INSTALLATION OF 10 FEET DIAMETER CIDHS IN SOFT CLAY USING ROTATOR/OSCILLATOR ON TRESTLE

Pirooz Barar, PB&A Inc., San Rafael, CA, USA, (415) 259-0191, pbarar@pbandainc.com
Babak Mamaqani, PB&A Inc., San Rafael, CA, USA, (415) 259-0191, babak.mamaqani@pbandainc.com

ABSTRACT:

The Moanalua trestle spanned over Moanalua Stream, Honolulu, HI and was designed to accommodate construction of five 10 feet diameter cast in drilled hole (CIDH) piers as a part of Honolulu Authority for Rapid Transportation (HART) project. Due to the proximity of piers to the existing bridge, the trestle was elevated 20 feet above grade. Stratigraphy of the site consisted of shallow depth of fill and 150 feet of loose to very loose recent alluvium (soft clay) underlain with stiff to hard old alluvium (stiff clay). CIDH casings were installed by a rotator or oscillator depending on the diameter of the piers. The challenge was to design the trestle, not only for heavy gravity loads, but also to resist significant lateral loads from rotator and oscillator with minimal deflection. Series of piles, called reaction piles, were integrated into the trestle at each CIDH pier location to provide adequate lateral support for the rotator/oscillator. Due to the lack of information regarding soil Young's modulus (E), a methodology was developed to calibrate and calculate E with two methods. Extensive analyses using LPILE and finite element analysis program, PLAXIS, were performed to model reaction piles and calculate lateral deflection.

Keyword: trestle, cast in drilled hole (CIDH), rotator, oscillator

PROJECT SPECIFICATIONS

The Honolulu Rail Transit includes 20-mile route and 21 stations to be built from East Kapolei to Ala Moana Center, with $1.55 billion construction budget. The project is divided into two phases as shown in Fig. 1: Phase 1 which connects East Kapolei to Aloha Stadium with expected operation in late 2020, and Phase 2 which connects Aloha Stadium to Ala Moana Center with expected operation in 2025.

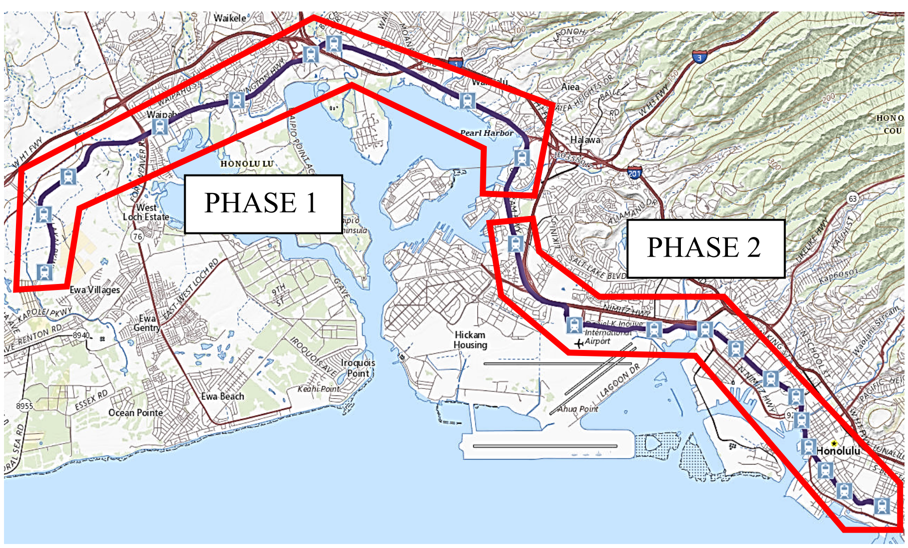

Fig. 1. The Honolulu Rail Transit Project, Honolulu, HI (HART, 2019)

Moanalua trestle was a temporary platform over Moanalua stream to construct five cast in drilled hole (CIDH) piers, namely piers 614 through 618, as a part of Phase 2 of Honolulu Authority for Rapid Transportation (HART) project. The diameter of piers typically was 10 feet with tip elevation at 250 feet below grade. Due to the proximity of piers to an existing bridge and required space for equipment, the trestle was elevated 20 feet above grade to clear conflicts. The location of the Moanalua trestle is shown in Fig. 2

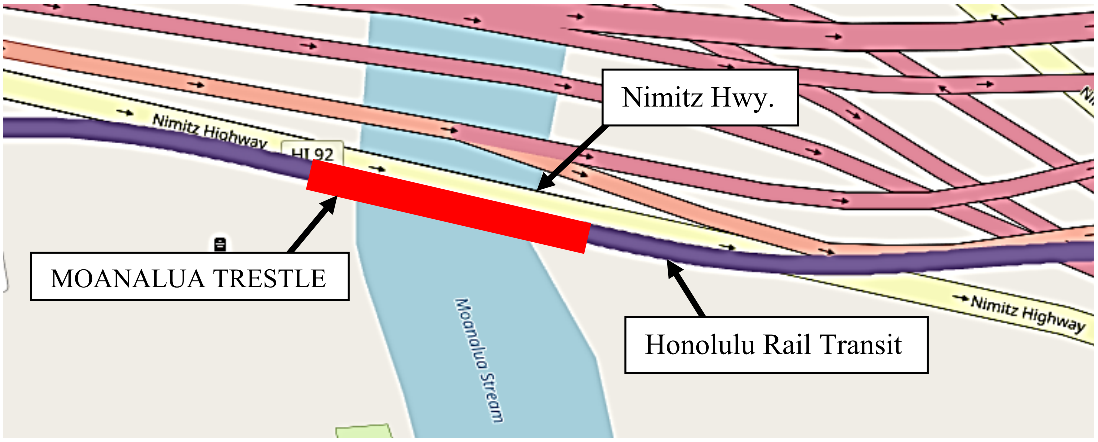

Fig. 2. Moanalua Trestle Location

SITE STRATIGRAPHY AND SOIL PROPERTIES

Per the geotechnical report, the stratigraphy of the job site consisted of shallow fill and almost 150 feet of loose to very loose recent alluvium (Ra) underlain with stiff to hard alluvium (Qa and Ql) as shown in Fig. 3.

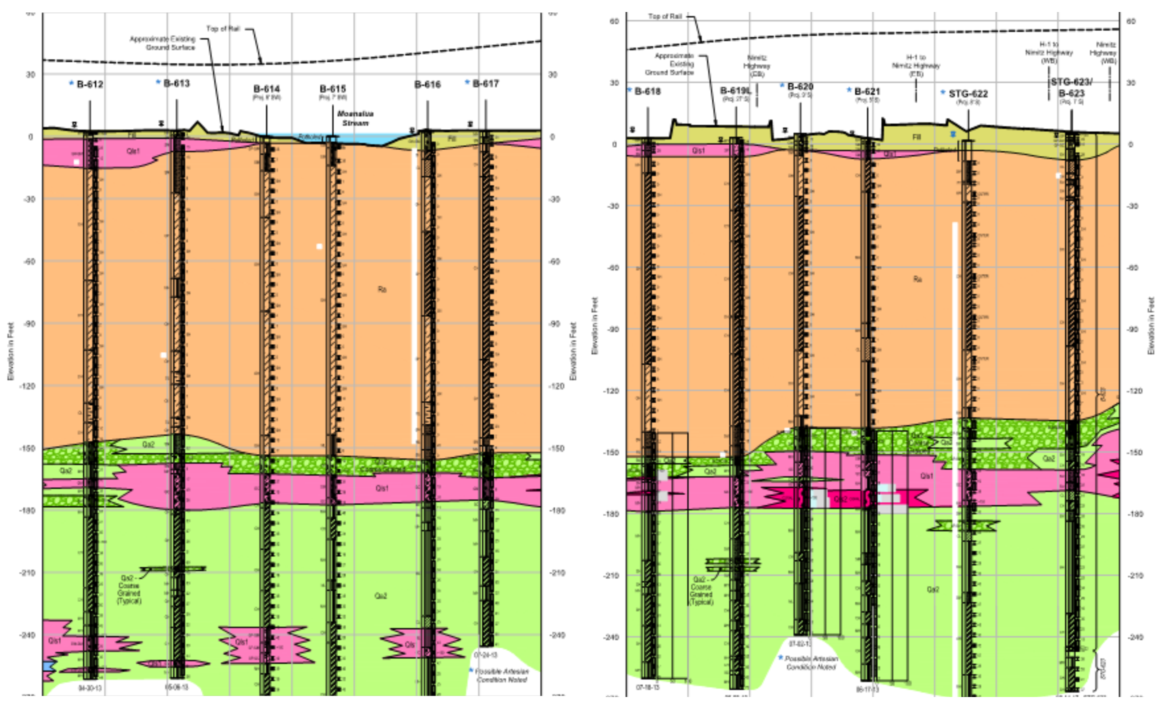

Fig. 3. Site Stratigraphy at Piers 614 Through 618

According to the standard penetration test (SPT) result, the N value for Ra layer is 0 and the hammer could penetrate the soil under its self-weight. Soil properties were developed to be used mainly for LPILE program as listed in Table 1. All the values in the geotechnical report were based on geotechnical investigations except soil Young's Modulus which was purely based empirical values in table C10.4.6.3-1 of AASHTO LRFD (2012).

Table 1. Soil Properties

Soil Type	Top Elevation (feet)	Soil Density γ (pcf)	Poisson Ratio ν	Young's Modulus E (ksi)	Friction Angle ϕ (degree)	Undrained Shear Strength S_u (psi)	Modulus of Subgrade Reaction k (pci)	Strain at 50% Max Stress ε_{50}
Fill	0	115	0.3	8.3	34	0	60	-
Ra	5	105	0.45	1.0	-	600	-	0.01
Qa2-CG	150.8	110	0.35	13.9	38	-	125	-
Qls1	160.3	110	0.25	6.9	32	-	30	-
Qa2	174.5	110	0.3	8.3	-	3,000	-	0.005

SPECIAL CONSTRUCTION EQUIPMENT

A BUMA rotator CR3000 was used to install CIDH casings for piers 614 through 617 using. The rotator uses clockwise or counterclockwise rotational force to drill and install casings through the soil. Per the manufacturer's specifications (BUMA, 2019), the rotator can exert up to 9,800 kip-feet of torque which translates into 260 kips of the lateral load if it is restrained at tongue end (point A) as shown in Fig. 4. The rotator can install up to 118.1 inch diameter casing and has the extraction capacity of up to 1180 kips.

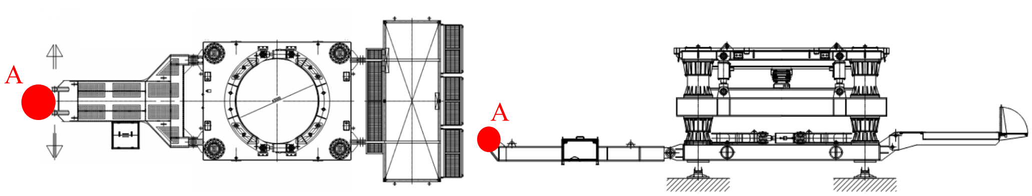

Fig. 4. Rotator BM-CR3000

CIDH casing for pier 618 was installed with a BUMA oscillator C3600. Unlike rotator, the equipment oscillates back and forth to install a casing. The oscillator has higher torque and extraction capacities compare to the rotator and can be used to install larger diameter casings. Per manufacturer's specification (BUMA, 2019), the oscillator can exert up to 14,000 kip-feet of torque which translates into 580 kips of the lateral load if it is restrained at tongue end as shown in Fig. 5. This equipment can install up to 141.7 inch diameter casing and has the extraction capacity of up to 28,000 kips. The self-weight of both rotator and oscillator is 195 kips. Per the manufacturer, rotator and oscillator displacement should be limited to maximum 2 inches to achieve optimum capacity and prevent any damages to the casing.

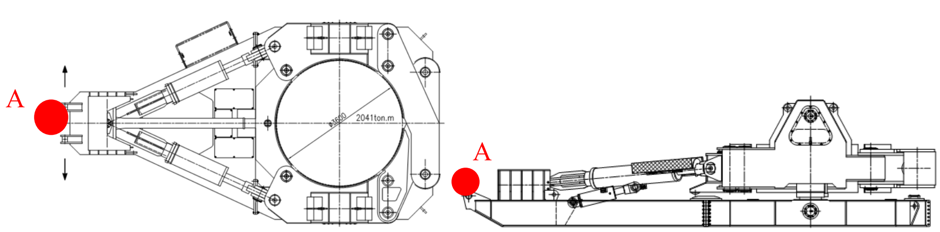

Fig. 5. Oscillator BM-C3600

TRESTLE GEOMETRY

Five and seven Pipe 42”X1” were initially assumed at rotator and oscillator reaction frames respectively to limit deflection to 2 inches as required by manufacturer’s specifications. These piles were connected by lateral bracings and cap beam to create a reaction frame at each pier location as shown in Fig 6.

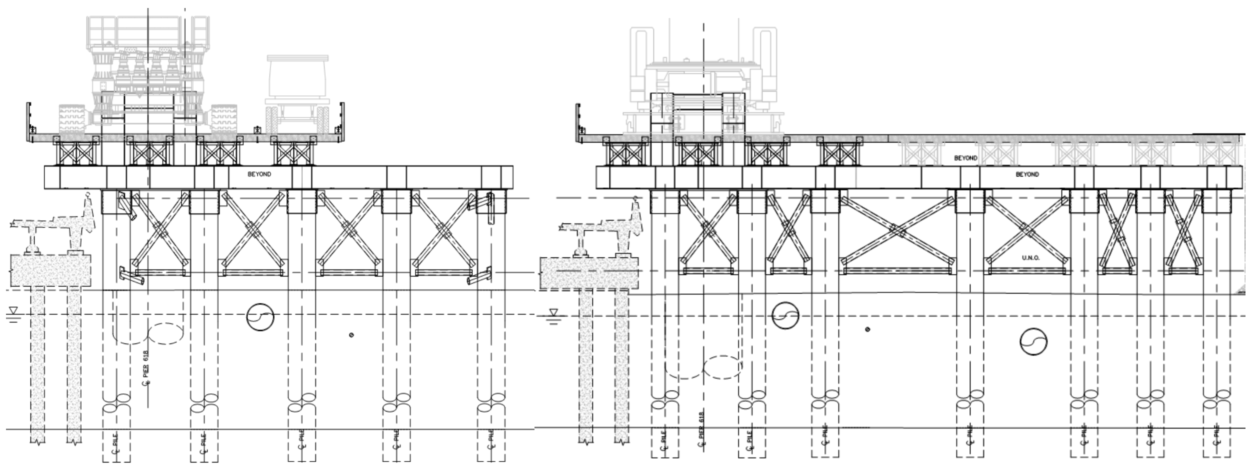

Fig. 6. Typical Reaction Frames; Left: Rotator Frame, Right: Oscillator Frame

LATERAL LOAD ANALYSIS

Trestle piles were divided into two main categories: 1) gravity piles which were mainly designed to resist and transfer gravity loads, and 2) reaction piles which were designed to resist lateral load exerted by rotator/oscillator with the minimal deflection on top of gravity loads. This section focuses on the design of reaction piles under lateral loads.

Due to the complexity and sensitivity nature of the project, finite element analysis (FEA) program, PLAXIS 2D, was selected to evaluate reaction pile deflection under the rotator/oscillator lateral load. Soil Young’s modulus (E) was needed to perform PLAXIS analysis. Therefore, Young’s Modulus in the geotechnical report needed to be verified since they were based on empirical values. A methodology was developed to calibrate and calculate accurate soil Young's Modulus.

Methodology

Recommended Young’s modulus in the geotechnical report was first calibrated using results obtained from LPILE and PLAXIS models with a single reaction pile. The calibrated Young’s modulus from this step is a constant value over the depth of the soil layer.

Second, Young’s modulus was calculated using the shear wave velocity value obtained from seismic CPT test in the geotechnical report. This resulted in variable Young’s modulus over the depth of the soil layer which was then idealized into three zones with constant E values to simplify the modeling procedure.

Finally, PLAXIS models were generated using both calibrated and calculated Young’s modulus and soil properties listed in Table 1 to investigate reaction frame deflection under lateral loads from rotator/oscillator. The adopted methodology in this paper is presented in Fig. 7.

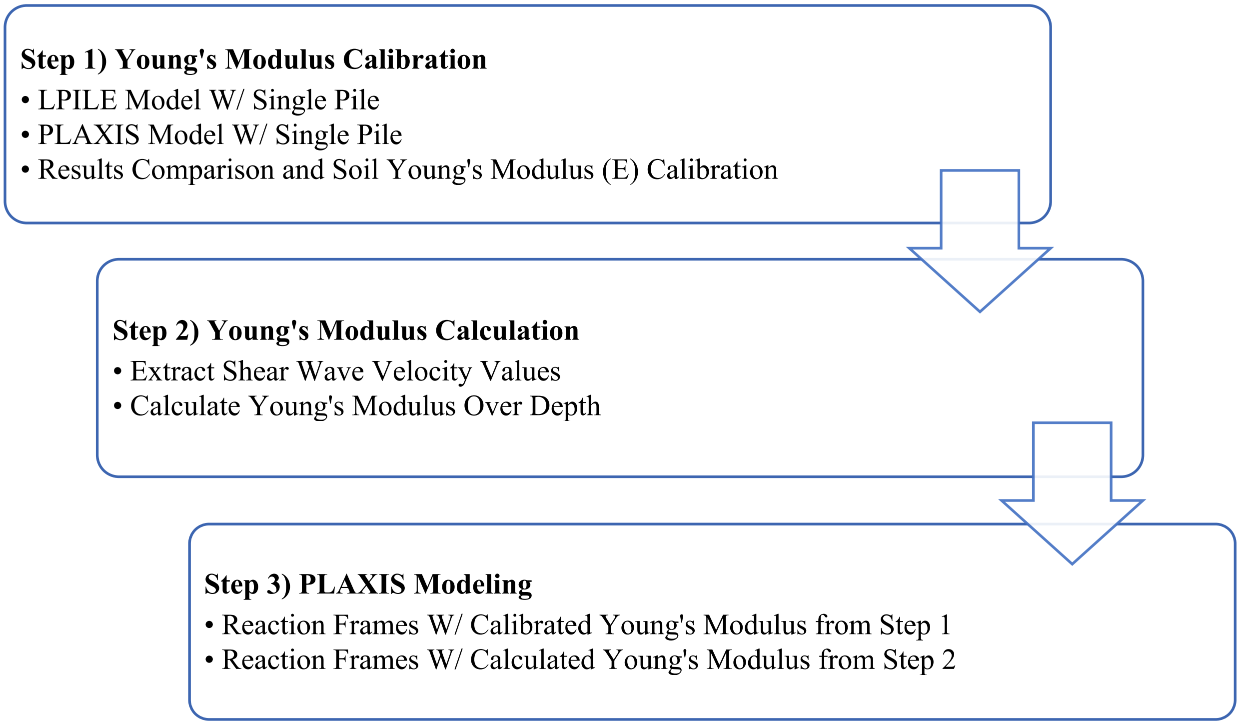

Fig. 7. Methodology to Evaluate Reaction Frame Deflection

Young's Modulus Calibration

LPILE is a powerful tool to investigate a single pile under lateral loads. One of the main advantages of LPILE over PLAXIS is that it can calculate pile deflection without input for soil Young's modulus. The program generates p-y curves over the depth of the pile which can be translated into soil Young' modulus. However, the program has two main limitations: 1) it can only model a single pile, and 2) it cannot accurately model pile head condition and multiple pile cross bracing frames.

Two identical models with a single pile were generated in LPILE and PLAXIS with properties listed in Table 1. Each model consisted of a single reaction pile with 52 kips of lateral load (260 kips for rotator/5 piles per reaction frame) applied at top of the pile. It was assumed that the pile head is fixed at the top, which means it is restrained against rotation but can freely move laterally. Only one pier was modeled since soil properties and stratigraphy were almost the same at all pier locations.

LPILE model results using soil properties listed in Table 1 showed that maximum deflection of 0.82 inches occurs at the pile head and then rapidly dissipates and reaches zero at almost 50 feet below the pile head within the top soil layer (Ra). This implied that Young's modulus of the top soil layer (Ra) only needed to be calibrated.

The identical PLAXIS model with recommended E value predicted 1.95 inches of deflection at pile head, which was significantly higher than the one calculated by LPILE as shown in Fig. 8. This meant that the recommended Young's modulus in the geotechnical report was significantly low considering other soil properties recommended in the geotechnical report. Therefore, the value for the Young' modulus (E) of the upper layer of soil (Ra) was increased gradually in an iterative process, and at each iteration, the results were compared to see whether the results of the PLAXIS and LPILE model would match. After several iterations, a PLAXIS model with constant moduli value (E) of 4.9 ksi for the upper soil layer, Ra, yielded results that are aligned with the LPILE model as shown in Fig. 8.

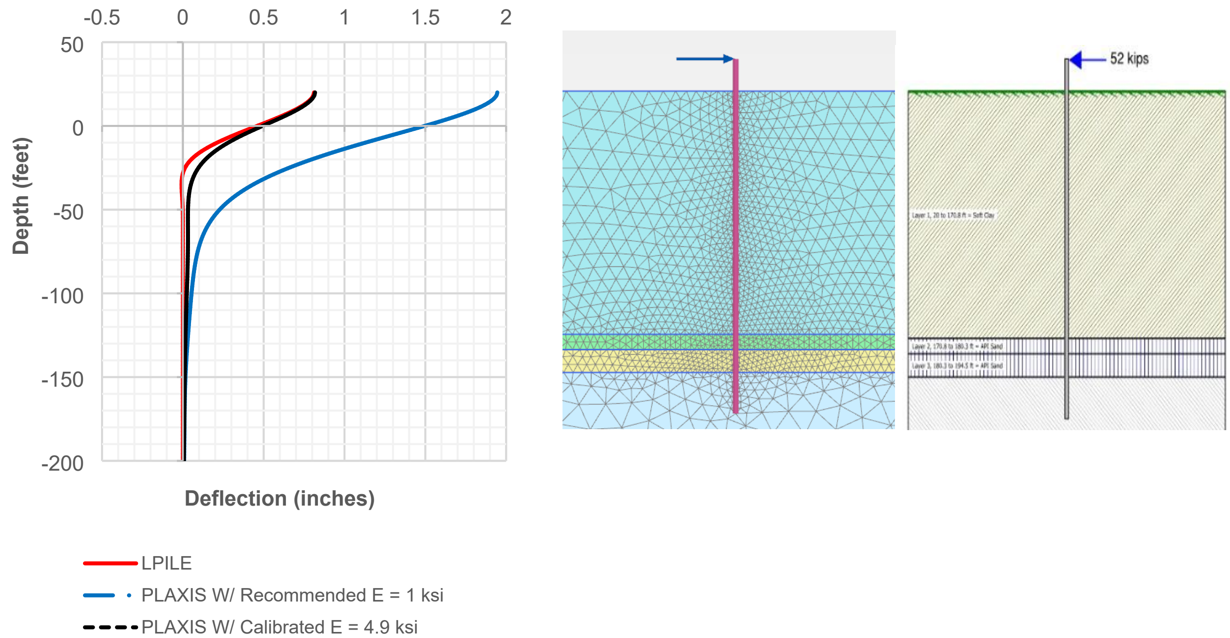

Fig. 8. Single Pile Models in LPILE (Right) and PLAXIS (Middle) with Results (Left)

Young's Modulus Calculation

Soil Young's modulus (E) can be caluacted using shear wave velocity results from seismic CPT tests. The first step was to calculate maximum shear modulus using the shear wave velocity as suggested by Kramer (1996) using the following equation.

$$G_{max} = \rho . V_s^2 \qquad [1]$$

Where G_{max} is the maximum shear modulus, ρ is soil density and V_s is shear wave velocity.

Vucetic and Dobry (1991) suggested modulus reduction curves as shown in Fig. 9 for clay with OCR up to 15 that can be used to calculate soil shear modulus using G_{max}, cyclic shear strain, γ_c and plastic index (PI).

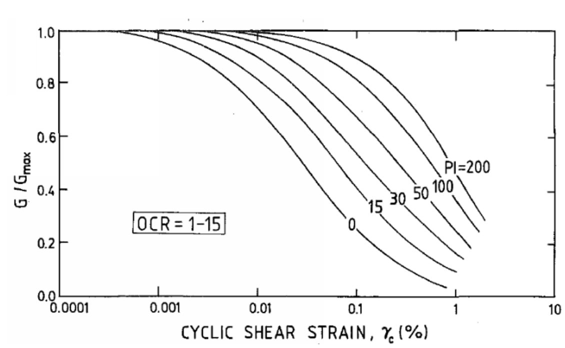

Fig. 9. Modulus Reduction Curves for Clay by Vucetic and Dobry (1991)

Shear strain ratio can be calculated as follow:

$$\varepsilon_{shear} = \frac{\Delta}{L} \qquad [2]$$

Where ε_{shear} is the shear strain, Δ is pile deflection at grade, and L is the length of the pile.

The shear strain was calculated for three pile defelection values namely, 2 inch, 0.8 inch, 0.3 inch and corresponding G/G_{max} ratios were extracted from Fig. 9, using PI of 49 per geotechnical report for soil layer Ra as listed in Table 2. The LPILE model in the previous section showed that the pile deflection at grade is close to 0.3 inches (Case 3). Other cases were considered to investigate lower Young's modulus impact on determining reaction pile deflection.

Table 2. G/G_{max} Ratio

Case #	Pile Defelection Δ (inches)	Shear Strain ε_{shear} (%)	Shear Stress/Max. Shear Stress G/G_{max}
1	2	0.08	0.73
2	0.8	0.032	0.86
3	0.3	0.012	0.95

Then, the Young' modulus (E) can be calculated using the following the equation:

$$E = G * 2(1 + \vartheta) \qquad [3]$$

Where E is Young's modulus, and ν is the soil Poisson's ratio.

Soil Young's modulus over depth of top soil layer (Ra) were calculated using shear wave velocity for each case as shown in Fig. 10.

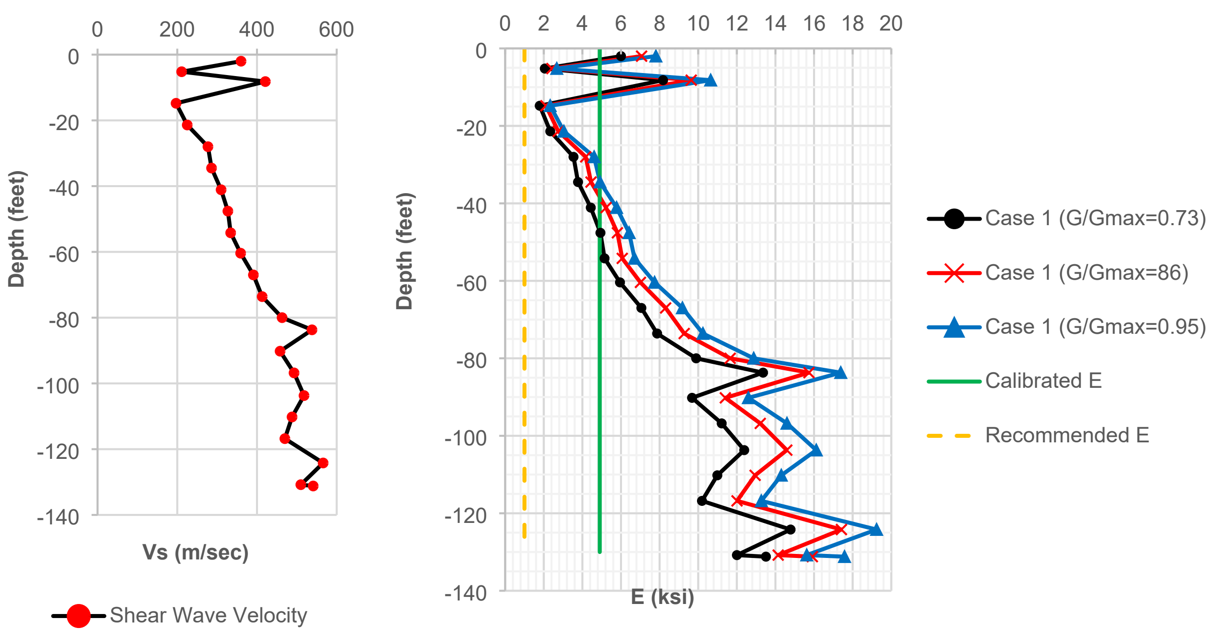

Fig. 10. Left) Shear Wave Velocity, Right) Calculated E value over Depth

Finally, Young's modulus over the depth was idealized into three zones with constant values to simplify the modeling process. Table 3 summarizes the calculated Young's modulus from this section, the calibrated Young's modulus from the previous section and recommended value in the geotechnical report per AASHTO LRFD (2012).

Table 3. Young's Modulus Values

Case #	Depth (feet)	Calculated E (ksi)	Calibrated E (ksi)	Recommended E (ksi)
1	0-20	2.1	4.9	1
	20-65	5.0		
	65-130	11.4		
2	0-20	2.4		
	20-65	5.9		
	65-130	13.5		
3	0-20	2.7		
	20-65	6.5		
	65-130	14.9		

PLAXIS Modeling

PLAXIS models for reaction frames under rotator and/or oscillator lateral loads were developed with calculated and calibrated Young's modulus (E) listed in Table 3 and soil properties listed in Table 1 as shown in Fig. 11. As shown, the piles are connected with a cap beam at pile head and lateral bracings were provided to distribute the lateral load among reaction piles equally and minimize lateral deflection.

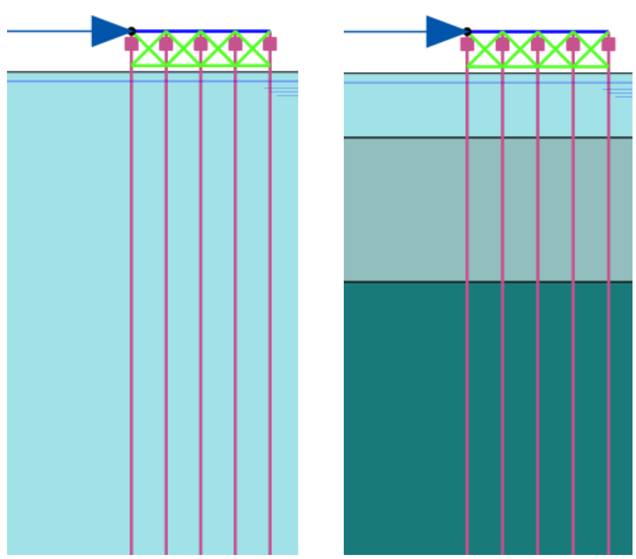

Fig. 11. PLAXIS Models for Reaction Frames: Left) Calibrated E, Right) Calculated E

As results show in Fig. 12, the deflection profiles with calculated and calibrated E values are consistent and they predict almost similar maximum pile deflection. Deflections in models with calculated Young's modulus dissipate faster than models with calibrated Young's modulus. This is because of higher Young's modulus over depth in the models with calculated Young's modulus. Also, results show that the deflection of the pile increases as G/G_{max} ratio decrease. This is because the lower G/G_{max} ratio corresponds with lower soil Young's modulus.

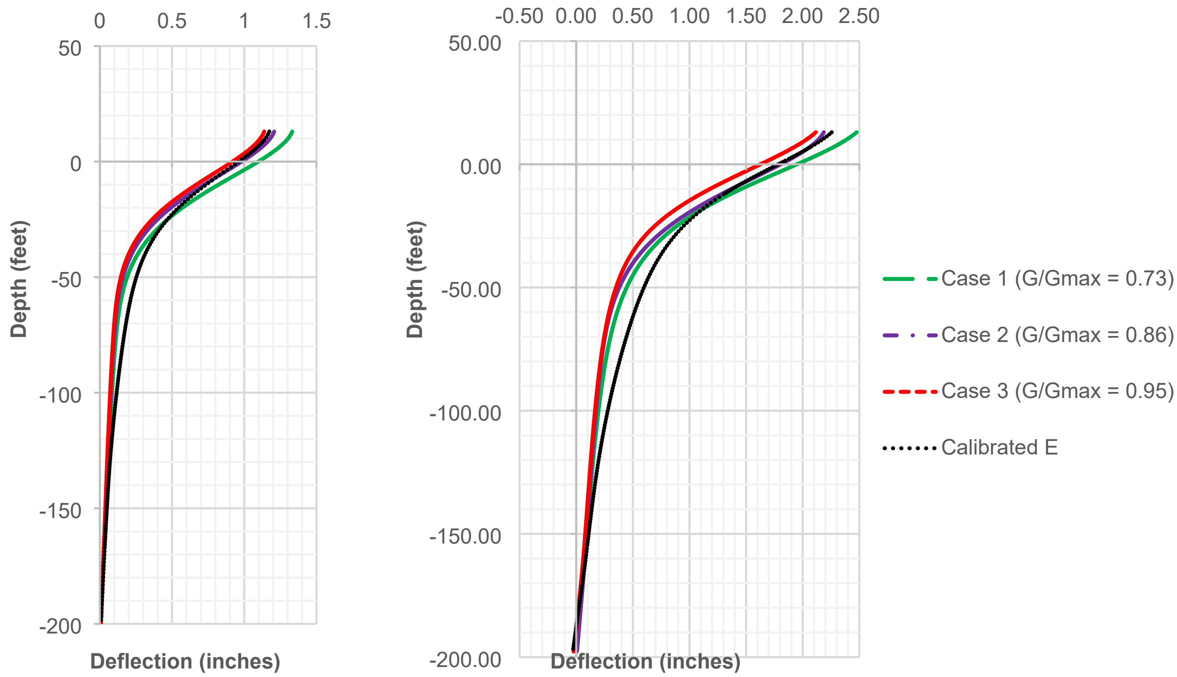

Fig. 12. Reaction Frame Defelection: Left) Rotator, Right) Oscillator

CONCLUSIONS

The calculations presented in this paper demonstrat that soil Young's modulus plays an important role in determining pile deflection under lateral load. Analyses proved that empirical values for soil Young's modulus in this project are significantly lower actual Young's modulus of the project and results in unrealistic pile deflection.

Results in this paper show that deflection of a pile under lateral load mainly occurs above grade and then dissipates rapidly over the pile depth into the soil. Calculations show that Young's modulus increases with depth and, therefore less deflection in the pile can be expected compared to a model with constant Young's modulus.

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