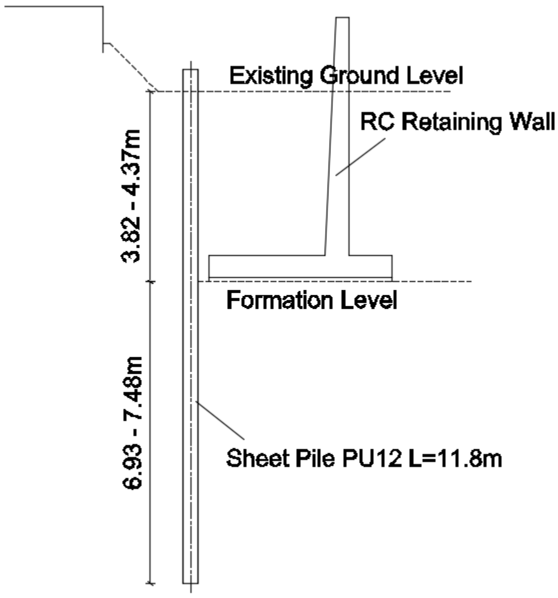

Fig. 6 Typical Cross Section - 1
(Cantilever SSP Wall and RC Cantilever Wall)

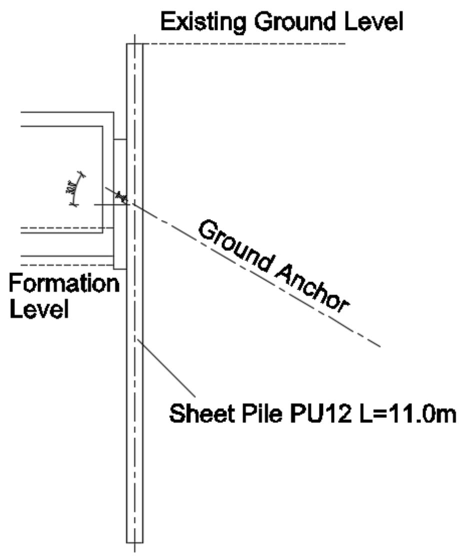

Fig. 7 Typical Cross Section - 2
(Anchored SSP Wall and RC Basement)

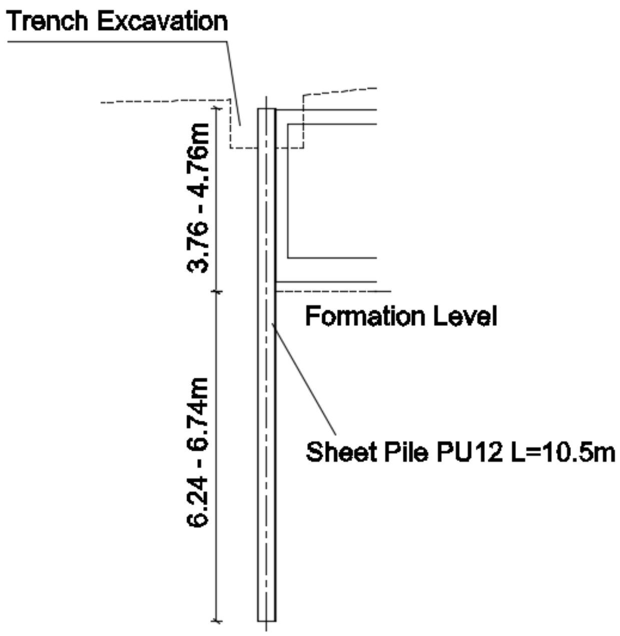

Fig. 8 Typical Cross Section - 3
(Cantilever SSP Wall and RC Basement)

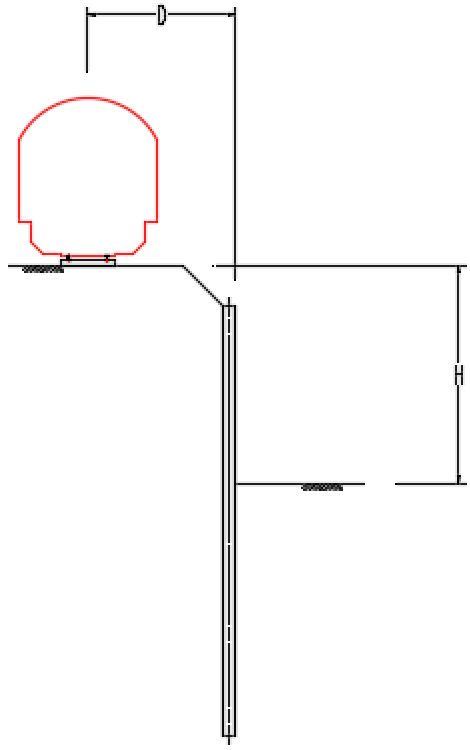

Fig. 9 Retained Height H and Distance between Pile Line and Railway Track D

According to the French railway regulations, the allowable deflection of retaining walls alongside railways is calculated by taking into account a. the velocity of trains, b. the retained height and c. the distance between the railway track (as shown in **Table 6** and **Fig. 9** below).

Table 6. Allowable Horizontal Deflection of Retaining Walls alongside Railways (V＜80km/h)

Allowable Deflection (mm)	D (m)			
	D≤3	3＜D≤4	4＜D≤5	5＜D≤6
H≤2m	50	100		
2m ＜ H ≤ 3m	46	70	100	
3m ＜ H ≤ 4m	41	61	100	
4m ＜ H≤ 5m	34	52	78	100

As shown in **Fig. 10**, the distance between the proposed pile line and the existing TGV track was more than 6.0m, which gives the allowable horizontal deflection of the retaining walls of 100mm as shown in **Table 6**. 600mm wide U sheet piles, PU12/ PU18 with lengths from 8m to 13m were used to satisfy the design requirement.

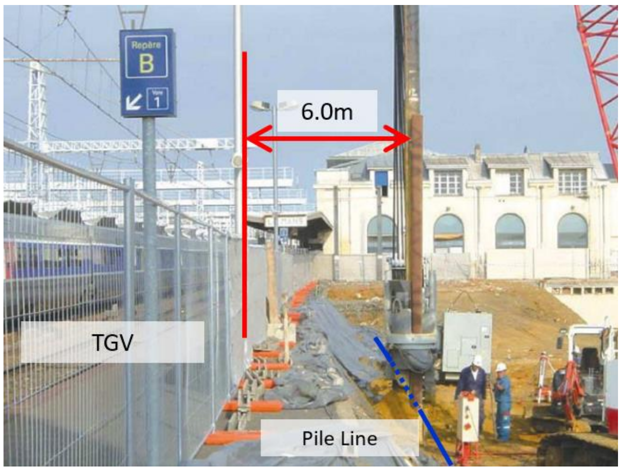

Fig. 10 Pile Line along the TGV Track

2.4. Piling method

In order to install sheet piles into dense to very dense sandy gravel and sandy layers, the Press-in with simultaneous augering method (**Fig. 11**) was utilized. The in-pan of each sheet pile is attached to the side of the auger casing. The sheet pile and the auger casing are then grasped by the chuck of the Silent Piler and installed into the ground simultaneously.

Fig. 11 Piling Work in Progress

3. Press-in piling

3.1. Layout

The pile layout is described in **Fig. 12**.

Fig. 12 Plan View Layout

3.2. Productivity

The piling work was carried out from July 24th to September 28th in 2006 by utilizing two SCU600M Silent Pilers fitted with Pile Augers. A total of 608, 600mm wide U sheet piles were installed, covering 3,826m^2 of the wall area. The average production rate was approximately 69.6m^2 of the wall area per day, which is equivalent to 116m of the total pile driving length.

3.3. Encountered difficulties

At the design stage, the ground disturbance by the augering was a concern because the impact of the ground disturbance on the lateral deflection of the retaining wall was unknown. In order to minimize the ground disturbance, 540mm diameter auger heads were used (as shown in **Fig. 13**). Also, in order to predict probable lateral deflection of the retaining walls, test piling with lateral load testing was carried out. With satisfactory results, the Press-in with simultaneous augering method was specified in the tender document.

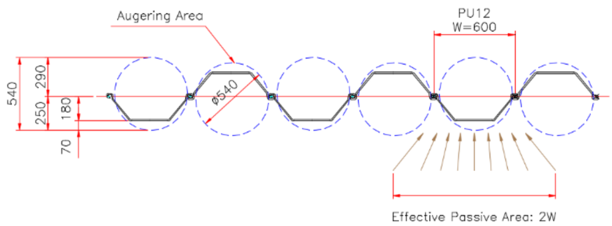

Fig. 13 Orientation of Augering Area

4. Additional data

After each pile installation, the area disturbed by augering was backfilled with augering spoils. Post pile installation, the lateral deflection of the retaining wall was continuously monitored through to the project completion. Despite the augering, the actual deflection at the top of the retaining wall remained within the design deflection allowance of 38.3mm as shown in **Table 7**, **Fig 14** and **Fig. 15**.

Table 7. Lateral Deflection of Retaining Walls

Monitoring Point	Lateral Deflection (mm)	Monitoring Point	Lateral Deflection (mm)
P1	20	P13	31
P2	11	P14	23
P3	11	P15	22
P4	10	P16	22
P5	9	P17	17
P6	4	P18	14
P7	18	P19	9
P8	4	P20	5
P9	6	P21	5
P10	10	P22	2
P11	21	P23	6
P12	38		

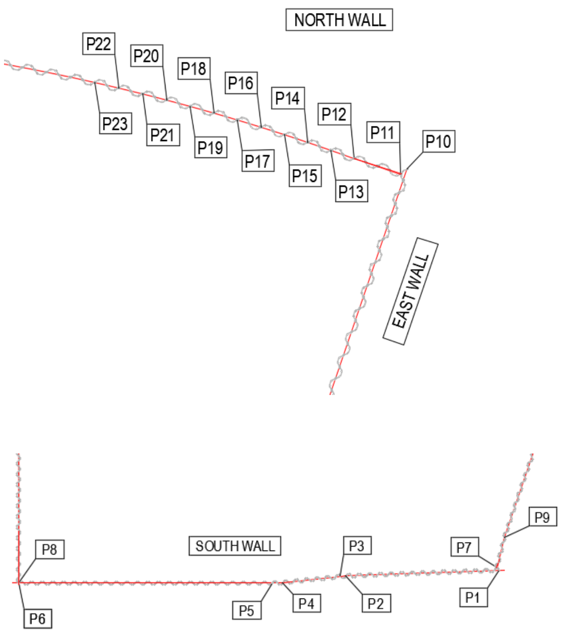

Fig. 14 Monitoring Points Location

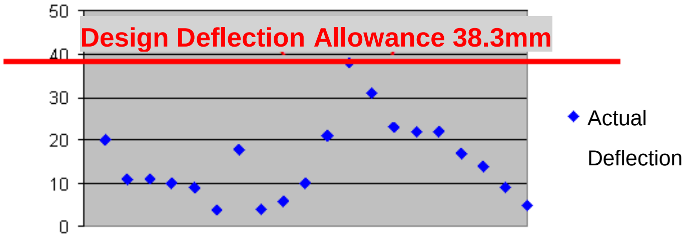

Fig. 15 Lateral Deflection of Retaining Walls

5. Design consideration

This report reveals that the augering method was effectively used to overcome difficult ground conditions. At the same time, the retaining wall design requirement was met, despite the ground disturbance as a consequence of the augering. It is thought that the following aspects may have contributed to achieving the design requirement.

1) Soil arch effect

When a retaining wall is loaded laterally, distribution of the soil stress can be simulated based on the Theory of Elasticity using the Boussinesq equation that considers a point load on the surface of a semi-infinite, homogeneous, isotropic, weightless, elastic half-space. The concept of the soil arch effect prepared from the Boussinesq's equation by Bowles [1996], (as shown in **Fig. 16**).

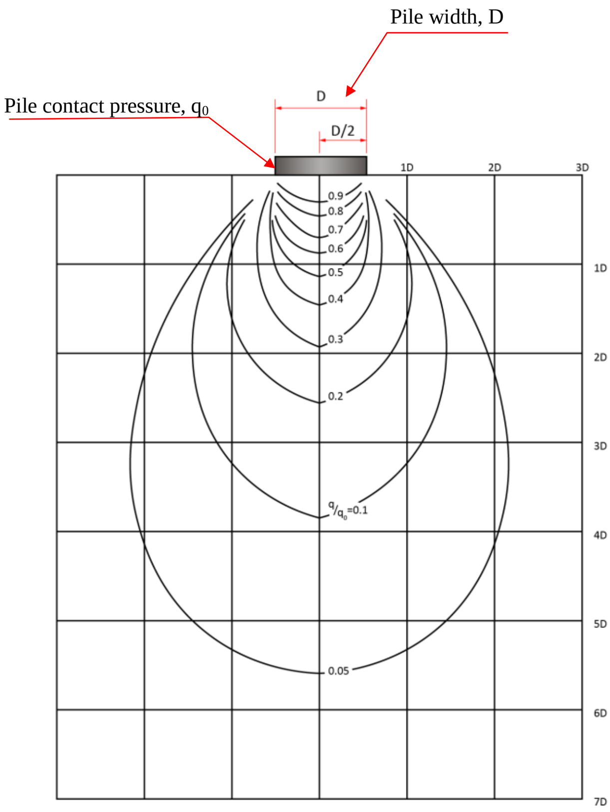

Fig. 16 Pressure distribution formed on the passive side of a pile, showing the intensity of pressure q/q0, based on the Boussinesq equation (after Bowles, 1996)

On the project, the auger mostly disturbed the in-pan side of each pile leaving very little disturbed area at the out-pan side as shown in **Fig. 17**.

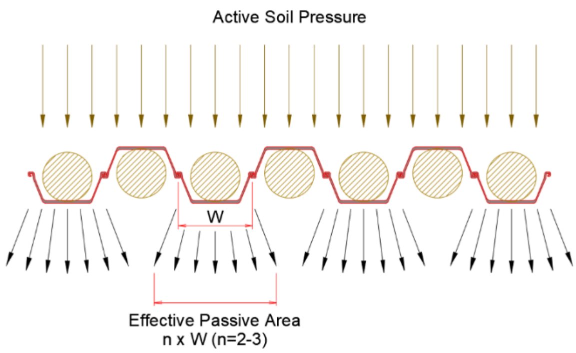

Fig. 17 Effective passive area

The diameter of the auger was selected so that both shoulders of each sheet pile snugly met with the undisturbed soil. The lateral load acting on the sheet pile wall is radially transferred to the soil at the passive side, through the arching action of the soil. The tendency of the arching action which depends on soil characteristics is described as "passive mobilization factor". The effective passive area is shown as follows: -

Effective passive area = nW
n: Passive mobilisation factor
W: Undisturbed area on pile surface

In general, a passive mobilisation factor of 2-3 is used depending on soil conditions. There is no simple relationship between the characteristics of the effective passive area (nW) and soil conditions, because any relationship is dependent on the pile size and on the nature and sequence of the strata. "nW" at a certain distance (H) in low strength cohesive soil is generally greater than that in dense, less cohesive soil.

2) Confined effect of disturbed soil

After pile installation, the auger is extracted and the augering spoils are backfilled. In general, the strength of the backfill is ignored for retaining wall design, due to its uncertainty as a result of disturbance. However, the augered areas are not left void, but are filled with augering spoils. As such, the augered areas are sufficiently confined and the backfill should transfer the active earth pressure to the surrounding undisturbed soil to some extent. It is thought that this "confined effect" contributed to a lateral deflection, which is smaller than the design deflection. However, this effect is not covered in this report, and the following aspects should be observed if checking this issue at another point in time.

a) Measuring density or stiffness of backfill
b) Measuring shear strength of backfill
c) Measuring compressibility of backfill
d) Measuring stress on pile surface on passive side
e) Measuring stress on surface of undisturbed soil on passive side
f) Measuring lateral deflection of retaining wall
g) Making speculation on linking above aspects.

6. Concluding remarks

When augering is required to install retaining walls, it is prudent to give retaining wall design careful consideration to this aspect, especially if the retaining wall is a cantilevered wall. This is because the impact on the soil parameters by augering is not scientifically ascertained and it is difficult to evaluate characteristics of the disturbed soil. Therefore, augering may cause unexpected large horizontal deflections of retaining walls if an overoptimistic retaining wall design is used. On the other hand, if over pessimistic retaining wall design is used, unnecessary remedial works, such as grouting or the like, may be required to stabilize the retaining wall. This will make retaining wall construction less economical.

Unless retaining walls are installed with a complete underreamed auger (larger auger diameter than the pile width), there are some undisturbed areas on the retaining wall surface, which have decent horizontal passive strength for the retaining wall. Based on this, the retaining wall can be designed with a reasonable passive mobilization factor, which determines the effective passive area. With this approach, retaining walls can be designed rather economically, avoiding overestimated/underestimated design.

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