January 6, 2021

NextEra Energy Resources
700 Universe Boulevard
Juno Beach, Florida 33408

Attn: Mr. Daniel Marieni – Solar Project Engineer
P: (561) 694-4529
E: Daniel.Marieni@nexteraenergy.com

Re: Evaluation of Vibration Amplitude by Impact Pile Drivers
Watkins Glen Solar Project
Town of Dix
Schuyler County, New York
Terracon Project No. J5195161

Dear Mr. Marieni:

We have completed this letter with regard to provide an evaluation of vibrations caused by the installation of piles proposed to support PV solar panels, and the potential impacts on surrounding properties and structures from pile induced ground vibrations.

We have completed an evaluation of vibration amplitude by impact pile drivers, and the results are attached at the end of this letter. Our evaluation is based on the guidelines presented in the Transportation and Construction Vibration Guidance Manual (Caltrans 2020)[1]. Maximum recommended vibration limits, set in units of inches per second as measured by the peak particle velocity (PPV), by the American Association of State Highway and Transportation Officials (AASHTO) are identified in Table 4 of Caltrans 2020, and also shown in the table below.

American Association of State Highway and Transportation Officials Maximum Vibration Levels for Preventing Damage	
Type of Situation	Limiting Velocity Peak Particle Velocity (inches/second)
Historic sites or other critical locations	0.1
Residential buildings, plastered walls	0.2–0.3
Residential buildings in good repair with gypsum board walls	0.4–0.5
Engineered structures, without plaster	1.0–1.5

[1] *https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/tcvgm-apr2020-a11y.pdf*

Based on AASHTO recommendations, limiting vibration levels to 0.2 PPV at residential structures and to 0.1 PPV at historic sites or other critical locations, would prevent structural damage regardless of building construction type.

Based upon the results of our evaluation, it is our opinion that vibrations induced by pile drivers during the installation of the driven post used to support the PV solar panels will be negligible at the following minimum distances from the pile drivers:

- Residential Structures (max 0.2 PPV): minimum distance from pile drivers of 15 feet
- Historic sites or other critical locations (max 0.1 PPV): minimum distance from pile drivers of 24 feet

In the proposed plans, the distances to neighboring houses or properties are generally greater than 300 feet and therefore the pile driving installation is not anticipated to impact any subsurface conditions and existing buildings or structures in those areas.

We appreciate the opportunity to be of service to you on this project. If you have any questions concerning this report or if we may be of further service, please contact us.

Sincerely,
Terracon Consultants-NY, Inc.

Michele A. Fiorillo, P.E.(NY)
Geotechnical Department Manager

James M. Jackson. P.E. (FL)
Geotechnical Engineer

Attachments:

- **Supporting Calculations: Evaluation of Vibration Amplitude by Impact Pile Drivers**

Evaluation of Vibration Amplitude by Impact Pile Drivers

(Reference Construction Vibration Guidance Manual (Caltrans 2020)
https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/tcvgm-apr2020-a11y.pdf

Based on AASHTO recommendations, limiting vibration levels to below 0.2 PPV at residential structures would prevent structural damage regardless of building construction type.

Table 15. AASHTO Maximum Vibration Levels for Preventing Damage

Type of Situation	Limiting Velocity (in/sec)
Historic sites or other critical locations	0.1
Residential buildings, plastered walls	0.2–0.3
Residential buildings in good repair with gypsum board walls	0.4–0.5
Engineered structures, without plaster	1.0–1.5

The National Cooperative Highway Research Program (NCHRP)

Vibration impacts from normal equipment to structures may be estimated at any distance from the following equation (see also next page):

$$PPV_{Impact\ Pile\ Driver} = PPV_{Ref}\,(25/D)^{n}\,x\,(E_{equip}/E_{Ref})^{0.5} \quad (in/sec) \quad (Eq.\ 9)$$

From the Vermeer website[2], the PD10 has a maximum energy (Equip) of 1,000 joules or about 740 foot-lbs.

Solving Eq. 9 for n and D, the following results are obtained:

Limiting PPV to 0.2 (residential structures):

- **Solving for n=1.5, D=15 ft;**
- **Solving for n=1.1, D=12 ft**

Limiting PPV to 0.1 (historic site or other critical locations):

- **Solving for n=1.5, D=24 ft;**
- **Solving for n=1.1, D=23 ft**

[2] (https://www.vermeer.com/getmedia/4b7f8a30-a44a-4d51-b715-cf2161c7518c/pd10-pile-driver-spec-sheet?ext=.pdf)

7.1.1 Vibration Amplitudes Produced by Impact Pile Drivers

An extensive review of the available literature (Martin 1980; Wood and Theissen 1982; Wiss 1967, 1974, 1981; Dowding 1996; Federal Transit Administration 2018; Woods 1997; Schexnayder and Ernzen 1999) and information provided by the manufacturers (Preston 2002; Morris 1991, 1996, 1997) indicates that the PPV from impact pile drivers can be estimated by the following equation:

$$PPV_{Impact\ Pile\ Driver} = PPV_{Ref}\,(25/D)^{n} \times (E_{equip}/E_{Ref})^{0.5} \quad (in/sec) \quad (Eq.\ 9)$$

Where:

PPV_{Ref} = *0.65 in/sec for a reference pile driver at 25 ft.*

D = *distance from pile driver to the receiver in ft.*

n = *1.1 is a value related to the vibration attenuation rate through ground*

E_{Ref} = *36,000 ft-lb (rated energy of reference pile driver)*

E_{equip} = *rated energy of impact pile driver in ft-lbs.*

The above equation is based on extensive review of the actual data points at various distances, measured for a wide range of impact pile drivers. The data were measured at the ground surface outside or within various types of buildings.

Literature indicates that the value of "n" in the above equation is generally 1 to 1.5. The suggested value for n is 1.1. The use of values greater than

1.1 would likely result in overestimation of amplitudes at distances closer than 25 ft and would be slightly conservative at distances beyond 25 ft.

If vibration impacts, based on the above approach, are expected to exceed the vibration assessment criteria, vibration estimates may be refined further by using values of "n" that are based on soil type classification, ranging from Class I–IV soils as outlined in the National Cooperative Highway Research Program (NCHRP) Synthesis 253 (Woods 1997), and based on data developed by Woods and Jedele (1985). This step would require detailed information on soil conditions at the site. Table 17 describes soil materials, soil classes, values of "n" determined by Woods and Jedele (1985), and suggested values for "n" for the purposes of estimating vibration amplitude.

Table 17. Measured and Suggested "n" Values Based on Soil Class

Soil Class	Description of Soil Material	Value of "n" measured by Woods and Jedele	Suggested Value of "n"
I	Weak or soft soils: loose soils, dry or partially saturated peat and muck, mud, loose beach sand, and dune sand, recently plowed ground, soft spongy forest or jungle floor, organic soils, top soil. (shovel penetrates easily)	Data not available	1.4
II	Competent soils: most sands, sandy clays, silty clays, gravel, silts, weathered rock. (can dig with shovel)	1.5	1.3
III	Hard soils: dense compacted sand, dry consolidated clay, consolidated glacial till, some exposed rock. (cannot dig with shovel, need pick to break up)	1.1	1.1
IV	Hard, competent rock: bedrock, freshly exposed hard rock. (difficult to break with hammer)	Data not available	1.0