Study of the Effects of Foundation Pile Installation due to the Planned Development near the Basilica of Saints Peter and Paul Catholic Church

Chattanooga TN, Patten Parkway

Summary and Engineering Analysis
with assistance from Chat GPT, Google AI, and Grok AI based research

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Executive Summary

This study is a companion to a previously submitted document "*Construction Considerations for Planned Development near the Basilica of Saints Peter and Paul Catholic Church*" and is intended to expand upon and further investigate potential damage mechanisms if proposed development on Patten Parkway goes forward.

Significant findings and analysis within the detail of this study:

- Confirmation that **Impact Pile driving** is the best method to install structural pilings for a high rise building on Patten parkway.
- Impact Pile installation can deliver **energy levels as high as 157,000 ft-lbs**. With a reasonably conservative estimate of **60,000 ft-lbs**., this results in Peak Particle Velocity (PPV) vibration values in excess of **3.0 in/sec. at 9 ft**. from the source (the closest approach of the development to the Basilica structure).
- The **U.S. Federal Transit Authority limits vibration levels to 0.12 in/sec**. for Class IV historic structures, and expert opinion is that **at levels of 0.12 in/sec., the minimum safe distance from the vibration source is 45 ft**. At PPV values of **3.0 in/sec.** the **minimum safe distance** is **over 400 ft.** from the source.
- **Pre-drilling to reduce vibration from Impact Pile will still result in PPV values of 0.25 in/sec**. at 9 ft., in excess of the 0.12 in/sec. allowable.
- The soil and substrate composition of the Patten Parkway area most likely has significant deposits of shale followed by limestone and dolomite bedrock. The effect of the **Devonian/Mississippian shale** near Chattanooga is soil and substrate that is **stiff and layered**, **which means it can transmit pile driving vibrations directly to the Basilica foundation with little dispersion. This soil / substrate composition is somewhat unique to the Chattanooga area.**
- The most likely **high-risk damage areas of the Basilica** are the **Tiffany stained glass** windows**, the *historic pipe organ,*** the **East Tower** structure, and **foundation upheaval or slip. *Any* of these failures would be catastrophic.**

The history and context to the Chattanooga area was explored a bit as well, beyond the engineering aspects, which merely serves to point to the priceless nature of the Basilica of Sts. Peter and Paul Catholic Church. So, while they are no new revelations in this study, it does further reinforce my professional opinion that **the construction of the planned 12 story development would likely cause grave irrevocable harm**.

Piling Methods for High-Rise Commercial Buildings in Chattanooga

For commercial buildings over six stories in Chattanooga, TN, the primary method used is the installation of **deep foundation systems**, specifically **driven steel H-piles** or **drilled shafts (caissons)**. These methods are necessary to bypass the region's variable surface soils and transfer the massive structural loads directly onto the underlying limestone bedrock. While helical piers are a common regional solution for stabilization and lighter commercial structures, high-rise construction typically requires the higher load-bearing capacity of impact-driven steel or reinforced concrete foundations.

Foundation Pile Installation Effects Chattanooga TN, Patten Parkway

Key Findings

- **Impact Driving:** This is the most common method for high-rise foundations, using hydraulic or diesel hammers to drive steel H-piles or prestressed concrete piles until they reach "refusal" at the bedrock layer.
- **Bedrock Reliance:** Chattanooga's geology requires deep foundations to reach stable limestone layers, as surface soils are often insufficient for buildings exceeding six stories.
- **Helical Piers:** These "screw-in" piles are widely used in the area for foundation repair and lighter commercial anchoring but are less common as the primary support for high-rise structures.
- **Material Standards:** Common piling materials in the region include steel H-piles, metal shell piles, and prestressed concrete, depending on specific site soil reports.
- **Vibratory Methods:** Vibratory pile drivers may be used initially in softer alluvial soils near the Tennessee River before switching to impact driving for the final set into rock. (including "gentle shaking pile driving" still being developed.)

Details

Geological Context

Chattanooga is characterized by karst topography and alluvial deposits near the river. For buildings over six stories, engineers must account for potential sinkholes and soft clay layers. Deep foundations ensure the building's weight is distributed to the competent limestone bedrock, which can be found at varying depths across the city.

Common Piling Techniques

1. **Impact Driving:** A pile driver machine uses a heavy weight to strike the top of a pile, forcing it into the ground. This is preferred for steel H-piles which can penetrate deeply into tough Tennessee soils.
2. **Drilled Shafts (Bored Piles):** Large diameter holes are drilled into the earth, reinforced with steel cages, and filled with concrete. This method is often used for the heaviest commercial loads.
3. **Helical Piles:** These consist of a central shaft with one or more helix-shaped plates. They are "screwed" into the ground using hydraulic machinery. While excellent for many Chattanooga projects, they are typically used for loads lighter than those produced by a 6+ story building.

Comparison of Methods

- **Steel H-Piles:** Best for reaching deep bedrock; high durability and load capacity.
- **Drilled Shafts:** High capacity but more expensive and slower to install than driven piles.
- **Helical Piers:** Faster installation and less vibration, but lower individual pile capacity compared to driven steel.

Of these methods, the **most likely method to be used for a structure over 6 stories is Steel H Pile Impact Driving**. This method uses a weight repeatedly lifted and dropped in a manner analogous to a hammer being used to drive a rod into the ground. (Figure 1)

Foundation Pile Installation Effects Chattanooga TN, Patten Parkway

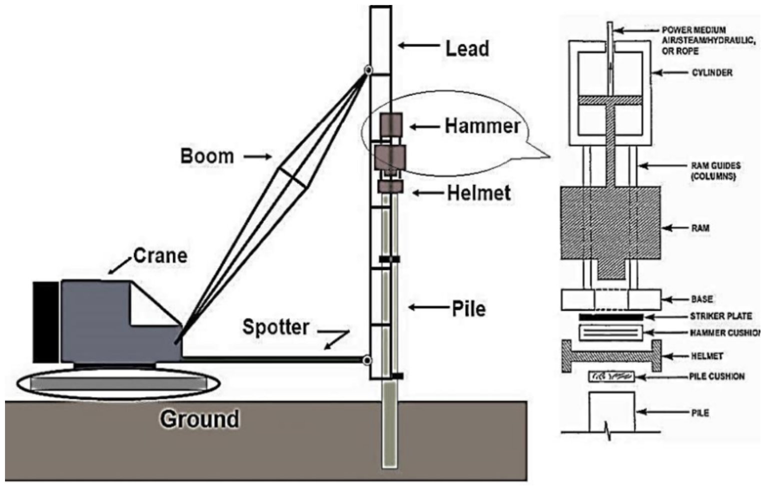

Figure 1 Impact Pile Driver Schematic

Practical Takeaway

- **Geotechnical Survey:** Always begin with a site-specific soil analysis to determine the exact depth of the bedrock in Chattanooga.
- **Load Requirements:** For buildings over 6 stories, expect to use impact-driven steel piles or drilled shafts rather than simpler push or helical piers.
- **Vibration Monitoring:** In downtown Chattanooga, impact driving may require vibration monitoring to protect adjacent historic structures.
- **Local Expertise:** Utilize local geotechnical firms familiar with the Tennessee Valley's unique limestone formations.

Pile Driving Impact Energy Near Patten Parkway, Chattanooga

For H-beam pile driving near **Patten Parkway in Chattanooga, TN**, the impact energy typically ranges between **30,000 and 60,000 foot-pounds (ft-lbs.)** per blow. This energy level is required to drive steel H-piles through the city's dense alluvial clays and silts to reach the underlying limestone bedrock, which is the standard "bearing layer" for significant structures in the downtown area.

Key Findings

- **Energy Range:** Most medium-to-heavy H-beam installations in downtown Chattanooga utilize hammers (often diesel or hydraulic) with rated energies of **32,000 to 55,000 ft-lbs**.
- **Soil Composition:** The area near Patten Parkway consists of stiff residuum and alluvial deposits; these soils require high impact energy to overcome "skin friction" before the pile reaches the rock.
- **Refusal Criteria:** Piles are typically driven until they reach "refusal," meaning the impact energy no longer moves the pile significantly (often defined as 10+ blows per inch) because it has hit the limestone shelf.

- **Vibration Concerns:** Due to the proximity of historic buildings around Patten Parkway, contractors often use **variable-moment hammers** or pre-drilling to manage the energy transfer and reduce ground vibrations.
- **Hammer Types:** Common models used in this region include the **Delmag D-19 or D-30 diesel hammers** or comparable hydraulic systems. (***D46-32 is the likely size for this type pile installation***)

Details

Soil Conditions at Patten Parkway

The geology of downtown Chattanooga is characterized by the **Knox Group**, which consists largely of limestone and dolomite. Near the surface at Patten Parkway, you will find:

- **Topsoil/Fill:** 2–10 ft. of urban fill.
- **Alluvium/Residuum:** 20–50 ft. of stiff clays and silts.
- **Bedrock:** The target for H-piles, where the "impact energy" is most critical for ensuring a solid seat.

More detail following from a US Department of Transportation study from 1975.

Hammer Energy Calculations

The energy required is determined by the formula for **Energy Efficiency**:

$$E=W\times H\times \mu$$

Where:
E is the transferred energy.
W is the ram weight.
H is the drop height.
µ is the efficiency of the hammer (typically 70-85% for modern diesel hammers).

Using a **hammer weight of 17,640lbs**, from a typical diesel D46-32 hammer, and a **drop height of 10.5 ft.** (maximum stroke), ***the transferred energy on each stroke could be as high as 157,437 ft-lbs***. Obviously, this is a very conservative estimate, but **values as high as 60,000 ft-lbs. could be expected**.

Impact on Surrounding Structures

In the Patten Parkway area, high-energy impact driving is often restricted or monitored because:

Vibration Waves: High impact energy (above 50,000 ft-lbs.) can cause peak particle velocities (PPV) that may distress older masonry foundations.

Settlement: Vibrations can cause "shakedown settlement" in loose sandy pockets of the alluvial soil.

Practical Takeaway

- **Standard Hammer:** For a typical 12-inch or 14-inch steel H-pile in this area, expect a hammer with a **32,000 ft-lbs.** rating for standard driving and up to **60,000 ft-lbs.** if deep penetration into weathered rock is required.

- **Pre-drilling:** If the soil is exceptionally stiff, contractors may "pre-bore" the first 20 ft. to reduce the required impact energy and noise.
- **Monitoring:** Seismic monitoring is standard practice for any pile driving within 100 ft. of existing structures in downtown Chattanooga.

Soil Stress Forces and Potential Damage Near Patten Parkway

Near Patten Parkway in Chattanooga, pile driving transmits stress through the soil primarily as **seismic waves (Body and Surface waves)**, which can cause significant ground deformation. While **pre-drilling** effectively reduces the energy required for the "start" of the drive and lowers overall vibration levels, it does not entirely eliminate risk; adjacent structures can still experience **differential settlement, cosmetic cracking, and subterranean utility displacement** due to soil densification and residual vibration.

Key Findings

- **Wave Transmission:** Impact forces are transmitted as **P-waves (compression)** and **S-waves (shear)** through the soil body, while **Rayleigh waves** travel along the surface, carrying the majority of the energy that affects foundations.
- **Soil Displacement:** As the pile is driven, it physically displaces a volume of soil equal to its own, creating **lateral stress** and potential "heave" in the surrounding ground.
- **Pre-drilling Benefit:** Pre-drilling a "pilot hole" removes a portion of the soil mass, which significantly decreases the **peak particle velocity (PPV)** and reduces the radial stress transmitted to nearby foundations.
- **Residual Risks:** Even with pre-drilling, the final "seating" of the pile into the limestone bedrock creates high-frequency vibrations that can still trigger settlement in loose alluvial sands common in Chattanooga.
- **Damage Thresholds:** Cosmetic damage (hairline cracks in plaster) typically occurs at lower vibration levels, while structural damage requires much higher energy levels rarely reached with pre-drilling unless the building is in poor condition.

Details

Soil Profile near Patten Parkway

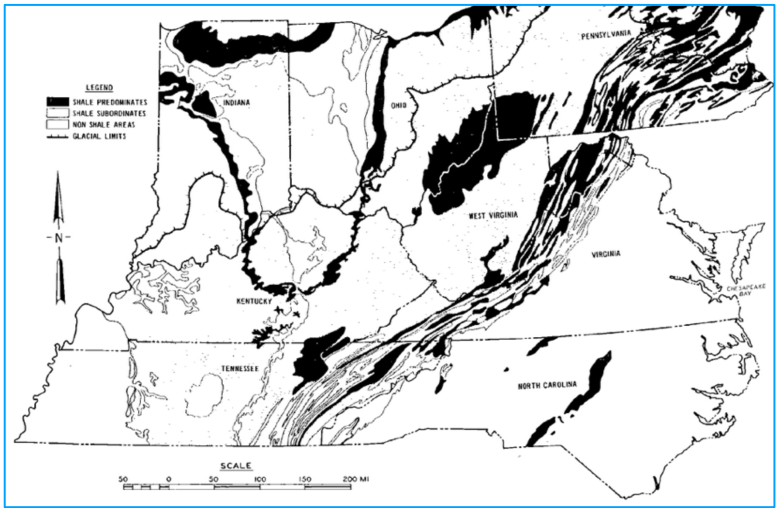

Figure 2 Soil by Region

Table 1 TN Soil Descriptions

State	Rock-Stratigraphic and Geologic Time Units	Description
TN	Chattanooga shale (Upper Dev & Miss)	Fissile, black, carbonaceous shale, dark phosphatic basal sandstone member (Hardin) usually present; thickness averages 20 ft in Middle Tennessee and ranges from 0 to 500 ft in East Tennessee
	Murray shale (Lower Camb)	Dull green, brown to grayish-blue micaceous silty and sandy calcareous shale; thickness is 300 to 500 ft
	Nolichucky shale (Upper Camb)	Pastel colored (pink, greenish, olive) flaky clay shale; commonly with oolitic limestone layers, thin blocky siltstone near middle; thickness is 50 to 800 ft
	Pennington formation (Upper Miss)	Heterogenous and varicolored (red, purple, green) clay shale, normally calcareous sandstone, shaly or silty fossiliferous limestone; limestone is minor in amount, proportions of shale and sandstone vary widely; thickness varies from 200 to more than 500 ft
	Rogersville formation (Middle Camb)	Light green, fissile clay shale with occasional beds of thin red sandy shale; in places massive blue limestone bed occurs; thickness is 70 to 250 ft
	Rome formation (Lower Camb)	A heterogeneous and varigated mixture of sandstone, siltstone, shale, dolomite, and limestone; proportions vary greatly; thickness is 700 to 1200 ft

Table 2 Chattanooga Shale

Tennessee	
Rock-Stratigraphic Unit	Geologic Time Unit
Pennington formation	Upper Mississippian
Chattanooga shale	Upper Devonian and Mississippian
Nolichucky shale	Upper Cambrian
Rogersville formation	Middle Cambrian
Rome formation	Lower Cambrian
Murray shale	Lower Cambrian

US Department of Transportation commissioned a study in 1975 (FHWA-RD-75-061) to characterize soil types throughout the country. This study was primarily for highway embankment construction but is instructive in helping to identify the types of soil in the Chattanooga area. In Figure 2, it is evident that Tennessee has significant deposits of shale, and Table 1 illustrates regional distribution of soil types and that Chattanooga shale is the predominantly Upper Devonian and Mississippian. The significance is that The **Upper Devonian/Mississippian shale** near Chattanooga is **stiff and layered**, **which means it can transmit pile driving vibrations effectively**.

Transmitted Stress Forces

The forces transmitted across the soil near Patten Parkway are categorized by how they move through the Chattanooga alluvium:

1. **Dynamic Shear Stress:** As the pile moves downward, it creates friction at the interface, sending shear waves outward. These waves can cause the soil to "liquefy" or densify if it is saturated and loose.
2. **Hydrostatic Pressure:** In the silty clays near the Tennessee River, pile driving can cause a temporary increase in **pore water pressure**, which may lead to delayed soil settlement once the pressure dissipates.
3. **Reflected Waves:** When the pile hits the hard limestone bedrock beneath Patten Parkway, energy is reflected back upward and outward, often creating the highest vibration spikes of the entire process.

A heavy hammer producing ~60,000 ft-lbs. per blow within ~10 ft of a building is likely to:

- Produce **significant vibrations**,
- Cause **cosmetic to structural damage** without mitigation,
- Require **careful vibration monitoring and mitigation** to protect the church.

The transmission of energy from the hammer down to the pile and then to the surrounding soil governs the entire vibration transmission process and forms a crucial part in analyzing the behavior of ground vibrations. A simple concept of the energy transmission is then presented. When the hammer hits the pile head, energy is being transferred down to the body of the pile in the form of a compressional body wave. S- waves are generated in the pile shaft and propagate conically from the pile. Compressional (P) – waves and Shear (S) - waves are also generated in the pile toe and they propagate in spherical waveforms in all directions. As these S and P – waves reach the ground surface, a part of the waves are being converted into Rayleigh (R) – waves, as seen in Fig. 3, which attenuate in amplitude in proportion to the square root of distance.

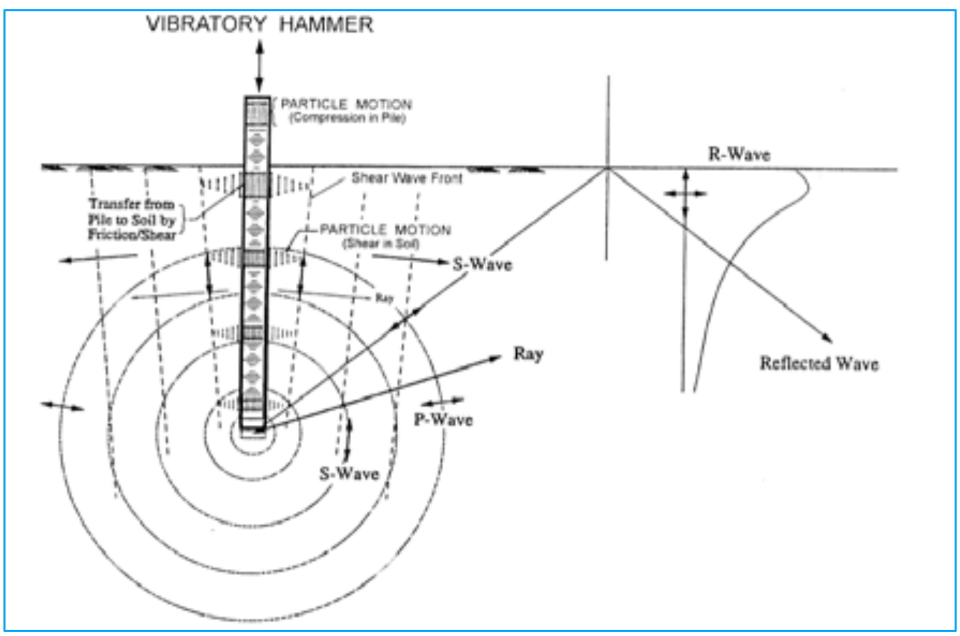

Figure 3 Waves generated from pile driving operations
(ref: Dungca, International Journal of GEOMATE, May, 2016)

The governing equation for soil stress forces (R-waves, S-waves, and P-waves) is defined by the Bornitz Equation. The Bornitz Equation considers the combined effect of both material and geometric damping, allowing the propagation of ground vibrations to be extensively characterized as it moves away from the vibration source, it is then expressed in the following format (Equation 1):

$$A_2 = A_1 \left(\frac{r_1}{r_2}\right)^n e^{-\alpha(r2-r1)}$$

Equation 1 Bornitz Equation

Where A_1 and A_2 are vibration amplitudes at distances r_1 and r_2, n is the geometric damping coefficient = 1 (surface waves). The material damping coefficient (α) can be estimated as a function of vibration frequency (f) and is expressed in Equation. 2 (simplified for illustration):

$$\alpha = \frac{2\pi D f}{c}$$

Equation 2 Material Damping Coefficient

Where, c is the propagation velocity of R-waves and D is the damping ratio. The dominant frequency (f) of vibration can then be approximated by knowing the pile and hammer properties and specifications utilized in the pile driving operation (dependent on the pile to ram weight ratio, pile length, and empirical coefficients).

Estimated Peak Particle Velocity (PPV):

At 10 ft, PPV ≈ 3.32 in/sec (unadjusted base ≈ 2.57 in/sec and reference of 0.65 in/sec at 25 ft). This is conservative; actual values depend on pile type, hammer efficiency, and site factors as described above, but measurements from similar energies often reach 2-4 in/sec near the source.

Per calculations by Dr John Ziegler's retrieved from the *Vibration Damage* website (https://vibrationdamage.com/vibrationanddistance.htm), the **minimum safe distance for an FTA Class IV structure (historical significance) is 45 ft at a PPV of 0.12 in/sec.** (ref Figure 4)

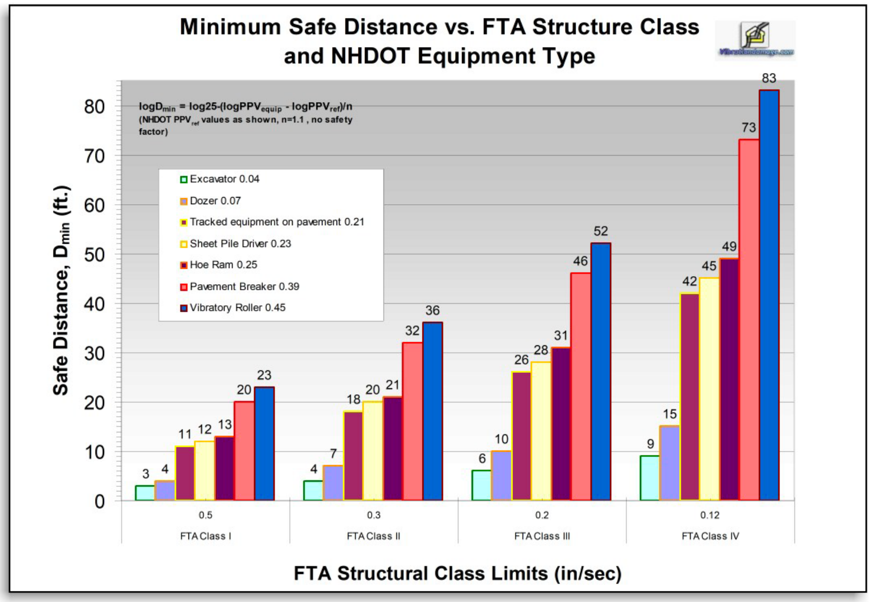

Figure 4 FTA Safe Distance per Class Structure

The **recommended minimum safe distance for FTA Class IV buildings is over 400 ft**. at PPV levels **at or above 3 in/sec**. (Figure 5)

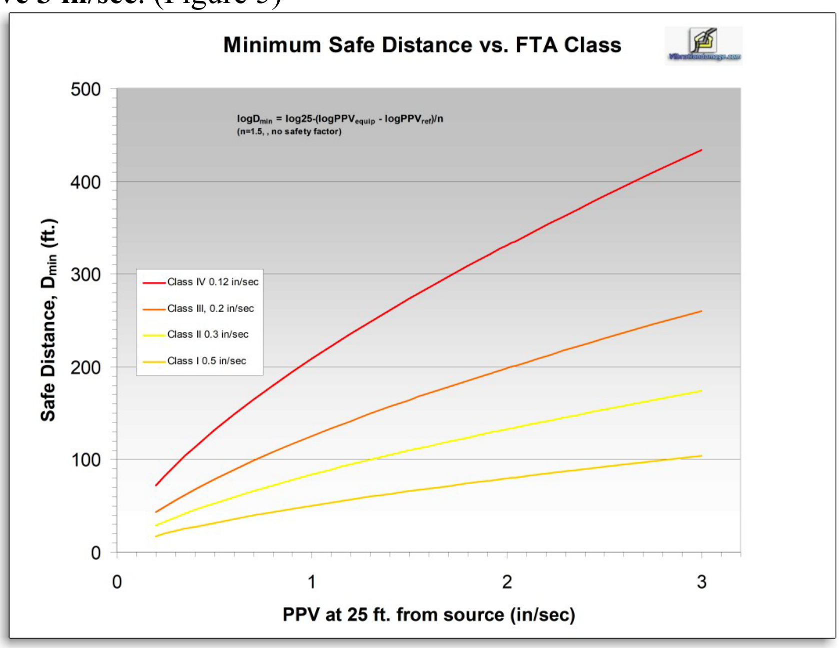

Figure 5 Minimum Safe Distance by Class

Expected Damage (Even with Pre-drilling)

Despite the mitigation provided by pre-drilling, the following issues can occur:

- **Cosmetic Cracking:** ***New or widened cracks in drywall, plaster, or masonry*** veneers of older buildings surrounding the parkway.
- **Differential Settlement:** If one side of a neighboring building sits on slightly looser soil, the ***vibrations can cause that side to settle more than the other***, leading to stuck doors or windows, and notably **damage to the priceless Tiffany stained glass windows**.

- **Utility Shearing:** ***Small lateral soil shifts*** (even millimeters) can stress or break old, brittle cast-iron water or gas lines buried nearby.

Limitations of Pre-drilling

Pre-drilling typically only extends to a certain depth (often just above the bedrock). ***The final "impact" required to seat the pile into the rock still generates 100% of the hammer's energy, which is transmitted directly into the ground without the "buffer" of the pre-drilled hole***.

Potential Damage from Drilling

Drilled piling (also known as bored piles, drilled shafts, or auger cast piles) involves excavating a hole with a drill or auger and then filling it with concrete and reinforcement, often without high-impact hammering. This method produces significantly lower ground vibrations compared to impact or vibratory pile driving, as the primary vibration sources are from the drilling equipment (e.g., rotating auger or drill rig) rather than repeated strikes. In the context of the Chattanooga Shale bedrock (stiff, low-damping material), vibrations may propagate more efficiently than in softer soils, but the overall amplitudes remain low due to the reduced energy input.

As described previously, Vibration levels are typically quantified as peak particle velocity (PPV in in/sec). **For drilled piling**:

- ***Reference PPV at 25 ft from caisson drilling (a comparable operation): ~0.089 in/sec***.
- Predicted PPV using the formula PPV = 0.089 × (25/D)^1.1 (where D is distance in ft):
    - At 50 ft: ~0.041 in/sec.
    - At 25 ft: ~0.089 in/sec.
    - **At 10 ft: ~0.239 in/sec**.

It is important to note that even though Drill Piling PPV values are substantially lower than Impact Piling PPV values, roughly 1/10th the energy, the Drill Piling PPV still exceeds the threshold of 0.12 in/sec.

The Basilica of Sts. Peter and Paul (a 136-year-old Gothic Revival structure with unreinforced masonry, brick, stone, plaster, and fragile elements like stained glass) is classified as a historic building extremely susceptible to vibration damage. Recommended damage thresholds include:

- **0.08-0.12 in/sec for ancient or highly fragile structures** (e.g., ruins or poorly maintained historic sites).
- **0.12**-0.2 in/sec for cosmetic damage (e.g., hairline cracks in plaster or masonry) in **sensitive historic buildings**.
- 0.2-0.5 in/sec for minor structural effects in well-maintained historic masonry.

At distances within 50 ft:

- Low risk overall: PPV levels from drilled piling are typically below 0.12 in/sec beyond ~20-25 ft, posing minimal threat of damage. The shale's stiffness may slightly amplify transmission, but not enough to exceed thresholds at these distances.
- **Potential concerns at closer ranges (e.g., 10-20 ft)**: PPV could reach 0.1-0.24 in/sec, approaching or slightly exceeding conservative thresholds (0.12 in/sec). This might cause minor cosmetic issues like exacerbated cracking in existing plaster or joints, or resonance in fragile features, especially if cumulative over many piles or if the building has pre-existing weaknesses.

Practical Takeaway

- **Pre-Construction Survey:** Document all existing cracks in neighboring buildings before driving begins to differentiate between old and new damage.
- **Seismic Monitoring:** Use geophones to monitor PPV at the nearest foundation; staying below **0.5 in/sec** is a common industry standard for protecting historic structures. **<u>However, US Federal Transit Authority standards are that PPV velocities do not exceed 0.12 in/sec</u>.**
- **Water Management:** Monitor for sudden changes in local water table levels, as increased pore pressure can signal impending soil instability.
- **Frequency Analysis:** Low-frequency vibrations are often more damaging to buildings than high-frequency ones; pre-drilling helps shift the energy to higher, safer frequencies.

Summary

Due to the distance from the energy source to the basilica (under 100 ft.), soil conditions, and how the energy is applied repeatedly in pile driving, 60,000 ft-lbs. transmitted through the soil could generate vibrations with a peak particle velocity (PPV) in the range of **0.1–2.5 in/sec or higher** at close range.

For a 136-year-old historic structure like the basilica, which features delicate elements such as Tiffany stained glass windows and masonry, this could result in:

- Cosmetic damage, such as **new or widened cracks in plaster, walls, or ceilings**.
- Potential **loosening or displacement of stonework, bricks, or ornamental features**.
- Risk of **differential settlement in the foundation** due to soil disturbance, which might compromise structural stability over time if vibrations are repetitive.
- Possible **damage to interior fixtures, artwork, or glass** if PPV exceeds conservative thresholds (typically 0.1–0.2 in/sec for fragile historic sites to avoid any risk).

Actual effects would require site-specific geotechnical analysis, as Chattanooga's urban soils (often clay-loam mixes) can amplify or attenuate vibrations variably.

Discussion of Unique Site Situations

It is intuitive that any study would presume that there is precedent to relate when constructing a large high rise building adjacent to fragile historic sites. This activity is routinely performed in urban areas throughout the country and indeed around the world. It is crucial to review why this project, and this locale has unique characteristics to be considered.

Patten Parkway locale

Aside from the obvious historical value of the area, particularly 19 Patten Parkway as the first Coca Cola bottling plant location and the Basilica, there are soil and substrate issues as defined above. The conditions include:

- Deep, variable residual soils and old urban fill: heterogeneous, compressible layers over rock; higher differential-settlement risk than bedrock-based cities.
- Karstic limestone/sinkhole potential: voids and pinnacled rock lead to unpredictable bearing and excavation hazards.
- Weathered shale/saprolite: slakes/softens when exposed, reducing stability of cuts and support of excavation.
- High groundwater near the Tennessee River: dewatering can induce settlements that affect adjacent shallow foundations; increases lateral pressures on support systems.
- Seismicity from the East Tennessee Seismic Zone: higher potential for amplification in soft soils versus stiff/bedrock sites common in some urban cores.
- Narrow right-of-way and proximity to a historic structure with likely shallow, masonry foundations: greater sensitivity to vibrations, ground loss, and lateral movements from piling, soil mixing, or deep excavations.
- Legacy utilities and old subsurface structures: voids/leaks can exacerbate ground loss during construction.

Case Studies in the Chattanooga Area

1. The Sportsbarn/Car Barn Partial Collapse (September 2025)
During the demolition phase to make way for a new eight-story Drury **Plaza Hotel** at Market and East Third streets, a portion of the 139-year-old **Car Barn** (formerly Sportsbarn) partially collapsed. While the building was already being razed, the sudden collapse scattered debris onto public sidewalks and highlighted how aging masonry in downtown Chattanooga can become unstable when nearby loads or structural supports are altered.

2. The 27 West Main Street Collapse (2023)
A three-story building over 100 years old collapsed during a renovation project intended to turn it into a **Hyatt Regency Hotel**. Though it was a restoration rather than new high-rise construction, the incident led to a total loss of the historic structure after city officials determined it was no longer salvageable. This case serves as a warning for how subsurface or foundational work on historic Chattanooga soil can lead to sudden structural failure.

3. The Cheeburger Cheeburger Building Failure (2017)
A 141-year-old building in downtown Chattanooga was destroyed following a collapse that sparked a lawsuit. The legal dispute centered on claims that weight from a newly poured concrete floor on an upper level caused irreparable structural damage. This illustrates the extreme sensitivity of historic Chattanooga foundations to new, heavy structural loads.

Case Studies in Urban Areas

Urban construction projects frequently cause structural damage to adjacent historic buildings through ground-borne vibrations and soil displacement. Key case studies and documented risks include:

1. Vibration Damage (New York City): In NYC, high-rise construction near landmarks often results in "substantial factors of harm" due to pile driving and rock drilling. While specific major failures are often settled privately, historic structures like St. Patrick's Cathedral and the Basilica of St. Patrick's Old Cathedral have required multi-million-dollar stabilization efforts (e.g., $177 million for St. Patrick's) to address cracks in masonry and plaster that were aggravated by decades of urban environmental stress, including nearby transit and construction vibrations.
2. Foundation Pit & Subway Construction (Shaoxing, China): A case study of the City Square Station showed that deep foundation pit excavation for subway construction near the historic Dashan Pagoda caused surface uplift and subsequent settlement, even with modern numerical modeling and protective measures.
3. Soil Settlement and Liquefaction: Research indicates that in areas with high liquefaction potential, construction vibrations can cause sudden ground settlement or shifting. This reduction in soil support, rather than the vibration itself, often leads to major structural cracking or failure in older buildings with shallow foundations.

Thus, it is evident that structural damage due to construction activity has been and continues to be a real concern in areas adjacent to historic structures. The Patten Parkway location is particularly susceptible and risky due to a combination of soil and substrate composition, relatively high water table and liquefaction potential, and previous historical subterranean construction.

The Basilica of Sts. Peter and Paul Catholic Church

The area surrounding the Basilica of Sts Peter and Paul has significant roots in the historical construct of Chattanooga dating prior to the U.S. Civil War. The area was known as ***Irish Hill*** prior to the Civil War, which was a historic working-class neighborhood in Chattanooga that primarily existed between **Cherry, Lindsay, 8th, and 9th Streets** during the 19th century. **Its history is deeply tied to the development of the city's early infrastructure and the immigrants who built it**.

- **Origin of the Name**: The area gained its name because many **Irish immigrant workers** who built the **first railroads into Chattanooga** (the Western & Atlantic in 1850 and later the East Tennessee & Virginia railroads in 1856) settled there.
- **Community Life**: The neighborhood was the center for the **early Catholic community in Chattanooga. In the 1850s**, Chattanooga's first resident priest, Father Henry Brown, bought a large tract of land in this somewhat isolated area and sold lots around the church building at cost, which led to the concentration of the Catholic community and the development of the "Irish Hill" area. ***The parish of Saints Peter and Paul was founded in January 1852***.
- **Sts. Peter and Paul Parish**: The ***first permanent Catholic church building was erected in 1857*** to serve the St. Peter and St. Paul congregation.

- **Civil War Interruption**: ***In 1858, the growing Catholic community began construction on a permanent stone church***. However, **during the Civil War in September 1863, the Union Army occupied the nearly completed structure and demolished it**, using the stone for fortifications and culverts.
- **Yellow Fever Epidemic**: Father Patrick Ryan, pastor from 1872 to 1878, died a martyr's death at only 33 years old while ministering to the sick during the ***yellow fever epidemic of 1878***. He is currently a candidate for canonization**. Father Ryan's remains reside in the sanctuary of the Basilic**a.
- **Expansion and Construction**: An Irish priest, Father William Walsh, was appointed pastor in 1887 and made plans for a new church. Following the Civil War, the church received a **government settlement of over $18,000** in 1889 to compensate for the war damage. Ground was broken for the current building on **February 1, 1888**, and the imposing Gothic structure was dedicated on **June 29, 1890**. The balance of cost in church's construction was paid for primarily by the **time, talent and treasure of these poor Irish immigrants**, many of whom served in the Civil War on both sides.
- **Architecture and Art**: The church was designed by noted Detroit architect Peter Dederichs Jr. It features:
  - ***Stained-glass windows*** designed by the renowned artist **Louis Comfort Tiffany**, depicting events in the lives of the patron saints.
  - ***Fourteen polychrome Stations of the Cross*** **created by a French artist**, which took years to design and model.
  - An ***historic pipe organ***, originally a Barckhoff organ from **1890**, which was **rebuilt in 1936** by Kilgen and Son. There are over 600 original pipes from the Basilica's 1890's organ, believed to be the oldest pipe organ in Chattanooga that is still in use. Many of the pipes are wooden. **Just as vibrations could cause damage to a violin or piano, severe, prolonged vibrations at best would cause tuning difficulties, and at worst cause pipe damage. Vibrations could also damage the supporting structures of the organ**.
  - ***Historic Star Window*** in the rear of the church behind the organ which commemorates the **reparation support given by the U.S. Government** in the construction of the current church building.
- **Structural Changes**: The church originally had 174-foot-high twin towers with pinnacles and turrets. However, due to crumbling sandstone trim, the towers were removed in **1939**, and the East Tower was shortened to its current height. Within the past year, **structural modifications were necessary to address settling and support framing in the East Tower**.

Modern Era

- **Historic Designation**: The church was added to the **National Register of Historic Places** in **1979**.
- **Elevated to Basilica**: On **May 12, 2011**, Pope Benedict XVI elevated the church to a **minor basilica**, the first in Tennessee, in recognition of its antiquity, dignity, historical value, and architectural significance.

- **Restorations**: The Basilica has undergone major restoration projects in recent decades including:
    - **1990's:** a ***$300,000 facelift in the late 1990s***, including restoration of priceless Stations of the Cross, restoring the original ceiling paint texture and colors from 1890, and replacement of gold leafing on extensive surfaces throughout.
    - **2018-2019**: ***Significant sanctuary and nave restorations*** which uncovered original heart pine floors and completed the pipe organ's original design.
    - **2023-2024**: The remaining ***East Tower had structural modifications*** to enhance safety and stabilize the structure.

Summation and Conclusions

This study did not result in any major differences in recommendation, but it did illuminate in more specificity what the potential effects of Impact Pile Driving for construction of a 12-story structure on Patten Parkway would be to the Basilica of Sts Peter and Paul Catholic Church. The research of foundation and other structural failures of similar historic structures due to construction activities was informative as well.

Here are several factors to consider:

- The **soil and substrate composition is somewhat unique to most urban locations**, with:
    - ***Deep, variable residual soils and old urban fill***: heterogeneous, **compressible layers over rock**.
    - ***Higher differential-settlement risk*** than bedrock-based cities.
    - ***Karstic limestone/sinkhole potential***: voids and pinnacled rock lead to **unpredictable bearing and excavation hazards**.
    - ***Weathered shale/saprolite***: **slakes/softens when exposed, reducing stability** of cuts and support of excavation.
    - ***High groundwater*** near the Tennessee River: **dewatering can induce settlements** that affect adjacent shallow foundations; **increases lateral pressures on support systems**.
    - ***Seismicity*** from the East Tennessee Seismic Zone: ***higher potential for amplification in soft soils*** versus stiff/bedrock sites common in some urban cores.
- The **most likely pile installation technique for this size structure is Impact Pile Driving**. This technique will cause **impact energies of 60,000 ft-lbs**., at distances of less than 50 ft. perhaps even much higher energy levels. **FTA Recommended minimum safe distance is 450 ft., <u>not possible</u> with the proposed Patten Parkway property development**.
- With an impact energy level of 60,000 ft-lbs., the **Peak Particle Velocity (PPV) will exceed 3.0 in/sec** at less than 50 ft.
- The Basilica is considered a Class IV structure by the US Federal Transit Authority (FTA). **The vibration limit of FTA Class IV structures is 0.12 in/sec**.

- The use of **Drill Pile installation** is a means to reduce the vibration levels of Impact Pile, however the potential vibration **PPV levels 0.25 in/sec** still exceed FTA Class IV limits.
- **Pile installation** by whatever method could likely result in **damages** such as:
  - Cosmetic damage (e.g., **hairline cracks in walls/plaster**).
  - **Structural damage** (e.g., shifts in brickwork, foundation settlement, or weakened arches/joints), with **particular concern that the remaining East Bell Tower could suffer complete collapse**.
  - **Irreparable harm to fragile elements**, stained glass vibration-induced breakage and **pipe damage and supporting structures of the organ**.
  - Cumulative effects from **repeated impacts**, potentially **leading to fatigue of sanctuary support elements**.

If the decision to go forward with construction were made, it is my continued professional opinion the likely effect would be irreparable harm to the Basilica of Sts. Peter and Paul Catholic Church. **These harmful effects could result in aesthetic damage to a priceless gem of beauty and historic value to the community, or up to structural failure of the foundation or supporting elements of the building**.

With all these factors in consideration, the decision to **deny zoning** **for construction** of a structure at heights above the 6-story limit is most highly recommended in the **strongest possible terms**.

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